Land-Use Regulation and Economic Development: Evidence from the Farmland Red Line Policy in China*

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Abstract

Many countries have land-use regulations to preserve farmland from urban sprawl. In this paper, I show that such regulations can distort economic activity across sectors and locations at a substantial cost to aggregate welfare in developing countries in the process of urbanization. I study a major policy restricting farm-to-urban land conversion in China – the Farmland Red Line Policy – to provide causal evidence on the impact of land-use regulation on local development, measured by GDP and population growth. The policy imposes an additional cost on urban land development, which depends on exogenous local geographical features. I show that a greater additional cost driven by geographical features significantly reduces the urban land supply, lowers GDP, and decreases the population size. To understand the aggregate impact of the policy, I develop a quantitative spatial equilibrium model that features endogenous land-use decisions. According to the model, the policy causes an excess supply of farmland and an undersupply of urban land, and the extent of such land misallocation varies across locations due to their local geographical features. In the constrained equilibrium, the spatial and sectoral mobility of workers implies that land misallocation leads to labor misallocation. The calibrated model reveals that the welfare of workers would have been 6% higher in 2010 if the policy had not been implemented. *JEL* Codes: R52, R13, R14, O18, Q18.

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1 Introduction

Most countries regulate the growth of cities (Hsieh and Moretti, 2018; Duranton and Puga, 2015; Glaeser et al., 2006; Katz and Rosen, 1987). Many of these regulations, such as greenbelts, urban growth boundaries, and agricultural and open space zoning, are designed to preserve agricultural and natural landscapes from urban sprawl (Dempsey and Plantinga, 2013; Nechyba and Walsh, 2004; Squires et al., 2002). They aim to maintain the open space and scenic vistas that farming provides, achieve ecological sustainability, and ensure local and national food security (Daniels, 2004; Johnson et al., 2002; Nelson, 1992, 1986). However, an often-missing element in these policy discussions is the recognition that these regulations can also generate substantial costs at both the local and aggregate levels. These policies essentially create frictions in land reallocation from the less productive agricultural sectors to the more productive urban sectors. However, empirical evidence on how such regulations affect urbanization and economic development is lacking.

In this paper, I study the impact of land-use regulation on economic development using China's Farmland Red Line Policy (1999) – a national land-use policy that restricts farm-to-urban land conversion – as a natural experiment. I examine both the local impacts of the policy on the urban land supply, GDP and population and the aggregate impacts of the policy on workers' welfare. The policy aims to preserve at least 1.2 million square kilometers (1.8 billion mu) of farmland nationwide by specifying that each local region must maintain a certain amount of farmland. The policy was implemented in the middle of the largest rural-to-urban migration in human history. From 1980 to 2010, 470 million Chinese people moved from rural to urban areas, and urbanization inevitably involved the conversion of former farmland to urban use. The Chinese government had grown concerned that the conversion of farms to urban land might compromise food security and hence adopted the policy to restrict such conversion (Chen, 2007).

I analyze this policy in three steps. First, I show that the policy imposes an extra cost on rural-to-urban land conversion that depends on exogenous local geographical features. Using a reduced-form analysis, I show that a larger extra cost driven by the geographical features in a local region significantly reduces its urban land supply, GDP and population. Second, I develop a general equilibrium model to quantify the aggregate welfare cost of the policy. My calibration of the model produces an estimate of the aggregate cost arising from the policy of 6% of workers' welfare. Moreover, distortions from the policy on urbanization manifest mostly in the overcongestion of urban sectors as opposed to a decrease in urbanization. Finally, by conducting a counterfactual exercise in which the government institutes a cap-and-trade platform that allows local regions to exchange farmland preservation requirements. I show that the Farmland Red Line Policy is an inefficient means of protecting farmland. I also show that this system would eliminate 60% of the cost to workers' welfare.

First implemented in 1999, the Farmland Red Line Policy forbids the conversion of farmland into urban land unless an equal amount of unused land (within a city jurisdiction) is converted into farmland.[1] The quality of the farmland has to be comparable to that of the existing farmland in the same city jurisdiction. As shown in Figure I (a), city jurisdictions in China are administratively categorized into urban and rural land. Rural land is then subdivided into farmland and unused land (land not cultivated for agricultural

[1]City jurisdictions include both central cities (Diji Shi) and county cities (Xianjin Shi).

production). There was no restriction on the conversion of farmland into urban land before 1999. From 1999, the policy guarantees that the total amount of farmland within each city jurisdiction does not decrease due to urbanization. The policy is equivalent to a minimum quantity constraint on farmland for each city jurisdiction.[2]

The policy creates an additional cost of urban land development that varies across city jurisdictions. Since the policy was adopted, whenever local governments convert farmland into urban land, they bear the additional cost of converting an equivalent amount of unused land into farmland within the city jurisdiction, as illustrated in Figure I (b). Therefore, the additional cost of urban land development refers to the labor and material expenses involved in the cultivation of unused land. This additional cost is endogenously affected by local economic conditions, such as labor costs and price levels. Hence, attempts to directly compare the economic outcomes of city jurisdictions with different additional costs of urban land development are problematic.

I isolate exogenous variation in the additional cost of urban land development and define it as the *land conversion barrier*. In particular, the cost of new farmland development depends on the ruggedness of unused land to be cultivated. Land ruggedness is a crucial determinant for the low-cost cultivation of land (Nunn and Puga, 2012; Zhang et al., 2010). Therefore, I define the *land conversion barrier* as the ruggedness of land near the administrative boundary of a city jurisdiction where unused land concentrates at the time of policy implementation.[3]

To identify the impact of the land conversion barrier on local economic outcomes, I use a difference-in-difference (DD) estimator with continuous treatment intensity. The empirical strategy is to compare economic outcomes between city jurisdictions with different levels of land conversion barriers before and after 1999. The identification relies on the assumption of parallel trends across city jurisdictions with different land conversion barriers throughout the period in my study had the policy never been adopted. In support of this assumption, I do not find any systematically different trends in growth in terms of the major outcome variables before 1999. A series of alternative regression specifications are provided as robustness checks.

The first empirical finding is that a one-standard-deviation increase in the land conversion barrier significantly reduces a city jurisdiction's urban land by 6.7%, its GDP by 5.3%, and its population by 5.0% by 2010.[4] Next, I find that the floor-to-area ratio (FAR hereafter) cannot freely respond to the land conversion barrier, and hence, a reduction in urban land supply leads to a floorspace decrease. This finding explains why urban land supply matters even though urban workers ultimately use floorspace for production and residency depending on both the urban land supply and the FAR. Finally, I show that the causal relation cannot be explained by alternative channels such as the deterioration of urban compactness or poorer government service in more affected jurisdictions (Harari, 2020; Chen and Kung, 2016). Altogether, the empirical evi-

[2]Compared to other urban containment policies, the Farmland Red Line Policy only requires the quantity of farmland to be fixed in a local region; the locations of individual farmland plots can be changed.

[3]I always exclude land that is either within or close to the existing urban land, such that the measured land ruggedness does not directly affect the cost of urban land development. I also show that the regression results are robust to controlling for the time varying effects of land ruggedness close to existing urban area.

[4]The estimated impacts are economically significant. They are equivalent to 11%, 11%, and 14% of one standard deviation of the growth rate of the corresponding variables across city jurisdictions during the study period.

dence shows that because of the Farmland Red Line Policy, city jurisdictions with a lower land conversion barrier were able to create more urban land after the policy was adopted. Ceteris paribus, urban land is cheaper in these city jurisdictions, hence encouraging more workers to move in during China's period of rapid urbanization. Therefore, these city jurisdictions have higher GDP and population sizes than those in which the land conversion barrier is higher.

The identified local effects of the policy on economic outcomes raise the question of whether the policy generates any significant aggregate impacts on the economy, which matters for policy evaluation. The policy is less of a concern if it does not create any inefficiency at the aggregate level but simply causes a reallocation of economic activities from more treated to less treated locations. Because locations are interlinked through flows of trade and migration, the impact of the policy on more treated locations may generate spillover effects on less treated locations in general equilibrium. Therefore, it is challenging to infer the aggregate impacts solely based on the estimates of the local effects. A general equilibrium model can incorporate the interlinkages between locations and separate the spillover effects from the direct impacts. The model can also simulate counterfactual outcomes under alternative policies and provide informative guidance for a more efficient design of the policy, which the Chinese central government has been considering.

To evaluate the aggregate effects of the Farmland Red Line Policy, I develop a static quantitative spatial equilibrium model that features endogenous land-use decisions. In the model, each location has both an urban sector and a rural sector. Each location-sector produces one variety of a final product. There are two types of agents: workers and absentee landlords. Workers maximize utility by choosing their location and sector, supplying one unit of labor to earn wage income, and spending income on tradable goods and residential land. Each location has a representative and immobile landlord that owns a continuum of land plots. A land plot can be developed into farmland or urban land at a cost or remain as unused land. Agricultural and urban sector workers rent farmland and urban land for production and residential use. Landlords choose the amounts of urban land, farmland, and unused land to maximize land development profit.

According to the model, aggregate welfare loss first comes from cross-sector and cross-location land misallocation caused by the Farmland Red Line Policy. Without the Farmland Red Line Policy, the landlord maximizes profit by equalizing the price of urban land, the price of farmland, and the marginal cost of land development.[5] The policy imposes a minimum quantity constraint on farmland. When the constraint is binding, more farmland is created to meet the minimum quantity relative to the no-policy market equilibrium, which increases the marginal cost of land development and hence decreases the urban land supply. Therefore, there is an undersupply (oversupply) of urban land (farmland) relative to the situation under the no-policy market equilibrium. Furthermore, the degree of cross-sector land misallocation is smaller in a location if the supply of developed land is more elastic. As the supply elasticity of developed land varies across locations, so does the degree of cross-sector land misallocation.

In general equilibrium, spatial and sectoral labor mobility indicate that land misallocation causes labor misallocation, the second source of aggregate welfare loss. First, an oversupply of farmland and an undersupply of urban land lead to an oversupply of rural workers because farmland is cheaper and to an

[5]I also provide an extended model that incorporates other frictions in the Chinese land market to affect the landlord's land development decision. In the extended model, the urban land price and farmland price are not necessarily equal to each other in the market equilibrium.

undersupply of urban workers because urban land is more expensive than it is under the no-policy market equilibrium. Second, the degree of land misallocation varies across locations, which leads to variation in labor misallocation across locations. When an undersupply of urban land occurs in productive yet highly constrained locations, workers have to reside in more affordable yet less productive locations.

I calibrate the model to quantify the aggregate welfare loss due to the Farmland Red Line Policy. The parameter unique to my setting is the price elasticity of developed land and is identified using the variation in land ruggedness as specified in the reduced-form analysis. The rest of the parameters are calibrated to match either values from aggregate data or estimates from the literature. With the parameters and the observed GDP, employment, land use, and land features from 2010, I recover the unobserved productivities, amenities, and prices that rationalize the observed data as an equilibrium of the model. I show that the model performs well in simulating the reduced-form results, which are not targeted throughout the model calibration. Amenities and productivities recovered from the model correlate well with out-of-sample proxies such as local FDI and the presence of theaters and museums. Three counterfactual analyses are conducted based on the calibrated model.

My quantitative model first produces an estimate of a 6% welfare loss for workers as a result of the Farmland Red Line Policy. The estimate is derived by comparing the simulated counterfactual equilibrium without the policy and real figures for 2010. Next, the economy would have specialized more in the manufacturing sector in the no-policy counterfactual equilibrium. Specifically, manufacturing output would have been 5.0% higher, while agricultural output would have been 2.8% lower.

An important question is how the policy intervened in the urbanization process between 1999 and 2010, as the policy was adopted when rural-to-urban migration accelerated. The policy-induced undersupply of urban land would both make urban areas more congested and slow urbanization. A quantitative exercise shows that distortions from the policy manifest mostly in overcrowding in urban areas as opposed to a decrease in urbanization. Without the policy, the urban population would have been 5.2% higher in 2010.[6] In contrast, without the policy, there would have been 40% more urban land in 2010. This indicates that urban population density would have been dramatically lower, decreasing by 25% from 12,170 to 9,249 per sq. km.

Finally, I show that using a cap-and-trade platform is a more efficient way of protecting farmland and food security than the Farmland Red Line Policy. Through this platform, a local government in one location can pay another to create new farmland if the former location needs to convert farmland into urban land. This cap-and-trade platform guarantees that the amount of farmland nationwide does not decrease, while the amount of farmland in each individual location is allowed to change. I simulate a counterfactual equilibrium with the cap-and-trade platform and find that the platform can eliminate 60% of workers' welfare loss from the Farmland Red Line Policy. Specifically, in the counterfactual equilibrium with a cap-and-trade platform, the welfare of workers would have been 3.5% higher than it was in reality in 2010.

Research in land-use regulations has a long history (e.g., Ohls et al., 1974; Rosen and Katz, 1981; Katz and Rosen, 1987; Glaeser et al., 2005; Glaeser and Ward, 2009; Saiz, 2010; Gyourko et al., 2013). An

[6] The actual increase in the urban population from 1999 to 2010 was more than 40%. Therefore, another 5.2% increase in the urban population in the counterfactual world is not too radical.

extensive theoretical literature has discussed the determinants of local land-use regulations and their impacts on the housing market, residential sorting, and social welfare (Hamilton, 1978; Epple et al., 1988; Wallace, 1988; Engle et al., 1992; Brueckner, 1995; Helsley and Strange, 1995; Calabrese et al., 2007; Hilber and Robert-Nicoud, 2013; Ortalo-Magné and Prat, 2014). However, the empirical studies on this topic are less developed. Earlier studies, restricted by data availability, examined one or a few cities; in addition, they focused on the effect of land-use regulation on the housing market (Gyourko and Molloy, 2015). Most empirical evidence was based on the U.S., which has a relatively elastic housing supply around the world.[7] Moreover, as noted in Quigley and Rosenthal (2005), the endogenous relationship between housing prices and land-use regulations poses a serious econometric challenge.

More recently, a series of studies advance the literature in different directions. To address the endogeneity of land-use regulations, a few recent studies adopt a difference-in-difference strategy by examining changes in a particular regulation (Cunningham, 2007; Zhou et al., 2008; Kahn et al., 2010; Dempsey and Plantinga, 2013). Another identification strategy is regression discontinuity design, as employed in Grout et al. (2011) and Turner et al. (2014).[8] A few studies have also managed to extend the scope of analysis to metropolitan areas across the United States (e.g., Glaeser et al., 2006, 2008), and more international evidence has been presented.[9] Finally, a strand of literature goes beyond the housing market and emphasizes the role of land-use regulations in the labor market responses to local productivity shocks (Glaeser et al., 2006; Saks, 2008; Ganong and Shoag, 2017). Along this vein, recent literature highlights the aggregate welfare loss caused by land-use regulations (Hsieh and Moretti, 2018; Parkhomenko, 2020; Bunten, 2017).[10]

Using the Farmland Red Line Policy in China, this paper addresses the four main challenges of the literature all at once. First, this policy imposes an additional cost on urban land development that varies across regions due to exogenous local geographical features, which allows me to establish the causal impact of the policy on local urban land supply, GDP, and population size. Moreover, the availability of panel data on the economic conditions of city jurisdictions and geographical features of land makes it possible to include almost all the Chinese city jurisdictions in the analysis. It also gives me rich variation to precisely estimate the effects. Third, by developing a quantitative spatial equilibrium model that features endogenous land-use decisions, I am able to quantify the aggregate welfare loss caused by the policy and examine the mechanisms through which land-use regulations lead to economic efficiency loss. Finally, findings based on the Chinese setting shed light on land-use regulation designs in other fast-growing economies in developing countries. The results demonstrate that land-use regulations that preserve farmland can generate a substantial cost to aggregate welfare for developing countries during urbanization.

More broadly, this paper emphasizes that land-use regulations play an important role in determining the spatial allocation of economic activities. Recent advances in the quantitative spatial literature accelerate

[7]Caldera and Johansson (2013) shows that the U.S. has the most elastic supply of housing among 21 OECD countries.

[8]Turner et al. (2014) compares land parcel values across municipal borders where land-use regulations change and are arguably uncorrelated with unobserved parcel characteristics from two sides of the border. In the same spirit, Grout et al. (2011) exploits a regression discontinuity design to measure effects of the Portland Oregon, metropolitan area UGB on property values.

[9]Some examples include Bertaud and Malpezzi (2001); Fu and Somerville (2001); Cheshire and Sheppard (2002); Solé-Ollé and Viladecans-Marsal (2012); Hilber and Vermeulen (2016); Cai et al. (2017).

[10]For example, Hsieh and Moretti (2018) develops a general equilibrium model to show that stringent restrictions to new housing supply prevent workers to have access to high productivity cities, and it has lowered aggregate U.S. growth by 36 percent from 1964 to 2009.

a series of research to understand the role of market access (Redding and Sturm, 2008), regional trade frictions (Donaldson and Hornbeck, 2016; Tombe and Zhu, 2020), and migration frictions (Hao et al., 2020) in shaping the uneven distribution of economic activities across space. My paper complements the literature by showing that land-use policies can effectively change the spatial distribution of economic activities, which matters for production efficiency at the aggregate level.

The remainder of this paper proceeds as follows. Section 2 provides institutional information about the Farmland Red Line Policy. Section 3 details the data and unit of analysis. Section 4 conducts regression analysis to study the effect of the Farmland Red Line Policy on local economic development. Section 5 develops a static spatial equilibrium model to demonstrate the impacts of the Farmland Red Line Policy on land allocation and labor allocation. Section 6 quantifies the model and calibrate it to the benchmark year. Section 7 estimates the aggregate effects of the Farmland Red Line Policy. Section 8 evaluates two counterfactual policies and compare the counterfactual outcome with reality. Second 9 concludes the paper.

2 Policy Background

This section provides a detailed discussion of the Farmland Red Line Policy and the relevant institutional background. I first outline institutional information about the administrative geography and land classification in China. China is divided into counties. A city jurisdiction is an administrative unit that is composed of one or several counties. Moreover, it contains both an urban area and a surrounding rural area.[11] Correspondingly, within a city jurisdiction, land is divided into urban land, farmland, and unused land. Figure I(a) provides an example of a stylized city jurisdiction. Urban land is typically located near the geometrical center of a city jurisdiction, surrounded by a mix of farmland and unused land. To create new urban land, a local government acquires rural land from rural residents at the urban fringe and converts it into urban land.[12] After this step, newly developed urban land is transferred to independent real estate developers through long-term leaseholds. Most land development profit counts as local government revenue (Chen and Kung, 2016).

The Farmland Red Line Policy was implemented at a time when urbanization was accelerating in China and the country switched from being an exporter to being an importer of agricultural products. From 1980 to 2010, 469.4 million Chinese people moved from rural areas to urban areas.[13] On the one hand, rapid urbanization drew land and labor from the agricultural sector to the manufacturing and service sector.[14] On

[11] Figure III shows the geographical coverage of city jurisdictions. City jurisdictions only include urban counties and nearby rural counties, but rural counties far away are not included. Depending on the number of counties, a city jurisdiction is either a central city (Diji Shi) composed of multiple counties or a county city (Xianji Shi) composed of only one county.

[12] By Chinese law, urban land and most of the unused land is owned by the state; farmland is collectively owned by local rural residents, who are represented by a village committee in each local area. To convert farmland into urban land, the local government first pays compensation to rural residents to transfer ownership of the land to the state. The compensation is based on the output value of the farmland, and rural residents have limited bargaining power. After the land is acquired, the local government cleans up the surface and provides urban infrastructure, such as electricity systems, for this new piece of land.

[13] The time-series data on the urban population come from the World Bank.

[14] New urban land is necessary to accommodate rural-to-urban migrants. Suppose no new urban land was created between 1990

the other hand, rising household income increased the domestic consumption of food. As a result, China's switch from agricultural exporter to an importer occurred in 1995 (Brown A., 1995). In September 1995, Lester Brown published the book 'Who Will Feed China?', in which he predicted that industrialization in China would soon make China a major importer of food. This would drive up the world food price and cause food shortages in the long run.[15] The book alerted the Chinese central government that rapid urbanization might soon endanger national food security (Wang et al., 2010).

Due to food security concerns, it became a national priority in China to preserve at least 1.2 million square kilometers (1.8 billion mu) of farmland ('National Land Use Plan for 1997-2010') in early 1997. This number is close to the total amount of farmland in the country around that time. When the goal was first announced, the central government was unclear about how to achieve the goal without fully halting urban land expansion. During 1997 and 1998, members of the central government quickly developed all of the regulatory details of the Farmland Red Line Policy. Meanwhile, to prevent local governments from overexpanding urban land before the new regulation came into force, the central government prohibited rural-to-urban land conversion nationwide.[16] The Farmland Red Line Policy was announced in August 1998. For the first time, strict regulations were in use to protect farmland, even if it could slow the urbanization process.[17]

The Farmland Red Line Policy prohibits local governments from converting farmland into urban land unless an equal amount of unused land is converted into farmland. Further, the new farmland should be in the same city jurisdiction as the farmland converted into urban land, unless a local government faces extreme difficulty in creating farmland; in this case, it might ask the government of another city jurisdiction within the same province to help create farmland (No.374[2001] of the Ministry of Land and Resources). In practice, asking another city jurisdiction's government for help involves high political costs, and hence, local governments typically create new farmland within their own jurisdictional boundaries (Liu et al., 2005).

To guarantee that the local governments' compliance with the policy, the central government adopted a sophisticated supervision system and devoted enormous efforts to monitoring urban land development and farmland change across locations. First, urban land development plans have to be approved by the central government on an annual basis; otherwise, the development is illegal. The central government will pay special attention to any urban land development project that uses more than 35 hectares of prime farmland or more than 70 hectares of farmland in total. Second, starting in 2000, the central government began using remote sensing techniques to detect illegal farmland conversion. If according to remote sensing data, urban land increases significantly more than the amount reported by local governors or there is a significant loss of farmland in that year, the local government could be investigated. Furthermore, since 2002, all the land

and 2010 and the amount of rural-to-urban migration was the same as in reality. By 2010, the average urban population density would have reached 27,941 people per km^2, which is even higher than Manhattan's population density.

[15]The book's main argument is that the reduction of farmland combined with an increase in food demand as the Chinese become wealthier would make China a primary importer in the global food market.

[16]The only exception was the national key projects detailed in No. 11[1997] of the CPC Central Committee and State Council.

[17]Although a farmland resource tax existed to protect farmland since the 1980s, the stringency, scope and efforts of monitoring were never comparable to those under the Farmland Red Line Policy (Lichtenberg and Ding, 2008). In particular, since 1987, the local government has had the authority to impose a farmland resource tax on local urban land developers and users. However, most local governors chose not to charge such a tax because they had no incentive to add any constraints to urban development, given that urban development was a very effective local development strategy.

legally converted from rural land to urban land has had to be registered with the national land-use registration platform (No. 374[2001] of the Ministry of Land and Resources). Each record provides information on the amount of farmland that used to be on a parcel and detailed information about the location and the condition of newly created farmland. The central government randomly selects records from the database and sends officials to the local area to check whether all the information on the record is accurately documented.

As a result of the enormous efforts devoted to regulating and monitoring urban land development across locations, the Farmland Red Line Policy successfully halted the loss of farmland due to urbanization. At the national level, the total amount of farmland has barely changed since the policy's implementation, as shown in Appendix Figure A.1. Across city jurisdictions, there is no significant negative correlation between the absolute change in urban land quantity and the absolute change in farmland quantity since the policy began, as shown in Appendix Table A.2.

The Chinese central government has recognized the obstacles to urban development created by the Farmland Red Line Policy and has been considering alternative policy designs. To reduce the constraint without endangering national food security, the Chinese central government announced in 2018 that there would be a national trading platform through which one city can pay another to create new farmland (Notice of the General Office of the State Council [2018] No.16). The platform will ensure that the total amount of farmland at the national level does not decrease, while in each location, the amount of farmland can be reduced as long as farmland increases by the same amount somewhere else. A more detailed discussion of the trading platform is provided in Section 8.

3 Data

This section explains how the data on city jurisdictions are assembled. I construct panel data on city jurisdictions in China by assembling data from a series of statistical yearbooks and the population census. This panel covers the years from 1990 to 2015 and includes most of the city jurisdictions in China. City jurisdictions cover most urban areas and nearby rural areas, but rural areas farther away are not included. Figure III shows the geographical coverage of city jurisdictions. City jurisdictions represented 80.1% of China's total GDP in 2010. They specialize in non-agricultural sectors. The agricultural GDP from city jurisdictions accounts for only 41.5% of national agricultural GDP, while the secondary sector (manufacturing and construction) and tertiary sector GDP from city jurisdictions account for 87.7% and 80.4% of the respective national totals.

The main outcome variables include the amount of urban land, GDP by sector, and population. Urban land and GDP data come from China's City Statistical Yearbooks, City Development Yearbooks, and China Data Online. Urban land refers to land that has been developed and used for non-agricultural activities. Next, GDP by sector at the level of city jurisdictions is available in the yearbooks only since 1994. Therefore, the analysis of GDP outcomes is based on panel data covering the period from 1994 to 2015. Finally, the population data are constructed using the 1982, 1990, 2000, and 2010 waves of the population census.[18]

[18]The data are from the China Data Center, University of Michigan. The main advantage of using the population census is that it offers a much more accurate accounting of the number of residents in city jurisdictions. See A.3 for a detailed discussion.

Several other variables are used in the empirical analysis to investigate the channels of the effects. First, government expenditures per capita and the number of hospital beds from 1990 to 2015 are used to measure the quality of government services. Second, the average price and the FAR of newly developed urban land sorted by land-use purpose, such as residential and commercial land, are available from 2007 to 2015. Third, the amount of urban land by land-use purpose is available in the City Development Yearbooks from 2002 to 2015. These variables are used to provide suggestive evidence about how urban land use responds to the land conversion barrier. Fourth, the compactness index of the urban area in a city jurisdiction for 1995 and 2010 is constructed using raster data on land use at 30-m resolution (Liu et al., 2018). This variable is used to test whether the compactness of the urban area deteriorates due to the policy.

Summary statistics for the main variables are provided in Appendix Table A.1. Appendix A.3 provides a more detailed discussion of all the datasets used in the empirical analysis.

4 Empirical Analysis

This section examines the local effect of the Farmland Red Line Policy on economic development.

4.1 Identification Strategy

To identify the impact of the Farmland Red Line Policy on local economic development, I use a DD estimator with continuous treatment intensity, and the cross-sectional variation is from the exogenous component of the additional cost of urban land development imposed by the policy.

The additional cost of urban land development imposed by the policy is equal to the cost of farmland development. Since the policy was adopted, whenever local governments convert farmland into urban land, they have to bear the additional cost of creating an equivalent amount of new farmland somewhere else in the city jurisdiction. Therefore, the additional cost of urban land development refers to the labor and material expenses involved in the cultivation of unused land. This additional cost is endogenously affected by local economic conditions, such as labor costs and price levels. Hence, attempts to directly compare the economic outcomes of city jurisdictions with different additional costs of urban land development are problematic.

I isolate exogenous variation in the additional cost of farmland development and define it as the *land conversion barrier*. In particular, the cost of new farmland development depends on the land ruggedness of the local region that is likely to be used for farmland development. In the agricultural engineering literature, the ruggedness of land is a crucial determinant for the low-cost cultivation of land (Nunn and Puga, 2012; Zhang et al., 2010).[19]

Next, land close to the administrative boundary is less developed and more likely to have open space for new farmland development in general than land further inside. As shown in Appendix Table A.3, moving away from the administrative boundary by 1 kilometer reduces the amount of unused land by close to 20%. This indicates that, on average, land more than 5 kilometers away from the administrative boundary of a city

[19] I do not consider the soil qualities of unused land for two reasons. First, soil qualities do not vary much across city jurisdictions. Moreover, it is not a major constraint in this context. According to the National Land Resource Department Annual Report (2006), when the original soil does not provide sufficient nutrition, an easy solution and hence a common practice is to move the topsoil of the farmland that is converted into urban land onto to the newly developed farmland.

jurisdiction is primarily unavailable for new farmland development. Therefore, in the baseline specification, I create a 5-km inward buffer from the administrative boundary and measure the ruggedness of land inside this buffer.[20] I define the average land ruggedness inside the buffer as the *land conversion barrier*.

Figure II illustrates the region used to measure land ruggedness in the baseline specification through the example of the Shanghai city jurisdiction. I always exclude land close to the existing urban area such that the measured land ruggedness does not directly affect the cost of urban land development in the near future. In the baseline specification, land close to the existing urban area is defined as land within a 2-km outward buffer from the boundary of the existing urban area before 1999. The specification of 2 km is to equalize the total amount of land in the outward buffers and the projected total new urban land needed to accommodate the urban population at its peak level throughout the 21st century. Note that this specification assumes that urban areas expand by extending all points along the current boundary outwards by an equal amount. The results are robust to alternative assumptions about the way urban area expands discussed in Harari (2020), as detailed in Appendix Table A.6.

The cross-sectional variation depends solely on predetermined geographical features. The data on land ruggedness were collected in the NASA Shuttle Radar Topographic Mission around the time of policy implementation (Fischer et al., 2008a). The land conversion barrier is essentially an exogenous determinant of the additional cost per unit of new urban land. Ceteris paribus, the higher the land conversion barrier is, the less new urban land should be developed after policy implementation.

A series of diagnostics of the land conversion barrier show that it has no clear spatial patterns on the map (Figure III), that the measure has rich cross-sectional variation (Appendix Figure A.2), and that city jurisdictions with different land conversion barriers are balanced along various dimensions of economic and demographic characteristics in 1990 (Table I).[21]

To identify the impact of the land conversion barrier on local economic outcomes, I use a DD estimator with continuous treatment intensity. The regression specification is the following:

$$\ln(y_{it}) = \beta C_{u,i} \times \text{Post1999} + \alpha_i + \gamma_t + \sum_{\tau \in 1991 \text{ to } 2015} X_i' \theta_\tau + \epsilon_{it}. \tag{1}$$

The dependent variable $\ln(y_{it})$ is (log of) the outcome variable of interest in city jurisdiction i in year t. $C_{u,i}$ represents the land conversion barrier, and Post1999 takes a value of 1 for years after 1999. β represents the causal impact of the land conversion barrier on the outcomes since policy implementation. I control for city jurisdiction fixed effects (α_i) and year fixed effects (γ_t). X_i is a set of state variables for city jurisdiction i and

[20]In the main analysis, I define land ruggedness as the percentage of land grids with a local slope greater than 15 degrees because the Chinese central government explicitly discourages farmland development on surfaces with a slope above 15 degrees. As shown in Appendix Table A.6, the results are robust to alternative definitions of land ruggedness, including those used in Nunn and Puga (2012). The results are also robust to using a 10-km inward buffer and all the land outside the existing urban area to measure land ruggedness.

[21]Locations with different land conversion barriers are overall very similar in terms of growth of population and employment, changes in economic structure (growth of employment in the non-agricultural sector), and human capital accumulation (changes in the illiterate population and college graduates) from 1982 to 1990. They are also quite similar along broad measures of local economic characteristics in 1990, including the employment structure, education, and in-migration. Locations with a higher land conversion barrier had slightly lower populations and employment rates in 1990. Therefore, I control for the time-varying impacts of population and the employment rate in 1990 in the main analysis.

includes region dummies across all regression specifications to guarantee that any cross-regional differences in economic development will not bias the estimation.[22] In the central regression specification, I include the population and employment rate in 1990 in the state vector X_i because the land conversion barrier is slightly correlated with these two variables. Finally, the error terms are clustered at the city jurisdiction level.

The identification relies on the assumption of parallel trends across city jurisdictions with different land conversion barriers throughout the period of study had the policy never been implemented. I have multiple years of data before the policy was adopted, which allows me to directly test the parallel trends assumption for the years up to 1998. As shown in Section 4.2, I do not find any systematically different trends in growth in terms of the major outcome variables before 1999. The identification is not contaminated by reverse causality given that the land conversion barrier is fixed over time.

4.2 Results: Main Outcomes

This subsection estimates the effects of the Farmland Red Line Policy on local economic outcomes.

4.2.1 Urban Land Supply

A higher land conversion barrier significantly reduces urban land supply after the policy was adopted, as shown in Table II Column 1. Panel A presents the baseline specification, while Panel B presents the central regression specification, which further includes the time-varying effects of the population and employment rate in 1990. In the central analysis, a one-standard-deviation increase in the land conversion barrier reduces the urban land supply by 5.2% ($= 18.7\% \times 0.276$).

Next, to provide evidence to support the parallel trends assumption, I estimate the effect year-by-year to allow the impact of the land conversion barrier on urban land supply to change over time.[23] Figure IV(e) confirms that city jurisdictions with different land conversion barriers have parallel trends in the urban land supply before policy implementation: β_τs are not significantly different from 0 before 1998.

The parallel trends test also shows that the land conversion barrier's negative impact on the urban land supply grows slightly over time. Therefore, I conduct the DD analysis using data from 1996 and 2010 only and label it as the long-run effect of the land conversion barrier.[24] As confirmed in Table IV Column 1, the long-run impact is more negative than the average treatment effect: a one-standard-deviation increase in the land conversion barrier reduces the urban land supply by 6.7% eleven years after policy implementation. The impact is equivalent to approximately 11% of one standard deviation of the growth rate of urban land across city jurisdictions from 1996 to 2010 and is economically significant.

[22]China is divided into four economic regions: the east, middle, west, and northeast. Regional time-varying effects can control for distortions from other land-use controls that vary across regions and times. For example, it controls for the pro-Western-region bias in the approval of urban land development projects from the central government since the 2000s.

[23]The regression specification is the following: $\ln(y_{it}) = \sum_{\tau\in 1990 \text{ to } 2015} C_{u,i}\beta_\tau + \alpha_i + \gamma_t + \sum_{\tau\in 1990 \text{ to } 2015} X_i'\theta_\tau + \epsilon_{it}$, where $\{1_{\tau=t}\}_{\tau\in 1990 \text{ to } 2015}$ is a set of dummy variables that take the value of 1 if the observation is from year τ. β_τ represents whether in year τ, city jurisdictions with greater land conversion barriers have less urban land, conditional on any initial difference in 1996. There is severely missing data issue for urban land during 1997 and 2001, and hence, I choose 1996 as the benchmark year.

[24]2010 is the last year for which the data on population size are available. Therefore, I choose 2010 as the post-period to make it the same across regressions in Table IV. There is a severe issue of missing data for urban land during 1997 and 2001, and hence, I choose 1996 as the pre-period.

4.2.2 GDP by Sector

A higher land conversion barrier significantly reduces the GDP of a city jurisdiction, as reported in Table II, Columns 2 to 5. The central estimates reported in Panel B suggest that after policy implementation, a one-standard-deviation increase in the land conversion barrier reduces GDP by 3.8% (Column 5). Furthermore, the negative impact on GDP is due to a 5.5% decrease in GDP in the secondary sector (Column 2), which is dominated by manufacturing. GDP from the service sector (Column 3) or the agricultural sector (Column 4) does not change significantly. This finding is consistent with the intuition that the secondary sector is more urban land intensive than the service sector and therefore is more negatively affected by the policy. The parallel trends assumption holds well for GDP and GDP by sector based on the estimation of the effects year-by-year, as shown in Figure IV(a) to (d).

I also estimate the long-run effects by using data from 1996 and 2010 in the DD analysis and present the results in Table IV. By 2010, a one-standard-deviation increase in the land conversion barrier reduced the GDP of a city jurisdiction by 5.3%. The impact is equivalent to approximately 11% of one standard deviation of the GDP growth rate across city jurisdictions from 1996 to 2010 and hence is substantial.

4.2.3 Population

This subsection shows that a higher land conversion barrier significantly reduces the population of a city jurisdiction. As reported in Table II, Column 6, a one-standard-deviation increase in the land conversion barrier reduces the population size by 3.9% in the main analysis. Next, I present the year-by-year estimates and plot the coefficients in Figure IV(f). After 1999, the negative impact of the land conversion barrier grew over time, which was consistent with the dynamics of urban land and GDP during the same period. Finally, I estimate the long-run effects by using population data from 1990 and 2010 in the DD analysis, and the results are shown in Table IV, Column 6. A one-standard-deviation increase in the land conversion barrier reduces the population by 5.0% by 2010, which is 14% of a standard deviation of population growth across city jurisdictions from 1990 to 2010.

4.2.4 Robustness Checks

This subsection presents a series of robustness checks to address several endogeneity concerns.

First, the presence of rugged land close to the administrative border might increase the transportation cost between this location and the rest of the country and hurt the local economy. If the negative effect varies across time, it would bias the estimation. To address this concern, I control for the number of railway lines that pass through a city jurisdiction in 2000 — an approximation of the connectivity of the city jurisdiction with other locations — interacted with year dummies. As shown in Table III, Panel A, the results are quite similar to the main estimates.

Second, the ruggedness of land close to the existing urban area might be correlated with the ruggedness of land close to the administrative boundary. The correlation would bias the estimation because the ruggedness of land at urban fringe can directly affect the cost of urban land development after 1999 (Saiz, 2010; Hilber and Vermeulen, 2016). To address this concern, I control for the time-varying effects of the ruggedness of the land in the 2-km outward buffer of the existing urban area. As shown in Table III, Panel B, the results are quite similar to the main estimates.

Other potential confounding factors include the distance to ports and the distance to the national capital. The former may affect a location's access to export markets, while the latter can affect the efficiency of a local government. If any factor discussed here correlates with the land conversion barrier and has time-varying effects on the local economy, it would bias the estimation. In Table III, Panel C, I show that adding the time-varying effects of both factors barely changes the results.

Fourth, there might be concerns that the land conversion barrier is systematically correlated with local economic fundamentals in the 1990s. Locations with different economic fundamentals in the 1990s have different growth paths, and a correlation would bias the estimation. The balance test shows that city jurisdictions with different land conversion barriers are similar along various dimensions except the population and employment rate in 1990. Therefore, the main specification included the time-varying effects of the two variables. This specification approximates the nonlinear specific time trends. As a robustness check, I further include the time-varying effects of state variables on sector structure, human capital, and migration.[25] As shown in Appendix Table A.4, Panel A, the results are close to the main estimates.

Fifth, to address the concern that city jurisdictions from different provinces might have different trends in economic growth and hence be less comparable to one another, I control for province time-varying effects in addition to the time-varying effects of the full set of economic characteristics. As shown in Appendix Table A.4, Panel B, the main patterns are consistent with the baseline results: a higher land conversion barrier leads to a relative decrease in the urban land supply and population. Its negative impact on local GDP is the most prominent in the secondary sector.

Sixth, I do not find empirical evidence supporting that urban land expansion in politically favored city jurisdictions is less affected by the land conversion barrier. Politically favored cities may face a lower political cost to delegate farmland creation tasks to other locations. If these city jurisdictions are less affected, by excluding them from the regression, β should be more negative than the baseline regression outcome. In Appendix Table A.5, I exclude 26 provincial capital cities in Panel A, 4 provincial-level city jurisdictions in Panel B, and 14 coastal port city jurisdictions in Panel C.[26] The coefficients from these subgroup regressions are very similar to the baseline outcomes.

Some additional robustness checks are presented at the end. First, I show that the results are robust to using the HAC spatial clustering method (Appendix Table A.7). Next, Appendix Table A.5, Panel A shows that the results are quite similar if 8% of city jurisdictions are dropped, which changes the administrative boundary by incorporating at least one county during the period of the study. Finally, as discussed in detail in Appendix Table A.6, the results are robust to using alternative indexes to measure land ruggedness as well as different ways to specify the projected region for farmland creation.

[25] I add region dummies, the population size, the employment rate, the share of agricultural sector employment, the illiteracy rate, and the percentage of in-migrants in the population in the state vector X_i.

[26] Chen et al. (2017) suggests that provincial capital cities have better political connections with the central government and thus have access to cheaper investment costs. Note that 26 out of 27 provincial capital cities are included in the baseline regression because Lasa has serious missing data issues for years after 1996, and thus, Lasa was excluded from the regression analysis. The four provincial cities enjoy a higher political hierarchy than the remaining city jurisdictions. The 14 coastal port cities have had a more favorable foreign investment policy and urban development policy since 1984.

4.3 Mechanism Investigation

This subsection tests several channels that might explain the causal relation between the land conversion barrier and local economic outcomes. I first show that the FAR of buildings cannot freely adjust to the land conversion barrier. Therefore, if urban land supply decreases, the effective urban space is reduced. Next, I find that the causal relation cannot be explained by alternative channels such as the deterioration of urban compactness or poorer government service in the more constrained city jurisdictions.

First, I find that the FAR cannot freely respond to the land conversion barrier, and hence, a reduction in urban land supply leads to a floorspace decrease. This finding explains why urban land supply matters even though urban workers ultimately use floorspace for production and residency, which depends on both the urban land supply and the FAR. As shown in Table V, I find a very weak correlation between the land conversion barrier and the average FAR across all the transacted new urban land plots during the post-policy period.[27] This result can be rationalized by the fact that nearly 90% of the newly transacted urban land plots are for industrial and commercial use. For many industrial and commercial buildings, the FAR is subject to industry-specific standards and cannot easily change even when there is a lack of urban land.

Second, the results are not driven by the channel of public service provision. This channel states that because a large fraction of the revenue from urban land sales in China goes to the local government, a lower land conversion barrier leads to higher local government revenue and better public services. Such jurisdictions attract more workers and have higher GDP and a greater population size. I test this channel by using the regression specification (1) to estimate the impact of the land conversion barrier on the number of hospital beds and government expenditures per capita. Government expenditures per capita can proxy for social welfare of residents because most local government expenditures are spent on the provision of social security and public education. Next, the Chinese government uses the number of hospital beds to measure the capacity of public health services. Both variables are available in the yearbooks throughout the study period.

As shown in Table VI, Column 1, a decrease in the land conversion barrier does not increase the number of hospital beds after 1999, suggesting that health care provision does not improve in city jurisdictions with a lower land conversion barrier. Next, as shown in Table VI, Column 2, a higher land conversion barrier leads to a slight decline in government expenditure per capita after 1999. Nonetheless, the negative impacts of the land conversion barrier on local economic outcomes are not due to reduced social welfare. As shown in Appendix Table A.4, Panel C, I add government expenditure per capita as an explanatory variable, and the estimated impacts of the land conversion barrier on local economic outcomes barely change. This finding indicates that the public expenditure channel cannot drive the results because otherwise, the coefficients would be much closer to 0 after controlling for government expenditure per capita.

Next, I find no evidence that a higher land conversion barrier deteriorates the shape of the urban area in a city jurisdiction. Harari (2020) notes that the compactness of an urban area can directly improve commuting

[27] The dependent variable exists only for the years between 2007 and 2015. Therefore, I cannot use DD analysis and control for location fixed effects. The identification instead relies on the cross-sectional variation. To control as many local fundamentals as possible, I include (a) the full set of economic and demographic characteristics of a location in 1990; (b) GDP, GDP in the non-agricultural sector, and the urban land supply in 1996; and (c) the ruggedness of land close to the existing urban areas. More details about the regression specification can be found in Table V.

efficiency within the urban area and is therefore valued by workers. On the one hand, the presence of expensive farmland next to existing urban land may incentivize the local government to develop unused land farther away from existing urban land, which reduces the compactness of the urban area. On the other hand, the local government is responsible for providing public transportation infrastructure and subsidizing public transportation. Thus, the local government internalizes the benefit of the compactness of the urban area. If the saved cost on transportation from a more compact urban area is greater than the additional cost of using farmland, the local government would use the farmland for urban land development and bear the additional farmland development cost.

To test whether compactness of an urban area deteriorates with a higher land conversion barrier, I conduct a DD analysis with the Polsby-Popper (PP) score of the urban area polygon as the dependent variable.[28] As displayed in Table VII, there is no significant change in compactness with respect to the land conversion barrier after policy implementation. Thus, the urban compactness channel cannot explain the causal impact of the land conversion barrier on local economic development.

Finally, I find no evidence that the land conversion barrier affects how local governments allocate urban land between residential use and business use. I collect data on the share of urban land as residential land, business land, land for public facilities, and land for public transport and squares from 2002 to 2015 from the City Development Yearbooks. Then, I test whether the share of urban land in each category is associated with the land conversion barrier. As shown in Table VIII, none of them is significantly associated with the land conversion barrier. This result implies that when the amount of urban land increases, the amount of urban land for each purpose increases proportionally.

Summary This section shows that because of the Farmland Red Line Policy, city jurisdictions with a lower land conversion barrier were able to create more urban land after the policy was adopted. Ceteris paribus, urban land was cheaper in these city jurisdictions, which attracted more workers to move in during the rapid urbanization period in China. Therefore, these city jurisdictions have higher GDP and a larger population than others. The findings show that the Farmland Red Line Policy has a significant impact on the spatial distribution of economic activities.

5 Model

The identified local effects of the policy on economic outcomes leave open the question of whether the policy generates any significant aggregate impacts on the economy, which matters for policy evaluation. To evaluate the aggregate impact of the Farmland Red Line Policy, I develop a static quantitative spatial equilibrium model with endogenous land-use decisions. When examined through the lens of the model, the Farmland Red Line Policy causes an undersupply of urban land and an excess supply of farmland. Moreover, the degree of cross-sector land misallocation depends on the predetermined geographical features. In general

[28] The PP score is among the most frequently used measures of the compactness of a polygon. It is defined as the ratio of the area of the district to the area of a circle whose circumference is equal to the perimeter of the district (Polsby and Popper, 1991). The urban area polygons for 1995 and 2015 are constructed by using the urban land-cover database at 30-m resolution developed in Liu et al. (2018).

equilibrium, land misallocation leads to labor misallocation due to the labor mobility between the agriculture and manufacturing sectors and across space. Therefore, abolishing the policy would generate gains in terms of workers' welfare.

5.1 Model Setup

In the model, each location has both an urban sector and a rural sector. Each location-sector produces a variety of a final product. Consumers' love of variety means that products produced in one location are shipped to the rest of the locations, and the transportation of final products is subject to an iceberg trade cost. Next, workers maximize utility by choosing the location and sector, supplying one unit of labor to earn wage income and spending income on tradable goods and housing. Finally, in each location, there is an immobile representative landlord that owns a continuum of land plots. A land plot can be developed into farmland or urban land at a cost or remain as unused land. Agricultural sector workers rent farmland for production and housing, while manufacturing sector workers rent urban land for housing. The landlord chooses the amount of urban land, farmland and unused land to maximize the land development profit. Finally, the landlord spends the land profit on tradable goods consumption.

5.1.1 Locations

I model China as consisting of N locations. Each location n has both an urban area where manufacturing production takes place and a rural area where agricultural production takes place. In each location and sector, a differentiated final good is produced. All the final goods can be traded between any two locations subject to an iceberg trade cost $T_{nn'}$.

A location n is distinguished by its productivity in the manufacturing sector and the agricultural sector $\{A_{Mn}, A_{Fn}\}$ and the amenity in the urban and the rural area $\{B_{Mn}, B_{Fn}\}$. Agglomeration effects exist in each urban sector: $A_{Mn} = \bar{A}_{Mn}(L_{Mn})^{\alpha}$, where α represents the degree of the agglomeration in production. Local amenities can respond endogenously to how populated the location is: $B_{sn} = \bar{B}_{sn}(L_{sn})^{\beta}$, $s \in \{M, F\}$.[29]

5.1.2 The Worker's Problem

The economy is inhabited by a measure $\bar{L}$ of workers. Workers are homogeneous except for their idiosyncratic preferences over locations and sectors, and they can freely choose their location and sector.[30] A worker in the manufacturing sector lives in an urban area and a worker in the agricultural sector lives in a rural area. Workers in the economy derive utility from manufacturing and agricultural goods consumption, housing consumption, and local amenities. Workers are price takers in all markets.

[29]This assumption allows local amenities to endogenously respond to the size of the local population. Under this assumption, more populous regions can be either more polluted or congested (which indicates a negative β) or more attractive due to public goods sharing (which indicates a positive β).

[30]In reality, changing sectors and locations is subject to nonnegligible switching costs (Tombe and Zhu, 2020). This makes the labor supply for a specific location and sector an upward-sloping curve. Although switching costs are not explicitly modeled here, workers' preference heterogeneity guarantees that the labor supply acts similarly for any real wage shocks. A high switching cost is approximated by a high preference dispersion.

The utility function of worker i who lives in location n and works in sector s is:

$$U(i,n,s) = \frac{\left(C_F(i,n,s)^{\mu} C_M(i,n,s)^{1-\mu}\right)^{\theta} h(i,n,s)^{1-\theta} B_{sn} z_{i,n,s}}{(\mu\theta)^{\mu\theta}((1-\mu)\theta)^{(1-\mu)\theta}(1-\theta)^{1-\theta}}.$$

where $C_M(i,n,s)$ is a CES bundle of manufacturing goods, $C_F(i,n,s)$ is a CES bundle of agricultural goods and $h(i,n,s)$ is housing consumption (the amount of residential land). Specifically, $C_M(i,n,s) = \left(\sum_{n' \in N_c} c_{Mn'}(i,n,s)^{\frac{\sigma_M - 1}{\sigma_M}}\right)^{\frac{\sigma_M}{\sigma_M - 1}}$, where $c_{Mn'}(i,n,s)$ is the manufacturing product from location n' and σ_M is the elasticity of substitution of the manufacturing products from alternative locations; $C_F(i,n,s) = \left(\sum_{n' \in N} c_{Fn'}(i,n,s)^{\frac{\sigma_F - 1}{\sigma_F}}\right)^{\frac{\sigma_F}{\sigma_F - 1}}$, where $c_{Fn'}(i,n,s)$ is the agricultural product from location n' and σ_F is the elasticity of substitution of the manufacturing products from alternative locations. θ represents the share of spending on tradable goods. Within the tradable goods category, μ is the share of spending on agricultural products and $1-\mu$ is the share of spending on manufacturing products. Finally, worker i derives utility from location n and sector s. B_{sn} is the utility common to all workers, while $z_{i,n,s}$ is the idiosyncratic utility of worker i. For model tractability, I assume that each $z_{i,n,s}$ is an independent draw from a Fréchet distribution: $z_{i,n,s} \sim F_z(x) = e^{-x^{-\tilde{\nu}}}$.

Next, I introduce the budget constraints of workers in the economy. Workers have a fixed unit of working time, normalized to 1. I denote w_{sn} as the wage rate for one unit of working time in sector s and location n. A worker spends labor income on tradable goods and housing consumption. The unit price of a sector s' product from location n' is $p_{s'n'} T_{n'n}$, where $p_{s'n'}$ is the product price at origin and $T_{n'n}$ is the iceberg trade cost from n' to n. A worker in an urban area rents urban land for housing and pays the unit urban land price p_{Hn} to the landlord; a worker in a rural area rents farmland for housing and pays the unit farmland rent p_{Rn} to the landlord. Therefore, her budget constraint is

$$\sum_{s' \in \{F,M\}} \sum_{n' \in N} p_{s'n'} T_{n'n} c_{s'n'}(i,n,s) + p_{H,sn} h(i,n,s) \leq w_{sn},$$

where $p_{H,Mn} = p_{Hn}$ and $p_{H,Fn} = p_{Rn}$.

The utility maximization problem for a worker is as follows. She first draws a vector of the idiosyncratic utilities she derives from different locations and sectors. Based on her realized preferences, she chooses the location and sector and earns wage income. She then allocates her income to tradable goods and housing. The worker solves the utility maximization problem through backward induction. In Stage 2, conditional on the choice of location and sector, she optimally allocates income across tradable goods and housing. In Stage 1, she chooses the location and sector combination that offers her the highest utility.

In Stage 2, a worker i who has already chosen to live at location n and work in sector s receives her maximum utility $\frac{w_{sn}}{\tilde{p}_n^{\theta} p_{H,sn}^{1-\theta}} B_{sn} z_{i,n,s}$, where $\tilde{p}_n$ is the price index of tradable goods,

$$\tilde{p}_n = \tilde{p}_{Fn}^{\mu} \tilde{p}_{Mn}^{1-\mu}. \tag{2}$$

$\tilde{p}_{sn}$ is the price index of the bundle of consumption goods from sector s chosen by consumers in location n,

$$\tilde{p}_{sn} = \left(\sum_{n' \in N} \left(T_{nn'} p_{sn'} \right)^{1-\sigma_s} \right)^{\frac{1}{1-\sigma_s}}. \tag{3}$$

In Stage 1, a worker chooses the location and sector combination that offers her the highest utility. Given that $z_{i,n,s}$ follows the Frechét distribution, the share of workers who choose location n and sector s is $\pi^L_{sn} = \frac{\left(w_{sn}\tilde{p}_n^{-\theta} p_{H,sn}^{\theta-1} B_{sn}\right)^{\tilde{\nu}}}{\sum_{s' \in \{F,M\}} \sum_{n' \in N} \left(w_{s'n'}\tilde{p}_{n'}^{-\theta} p_{H,s'n'}^{\theta-1} B_{sn}\right)^{\tilde{\nu}}}$.[31] We define $\nu = \frac{\tilde{\nu}}{1-\beta\tilde{\nu}}$ to simplify the calculation. The expected utility of a worker is defined as the expected utility before her idiosyncratic preferences are realized. It can be expressed as $\tilde{V} = \bar{V}\bar{L}^{\beta}\Gamma\left(1 - \tilde{\nu}^{-1}\right)^{\frac{1}{\nu}}$, and $\bar{V}$ is expressed as follows:

$$\bar{V} = \left(\sum_{s' \in \{F,M\}} \sum_{n' \in N} \left(w_{s'n'} \tilde{p}_{n'}^{-\theta} p_{H,s'n'}^{\theta-1} \bar{B}_{sn} \right)^{\nu} \right)^{\frac{1}{\nu}}. \tag{4}$$

The labor supply for the manufacturing sector and the agricultural sector in location n can be expressed as

$$L_{sn} = \bar{L}\bar{V}^{-\nu} \left(w_{sn} \tilde{p}_n^{-\theta} p_{H,sn}^{\theta-1} \bar{B}_{sn} \right)^{\nu}. \tag{5}$$

Next, the share of spending on the product variety from location n' and sector s' is $\pi^C_{n'n,s'} \equiv \frac{(p_{s'n'}T_{n'n})^{1-\sigma_{s'}}}{\tilde{p}_{s'n}^{1-\sigma_{s'}}}$. Finally, the aggregate demand for urban land in location n is

$$(1-\theta) w_{Mn} L_{Mn} = p_{Hn} H_n. \tag{6}$$

The aggregate demand for farmland used for housing in location n is

$$(1-\theta) w_{Fn} L_{Fn} = p_{Rn} R_{Hn}. \tag{7}$$

A detailed derivation of workers' utility maximization problem is provided in Appendix B.1.

5.1.3 Production

The production function of the manufacturing good variety produced in location n, Y_{Mn}, is

$$Y_{Mn} = A_{Mn} L_{Mn}. \tag{8}$$

Note that even though urban land is modeled as residential land for simplicity, we can interpret it as urban workers using a fraction of urban land for production purposes and the rest for residential housing.

Next, the production function of the agricultural good variety in location n, Y_{Fn}, is

$$Y_{Fn} = \bar{A}_{Fn} L_{Fn}^{\gamma} R_{Fn}^{1-\gamma}. \tag{9}$$

[31] This equals the probability that a worker will choose location and n sector s before her idiosyncratic preferences are realized.

All product markets and labor markets are assumed to be competitive. At a given wage rate in the manufacturing sector w_{Mn} and the agricultural sector w_{Fn}, farmland price p_{Fn}, and product prices p_{Mn} and p_{Fn}, the demand for labor from the manufacturing sector in location n is

$$w_{Mn} = p_{Mn}\bar{A}_{Mn}L_{Mn}^{\alpha}, \tag{10}$$

the demand for labor from the agricultural sector in location n is

$$w_{Fn} = \gamma p_{Fn}\bar{A}_{Fn}L_{Fn}^{\gamma-1}R_{Fn}^{1-\gamma}, \tag{11}$$

and the demand for farmland is

$$p_{Rn}R_{Fn} = \frac{1-\gamma}{\gamma}w_{Fn}L_{Fn}. \tag{12}$$

5.1.4 The Landlord's Problem

At each location n, an immobile representative landlord owns land with measure $\tilde{R}_n$. A fraction, $1-\phi_n$, of the land is developable.[32] The developable land can be further divided into a continuum of land plots indexed by $l \in [0,1]$. A developable land plot l can be developed into either farmland or urban land at a cost of $\tilde{p}_n f(\Psi_n)x_{nl}$. This specification is equivalent to assuming that the landlord first cultivates unused land into farmland; in step 2, urban land is developed by converting farmland into urban land with no additional development cost. $\tilde{p}_n f(\Psi_n)$ represents the constant land development cost, where $\tilde{p}_n$ represents the local price level and Ψ_n represents other soil quality features that affect the development cost. x_{nl} represents the heterogeneity of land development suitability across land plots within a location. The heterogeneous suitability of land plots for development guarantees that the farmland supply function is upward sloping. For model tractability, x_{nl} is an independent draw from the Pareto distribution: $x_{nl} \sim F(X) = 1 - X^{-\frac{1}{\zeta}}$.[33]

A landlord obtains payoff p_{Rn} by providing one unit of farmland in the farmland rental market and p_{Hn} by providing one unit of urban land in the urban land rental market. Farmland is rented by agricultural sector workers for agricultural goods production and housing. Urban land is rented by manufacturing sector workers for housing. The profit from land development is obtained by the immobile landlord and spent on tradable goods.[34]

The farmland supply function and the urban land supply function can be derived by solving a landlord's profit maximization problem. First, without any policy intervention, the urban land rent equals the farmland

[32] ϕ_n corresponds to the percentage of land with a local slope above 15 degrees.

[33] Any distribution that is not bounded from above would guarantee that as the amount of developed land in a location is infinitely close to the total amount of developable land $(1-\phi_n)\tilde{R}_n$, the marginal cost of land development goes to infinity. This feature helps avoid the corner solution in which the farmland price is greater than the marginal farmland cost in equilibrium. Therefore, all the qualitative results discussed in this section are robust to any distribution that satisfies this feature. I choose the Pareto distribution for the quantitative exercise because it delivers a simple functional form of the supply of developed land.

[34] This assumption causes the model to incorporate general equilibrium effects from changes in the value of urban land and farmland without introducing any mechanical externality into workers' location decisions from the local redistribution of land development profits (Monte et al., 2018). In a robustness check, detailed in Appendix B.7, I assume that a national portfolio aggregates the land development profits of the whole economy and equally redistributes them across all the workers in the economy.

rent.[35] Second, a landlord will develop a plot into farmland or urban land if and only if

$$p_{Rn} = p_{Hn} \geq \tilde{p}_n f(\Psi_n) x_{nl}.$$

Therefore, at given land rents p_{Rn}, the proportion of developable land that is urban land or farmland is

$$\frac{R_n + H_n}{(1-\phi_n)\tilde{R}_n} = 1 - \left(\frac{p_{Rn}}{\tilde{p}_n f(\Psi_n)}\right)^{-\frac{1}{\zeta}}. \tag{13}$$

I denote by R_n the amount of farmland rented by agricultural sector workers and by H_n the amount of urban land rented by urban workers. Rearranging Equation (13) makes it possible to derive the farmland supply function as follows:

$$p_{Rn} = \tilde{p}_n f(\Psi_n)\left(1 - \frac{R_n + H_n}{(1-\phi_n)\tilde{R}_n}\right)^{-\zeta}. \tag{14}$$

The urban land supply is

$$p_{Hn} = p_{Rn}. \tag{15}$$

I extend the baseline model in Section 5.3 to incorporate other frictions in the Chinese land market to affect the landlord's land development decision. In the extended model, the urban land price and farmland price are not necessarily equal to each other in equilibrium.

5.1.5 Land Supply Decision under the Farmland Red Line Policy

The Farmland Red Line Policy stipulates that farmland cannot be converted into urban land unless an equal amount of unused land is converted into farmland. This is equivalent to imposing a minimum farmland quantity $\bar{R}_n$ that the landlord in location n has to supply. The minimum quantity is determined by the amount of farmland that existed in location n by the time the policy was adopted. When there is a quantity requirement, the farmland supply falls into one of the following two scenarios: either the landlord's pure economic incentive makes her provide farmland that is weakly greater than the requirement $\bar{R}_n$, in which case, the marginal cost of land development still equals the marginal farmland rent or the landlord supplies excess farmland to meet the quantity requirement $R_n = \bar{R}_n$ and the marginal land development cost is greater than the marginal farmland rent. This complementary slackness condition is expressed as follows:

$$\tilde{p}_n f(\Psi_n)\left(1 - \frac{R_n + H_n}{(1-\phi_n)\tilde{R}_n}\right)^{-\zeta} \geq p_{Rn},\ R_n \geq \bar{R}_n,$$

$$\left(\tilde{p}_n f(\Psi_n)\left(1 - \frac{R_n + H_n}{(1-\phi_n)\tilde{R}_n}\right)^{-\zeta} - p_{Rn}\right)\left(R_n - \bar{R}_n\right) = 0. \tag{16}$$

[35] This is because conditional on developing a land plot, a landlord always turns a land plot into the type of land that offers her the highest payoff. Therefore, she supplies only farmland if $p_{Hn} < p_{Rn}$ or only urban land if $p_{Hn} > p_{Rn}$. However, the Cobb-Douglas functional form of the utility function and the production function guarantees that as the quantity of either type of land goes to zero, its price goes to infinity. As a result, the only possible outcome is that $p_{Hn} = p_{Rn}$, in which case, the landlord is indifferent between developing farmland and urban land.

The urban land price equals the marginal cost of land development regardless of the constraint binding condition,

$$p_{Hn} = \tilde{p}_n f(\Psi_n) \left(1 - \frac{R_n + H_n}{(1-\phi_n)\tilde{R}_n}\right)^{-\zeta}. \tag{17}$$

When the constraint is not binding, profit maximization indicates an equalization of the price of urban land, the price of farmland, and the marginal cost of land development. When the constraint is binding, more farmland is created to meet the minimum quantity requirement relative to the no-policy market equilibrium. This increases the marginal land development cost and hence decreases the urban land supply. Therefore, there is an undersupply of urban land and an oversupply of farmland relative to the no-policy market equilibrium scenario. The constraint is binding if, after policy implementation, there are demand shifts for urban land and farmland such that it is profitable to reduce farmland.

Finally, when the constraint is binding, an excess supply of farmland causes a less severe undersupply of urban land if the supply of developed land is more elastic in a location. The intuition is that when the supply of developed land is more elastic, supplying an additional unit of farmland crowds out more unused land and less urban land. As the supply elasticity of developed land depends on the amount of developable land ϕ_n and hence varies across locations, so does the degree of cross-sector land misallocation.

Appendix B.2 provides a more detailed analysis alongside proofs of the comparative statics discussed above. It also proves that in the partial equilibrium of the land market, locations with a higher ϕ_n would have a relative decrease in urban land supply under the policy, which is consistent with the reduced-form results in Section 4.

5.2 General Equilibrium

At the general equilibrium, all the markets clear. Therefore, the aggregate demand for the final good produced in location n and sector s from all the locations equals the total sales of that final good:

$$p_{Fn}Y_{Fn} = \mu \sum_{s'} \sum_{n'} p_{s'n'}Y_{s'n'} \frac{(p_{sn}T_{nn'})^{1-\sigma_F}}{\tilde{p}_{sn'}^{1-\sigma_F}}, \tag{18}$$

$$p_{Mn}Y_{Mn} = (1-\mu) \sum_{s'} \sum_{n'} p_{s'n'}Y_{s'n'} \frac{(p_{sn}T_{nn'})^{1-\sigma_M}}{\tilde{p}_{sn'}^{1-\sigma_M}}. \tag{19}$$

Next, labor markets for the manufacturing sector and the agricultural sector in each location also clear. Finally, the urban land market and the farmland market in each location clear. Farmland is used for both rural residential purposes and agricultural production. Therefore, at equilibrium,

$$R_{Fn} + R_{Hn} = R_n. \tag{20}$$

Formally, equilibrium in the economy is defined as follows. Given the parameters of the model $\{\alpha, \theta, \mu, \nu, \sigma_F, \sigma_M, \gamma, \zeta\}$; the total working population $\bar{L}$; vectors of location characteristics $\{\bar{A}_{Mn}, \bar{A}_{Fn}, \bar{B}_{Mn}, \bar{B}_{Fn}, \bar{R}_n, \Psi_n, \phi_n, \tilde{R}_n\}_{n\in N}$; and trade costs $\{T_{nn'}\}_{n,n'\in N}$, the general equilibrium of the model when there is no Farmland Red Line Policy is referenced by 17 vectors, $\{w_{Mn}, L_{Mn}, w_{Fn}, L_{Fn}, H_n, R_n,\ R_{Fn}, R_{Hn},$

$p_{Hn}, p_{Rn}, Y_{Fn}, p_{Fn}, \tilde{p}_{Fn}, Y_{Mn}, p_{Mn}, \tilde{p}_{Mn}, \tilde{p}_n\}_{n\in N}$ and one scalar $\{\bar{V}\}$. These 18 components of the equilibrium are determined by the labor supply (5), labor market demand (10) and (11), manufacturing products supply (8), agricultural products supply (9), product market clearing conditions (18) and (19), tradable goods price index (3) and (2), urban land supply (15) and demand (6), farmland supply (14) and demand (9), (12) and (20), and expected utility of a representative worker (4).

When the Farmland Red Line Policy exists, the general equilibrium is referenced by the same set of vectors and scalars. The equilibrium conditions it has to satisfy are the same except for the farmland and urban land supply functions, which change to (16) and (17), respectively.

In general equilibrium, sectoral and spatial labor mobility implies that land misallocation causes labor misallocation. First, an oversupply of farmland and an undersupply of urban land lead to an oversupply of rural workers because farmland is cheaper and an undersupply of urban workers because urban land is more expensive than they are in the no-policy market equilibrium. Second, the degree of land misallocation varies across locations, which leads to variation in labor misallocation across locations. When an undersupply of urban land occurs in productive yet highly constrained locations, workers have to reside in more affordable yet less productive locations. Finally, inefficiency due to the misallocation of land and labor is amplified through the regional trade network: trading with a less efficient location makes oneself worse off.

5.3 Model Extension

Two extensions are made to the baseline model before the model is run with the data.

First, to allow for the price distortion caused by other land-use controls (Fu et al., 2019), I introduce a markup between the urban land price and the marginal land development cost. Rural-to-urban land conversion is subject to several taxes on urban land development, such as the urban maintenance and construction tax and the property tax. The central government also regulates the amount of new urban land that can be developed in city jurisdictions every year. These other land-use controls also create distortions in land prices, which need to be isolated from the price distortions caused by the Farmland Red Line Policy. I separately model the land price distortions caused by the Farmland Red Line Policy and the other land-use restrictions. In the counterfactual equilibrium, only the price distortion caused by the Farmland Red Line Policy is removed.[36]

These other land-use controls are modeled as a location-specific markup, λ_{Hn}, on the marginal land development cost. The price of urban land now becomes

$$p_{Hn} = \lambda_{Hn}\tilde{p}_n f(\Psi_n)\left(1 - \frac{R_n + H_n}{(1-\phi_n)\tilde{R}_n}\right)^{-\zeta}. \tag{21}$$

λ_{Hn} is assumed not to change in the counterfactual equilibria. Therefore, when removing the Farmland Red Line Policy from the economy, the only urban land price distortion corrected is the part caused by the

[36]Another benefit of this extension is that it makes the model isomorphic to one in which each representative landlord is a monopolist in the local urban land market, and she takes into account that the number of urban workers is endogenous to the urban land price, as described by the manufacturing labor supply function (5). In this alternative setup, the landlords from different locations are essentially in monopolistic competition. Therefore, the markup, λ_{Hn}, arises from both the monopolistic competition of urban land markets and distortions from other land-use regulations. A more detailed discussion is provided in Appendix B.6.

Farmland Red Line Policy. Any price distortions caused by other land-use taxes are assumed not to change. Any profit caused by the markup is obtained by the representative landlord.

Second, I incorporate rural regions in China that do not belong to any city jurisdictions.[37] They are prefecture remainders that do not belong to any county cities. These newly incorporated rural regions are far from urban areas and hence do not belong to any city jurisdiction. This extension guarantees that all the regions in China are included in the general equilibrium analysis. In the extended model, each rural region produces one differentiated agricultural product that is traded across locations, and the other specifications are quite similar to a rural sector within a city jurisdiction.[38] In contrast to the baseline framework, this extension allows for migration and trade between city jurisdictions (urban areas and nearby rural areas) and the rest of the rural regions. The extension has no qualitative effect on the change in the variables of interest in the counterfactual analysis.[39]

6 Structural Estimation

This section structurally estimates the model from Section 5. I first outline the procedure to calibrate the model's parameters related to workers, tradable goods production, and land markets. With the parameters and the observed variables, I recover the unobservable productivities, amenities and prices that rationalize the observed data as an equilibrium of the model. The results of model diagnostics are provided at the end of this section.

6.1 Parameter Calibration

I estimate the spending share on agricultural products, μ, to be 0.28 to match the national share of GDP from all rural areas (the rural sector in city jurisdictions and the rural regions). I set the farmland share in agricultural production, $1-\gamma$, to be 0.23 to match the farmland share in agricultural production at the national level in 2010.[40]

I allow the income share from residential land to differ between the rural and urban sectors because although urban land is modeled as residential land for simplicity, we interpret it as urban workers' use of a fraction of urban land for production purposes and the rest for residential housing. The income share from urban land is therefore specified as the sum of the structure share in manufacturing production and the labor share in manufacturing production multiplied by the urban workers' spending share on residential land. The

[37] They account for 46% of the population in China according to the 2010 Census, and most of them specialize in the agricultural sector. These rural regions produce approximately half of the national agricultural GDP.

[38] In particular, I add N_r rural regions to the model. A rural region is defined as any rural area within a prefecture that does not belong to any city jurisdiction. Rural regions differ from one another in terms of productivity, amenities, and land development costs. The Farmland Red Line Policy imposes a minimum farmland quantity constraint on rural regions as well. Landlords in these rural regions produce only farmland. In the consumer utility function, there are N_r more varieties of agricultural products.

[39] Please refer to Section 7.2 for a detailed comparison of the counterfactual results with and without incorporating these rural regions.

[40] The data come from the China Rural Statistical Yearbook for 2010. The labor share, farmland share and intermediate input share are 0.51, 0.15 and 0.34, respectively. The farmland share is derived after a re-normalization to exclude intermediate inputs that are absent from my model. This value is close to the cost share of farmland in the US in the 1980s (Caselli and Coleman, 2001).

structure share and labor share in manufacturing production are specified as 0.156 and 0.844, respectively, following Tsivanidis (2018). I set the urban residential housing spending share in China to be 0.22, as estimated in Reinbold et al. (2018). This indicates that $1 - \theta_M$ equals 0.344.[41] I consider the robustness of the results to alternative values of the residential housing spending share ranging from 0.1 to 0.3 that have been used in the literature (Tombe and Zhu, 2020). Finally, I set $1 - \theta_F$ to be 0.1 to match the rural housing expenditure share in 2010 reported in the China Rural Statistical Yearbook (2010).

For several parameters that are best estimated using bilateral trade/migration flow data or firm level data, I set their values to equal the estimates in the literature. First of all, I specify the degree of agglomeration effect in the manufacturing sector, α, as 0.05 in the baseline according to the review in Combes and Gobillon (2015). I provide robustness checks to the value of α in the range $\alpha \in [0.02, 0.08]$.

Next, I set the labor supply elasticity to real income, ν, to be 3 and provide robustness of the results to alternative values within the range of 2 to 4 (Tombe and Zhu, 2020; Morten and Oliveira, 2014; Bryan and Morten, 2018; Balboni, 2019).

The last parameter is the by-sector elasticity of substitution between products from different locations. The estimates about the elasticity of substitution between products produced from different locations within the same country range from 4 to 9 (Ossa, 2015; Allen and Arkolakis, 2014). However, a distinction between agricultural products and non-agricultural products is rarely considered. I set the elasticity of substitution between manufacturing products, σ_M, to be 7. The elasticity of substitution between agricultural products, σ_F, is chosen as 8.3, following Donaldson and Hornbeck (2016). By making σ_F greater than σ_M, the model allows agricultural products produced across locations to be more substitutable relative to manufacturing products. I consider the sensitivity of results to allowing the two parameters to have the same value as well as specifying alternative values in the range of 4 to 9 to σ_M and σ_F.

Finally, a series of geographical features of a location must be specified. First, the percentage of undevelopable land, ϕ_n, the soil qualities, Ψ_n, and the total area of land in a location, $\tilde{R}_n$, are constructed using the Harmonized World Soil Database and the shapefiles of administrative boundaries in China. Second, the minimum farmland quantity constraint, $\bar{R}_n$, is set to equal the amount of farmland in location n immediately before the Farmland Red Line Policy was implemented. Appendix A.4 provides a more detailed description of the data used in this section.

6.2 Estimation of the Price Elasticity of Developed Land

The parameter unique to my setting is the price elasticity of developed land, ζ. The higher its value, the greater the increase in the marginal cost of developed land there is for an additional unit of land being developed into farmland or urban land. Denote the marginal cost of land development as c_{Rn}, and the supply function of developed land becomes

$$c_{Rn} = \tilde{p}_n f(\Psi_n) \left(1 - \frac{R_n + H_n}{(1-\phi_n)\tilde{R}_n}\right)^{-\zeta}. \tag{22}$$

[41] The income share on urban land, $1 - \theta_M$, is $0.156 + 0.844 \times 0.22 = 0.344$.

Log-linearize the above equation and we have the following regression specification:

$$\ln c_{Rnt} = -\zeta \ln \left(1 - \frac{H_{nt} + R_{nt}}{(1-\phi_n)\tilde{R}_n}\right) + \Psi_n \beta_t + X_n \gamma_t + \epsilon_{nt}.$$

I introduce the time dimension because data from multiple years are used for the estimation. I control for province-level time-varying effects and time-varying effects of the population, employment rate, and agricultural employment in 1990 to allow the local economic conditions in the 1990s to affect the cost of land development. I use data from 1999 to 2004 to estimate this equation mainly because the outcome variable is available for those years at the local level.[42]

An OLS regression could generate a biased estimation of ζ because the percentage of unused developable land is affected by the endogenous amount of urban land and farmland. For example, more advanced local agricultural techniques that reduce the cost of land cultivation would cause residents to develop more farmland. It would bias the estimation of ζ towards zero. The actual ϕ_n might also be endogenous if, in historically more densely populated areas, part of the land surface had been modified to make it more suitable for settlement.

To address these endogeneity concerns, I use the percentage of undevelopable land in the area close to the administrative boundary, $\hat{\phi}_n$, to predict the percentage of undevelopable land within the entire city jurisdiction. As discussed in Section 4, land close to the administrative boundary is more likely to be undeveloped and hence preserve its natural features. Next, I use $\left(1 - \hat{\phi}_n\right) \tilde{R}_n$, the predicted amount of developable land in location n, to instrument the independent variable.[43]

The relevance condition is likely satisfied because two locations from the same province that have similar levels of population size, agricultural sector employment and soil quality tend to have similar amounts of developed land in use. Therefore, a higher stock of developable land within the administrative boundary leads to a greater amount of unused developable land and hence a higher percentage of unused developable land. The exclusion restriction assumption is that conditional on population size, agricultural sector employment, soil quality, and being located in the same province, the instrument is uncorrelated with unobserved factors that affect the marginal farmland development cost.

Table IX, Panel A reports baseline regression results, and Appendix Table A.8 shows the rest of the robustness checks. Across all regression specifications, the estimated value of ζ is between 1.25 and 2.52. The baseline specification suggests that the price elasticity of farmland supply is 1.78, which indicates a 5.6% increase in farmland supply for a 10% increase in farmland price (Column 1). The corresponding OLS estimate (reported in Column 5) is biased toward zero and not significant. This is explained by the endogeneity issue discussed earlier and attenuation bias due to measurement errors in the independent variable.[44] A more detailed discussion of the alternative regression specifications and results is provided in the

[42]Appendix A.4 provides details about all the variables used in this regression.

[43]Note that I rely on cross-sectional variation to identify ζ because data on the development cost of farmland at the local level are available only from 1999 to 2004. Demand shocks to farmland cannot be used to estimate supply-side parameters because the farmland market was already distorted during this period.

[44]The measurement errors come from the fact that the farmland data from 2001 to 2004 and the data of urban land for 70% of city jurisdictions from 1999 to 2001 are missing and hence are interpolated using data from other years. A detailed explanation is provided in Appendix A.4.

footnotes of Table IX.

For the counterfactual analysis in Sections 7 and 8, I set the baseline value of ζ to be 1.78 and show that the counterfactual results are not sensitive to ζ within the range of 1.25 to 2.52.

6.3 Recovering Unobservables

To conduct counterfactual analysis, a calibration of the model to the benchmark year 2010 is needed. This requires a recovery of the values of unobserved variables that rationalize the observed data from 2010 as an equilibrium. Adapting Ahlfeldt et al. (2015) to my setup, it can be shown that given parameters $\{\alpha, \sigma_M, \sigma_F, \gamma, \nu, \theta_M, \theta_F\}$, bilateral trade costs $\{T_{nn'}\}$, and location level data about land use and economic outcome by sector $\{H_n, R_n, L_{Mn}, L_{Fn}, E_{Mn}, E_{Fn}\}$ in 2010, there exist unique values of productivity in urban and rural areas ($\bar{A}_{Mn}$ and $\bar{A}_{Fn}$) that are consistent with the data up to a normalization, which corresponds to a choice of price level.[45] In addition, unique values of residential amenities ($\bar{B}_{Mn}$ and $\bar{B}_{Fn}$) exist, which are consistent with the data up to a normalization, which corresponds to a choice of the unit in which to measure amenities. Correspondingly, the rest of the unobserved prices $\{p_{Rn}, p_{Hn}, \lambda_{Hn}, \tilde{p}_n, \tilde{p}_{Mn}, \tilde{p}_{Fn}, p_{Mn}, p_{Fn}, w_{Mn}, w_{Fn}\}$ and quantities $\{R_{Hn}, R_{Fn}, Y_{Mn}, Y_{Fn}\}$ can be uniquely determined as well. The calibration of the model to the benchmark year proceeds in five steps and a detailed explanation of each step is provided in Appendix B.4.

6.4 Model Fit

Before proceeding to the counterfactual analysis, I show that the model is a good approximation of the real economy in two steps. In Step 1, I use the calibrated model structure to simulate the reduced-form effects of the Farmland Red Line Policy and compare these predictions to the realized reduced-form results from Section 4. The simulated results are quantitatively similar to the reduced-form results. Given that none of the reduced-form results is targeted in the model calibration, this outcome suggests that the model captures the cross-sectional variation well. In Step 2, I show that the recovered unobservables such as productivity, amenities, and land prices are closely correlated with proxy variables not used in the calibration.

6.4.1 Structural Simulation of the Reduced-Form Results

This subsection simulates the impacts of the Farmland Red Line Policy on each location and compares these predictions to the realized reduced-form results described in Section 4. None of the realized reduced-form results are explicitly targeted when calibrating the model. Therefore, if the simulated results are close to the realized reduced-form results, this suggests that the model is a good approximation of the real economy both qualitatively and quantitatively.

To conduct the exercise, I simulate the counterfactual equilibrium following the removal of the Farmland Red Line Policy. $d \ln y_n$ is defined as the difference between the realized outcome and the counterfactual outcome for city jurisdiction n in 2010, where y is the outcome of interest, including the urban land supply,

[45] The bilateral trade costs are calibrated using the method adopted in Redding (2016). Details are explained in Appendix B.4.

GDP by sector and population. $d \ln y_n$ hence represents the simulated impact of the Farmland Red Line Policy on outcome y in location n.

Next, I regress $d \ln y_n$ against the land conversion barrier constructed in Section 4 and compare the simulated results with the estimated long-run effects of the policy in Section 4.

The comparison of Panels A and B in Table X reveals that the simulated impacts of the land conversion barrier on the urban land supply, GDP, and population size are close to the estimates based on the realized data. As shown in Panel B, Column 1, a one-standard-deviation decrease in the land conversion barrier increases the urban land supply by 4.9%, which is quite close to the estimates using the realized data (Panel A, Column 1). Next, based on the simulation, a one-standard-deviation decrease in the land conversion barrier leads to a 1.4% decrease in GDP, which is driven by a 2.0% decrease in GDP from the non-agricultural sector and a 0.8% decrease in population size. These estimates are of the same order as the estimates based on the realized data.[46]

6.4.2 Out-of-Sample Test

This subsection evaluates the fit of the model by testing the correlation between recovered unobservables and proxy variables not used in the calibration. I find that the productivity of the manufacturing sector is strongly correlated with foreign direct investment (FDI hereafter) per worker, the percentage of college graduates and the average years of education of the population. Next, the amenities in the urban sector are positively correlated with the number of theaters and the number of books collected by the public library. Third, the farmland price calibrated using the model is close to its counterpart calculated using rural household survey data. Finally, the urban land price recovered from the model is positively correlated with its counterpart calculated based on urban land transaction data. These results suggest that the quantitative model, albeit simplified from reality, provides a good approximation of the real-world scenario. These findings lend additional confidence to the simulated counterfactual results. A detailed discussion of the analysis and findings is provided in Appendix A.5.

7 The Aggregate Effects of the Farmland Red Line Policy

This section evaluates the aggregate effects of the Farmland Red Line Policy by simulating its removal from the economy and comparing the simulated counterfactual equilibrium with reality in 2010.[47] Without the Farmland Red Line Policy, the welfare of workers would have increased by 6%. Moreover, distortions from the policy on urbanization manifest mostly in the overcongestion of urban sectors as opposed to a decrease

[46]The fact that the coefficients from estimation using the simulated data are slightly smaller than those from the realized data suggests that the baseline quantitative model is, if anything, too conservative in predicting the impacts of the policy on economic development. As shown in Appendix Table A.9, if the labor supply elasticity is specified to be 6, which is towards the high end of the estimates of this parameter in the literature, the simulated impacts on GDP and population size would be very close to the estimates using the realized data. The aggregate gain in real GDP and welfare from removing the policy is larger here than that in the baseline case.

[47]As detailed in Appendix B.5.1, I apply the hat algebra to simulate the counterfactual outcome without the Farmland Red Line Policy in 2010.

in urbanization. The counterfactual results are robust to various parameter values in the range discussed in the literature and alternative model specifications.

7.1 Baseline Results

My quantitative model first produces an estimate of worker welfare loss of 5.8% from the Farmland Red Line Policy (Figure V). The estimate is derived by comparing the simulated counterfactual equilibrium without the policy and the real data for 2010. The welfare loss comes from the misallocation of both land and labor. The estimates are of the same order as the estimated welfare gain if the US were to adopt optimal zoning regulations (Bunten, 2017) or use federal policies to weaken incentives to regulate the housing supply (Parkhomenko, 2020). Next, in the no-policy counterfactual equilibrium, the economy would have specialized more in the manufacturing sector and less in the agricultural sector. Specifically, manufacturing output would have been 5.0% higher, while agricultural output would have been 2.8% lower.

One important question is how the policy intervened in the urbanization process between 1999 and 2010, given that the policy was adopted when rural-to-urban migration accelerated. The policy-induced undersupply of urban land would both make urban areas more congested and slow urbanization. A quantitative exercise shows that distortions from the policy manifest mostly in overcrowding in urban areas as opposed to a decrease in urbanization. Without the policy, the urban population would have been 5.2% higher in 2010. The actual increase in the urban population from 1999 to 2010 was more than 40%. Therefore, another 5.2% increase in the urban population in the counterfactual world is not too radical. In contrast, without the policy, there would have been 40% more urban land in 2010.[48] This indicates that urban population density would have dropped dramatically, by 25%, decreasing from 12,170 to 9,249 people per sq. km.[49]

Next, I find that the Farmland Red Line Policy does not significantly boost agricultural output. Although the agricultural output would have been 2.8% lower without the policy, this is mainly because more agricultural sector workers switch to the manufacturing sector in the counterfactual world than in reality. To see this, I simulate an alternative counterfactual equilibrium in which the Farmland Red Line Policy did not exist and workers could not switch locations or sectors.[50] In this alternative counterfactual scenario, GDP in the agricultural sector would decrease by less than 1%.

Third, the distortionary effects of the Farmland Red Line Policy and workers' welfare loss are mitigated by the existence of the hukou system and other types of labor market frictions in China. This is because

[48]To see why urban population growth is small relative to the urban land increase, I decompose the change in the urban population into a weighted average of the urban population increase across locations in the counterfactual equilibrium: $d\ln L_M = \underbrace{-1.5 * d\ln \bar{V}}_{-8.3\%} + \underbrace{0.5 * \sum_n \pi_n d\ln H_n}_{13.8\%} + \underbrace{1.0 * \sum_n \pi_n d\ln \tilde{w}_{Mn}}_{-1.9\%} + \underbrace{\varepsilon_{Jensen}}_{1.6\%}$. $d\ln \bar{V}$ is the change in welfare, $d\ln H_n$ is the change in the urban land supply in location n, and $\tilde{w}_{Mn}$ is the real wage in terms of consumption goods. The main negative driver ($-1.5 * d\ln \bar{V}$) is that in the counterfactual scenario, an overall improvement in other locations makes a location with no change in the urban land supply or real wage relatively less attractive. The urban population in such a location would move to other locations with a greater urban land supply, causing a decline in urban population density in this location. Note that the increase in urban land supply is heterogeneous across locations and therefore leads to a smaller urban population increase than there would be if there were a uniform increase in urban land by 39.58%, which would increase the second term in the earlier equation to 19.79%.

[49]For comparison, the population density in New York City in 2017 was 10,947 people per sq. km.

[50]This is modeled as specifying the wage elasticity of labor supply, ν, to be very close to 0 (0.01 in the quantitative exercise) in the counterfactual equilibrium.

labor market frictions make workers less mobile. Therefore, the labor supply is less responsive to the real wage differentials caused by the suboptimal land allocation across sectors and locations. As a result, labor misallocation caused by land misallocation is smaller than that in a frictionless labor market. To determine the welfare loss of workers in a more frictionless labor market, I simulate a counterfactual equilibrium and set the wage elasticity of labor supply, ν, to be 6, which is towards the high end of the estimation of the local labor supply elasticity across countries (Balboni, 2019). I find that the workers' welfare loss would be 6.6%.

Finally, there is substantial spatial relocation of the urban population across city jurisdictions; 40.0% of the city jurisdictions would have lost more than 5% of their urban population, while 36.5% of the city jurisdictions would have experienced an increase in urban population of at least 5%.

My results shed light on land-use regulation in other countries that constrain urban growth. Research and policy discussions typically focus on the benefits of land-use regulations but neglect the costs. As the analysis demonstrates, the cost of land-use regulations arises from inefficient land allocation and can be economically significant. Two features of the context make the welfare loss from the Farmland Red Line Policy exceptionally high. The first is that China adopted the policy at a time when there was a high demand for rural-to-urban land conversion. The second is that it is unlikely for workers to reside in a city jurisdiction with sufficient land while enjoying the productivity of another city jurisdiction. To the extent that similar features apply to land-use regulations, the efficiency cost is likely to be high and warrants a thorough examination.

7.2 Robustness and Model Extensions

I first demonstrate the robustness of the quantitative results to alternative parameter values. As shown in Appendix Table A.14, the increase in workers' welfare is between 3.85% and 7.09% across specifications and the increase in national output in the counterfactual equilibrium is always between 1.96% and 3.15%.

Next, I compare the difference in the results when not including the rural regions that do not belong to any city jurisdictions. As shown in Appendix Table A.15, Column 2, the change in variables yields qualitatively similar results to the baseline. By dropping rural regions, the trade and migration flow between city jurisdictions and rural regions cannot adjust to policy change. The first consequence is that more urban land would increase the utility of workers who already reside in city jurisdictions but not the total population across city jurisdictions. Therefore, the welfare increase is higher, but the urban population increase is smaller. The second consequence is that city jurisdictions cannot shift agricultural production to rural regions and therefore cannot specialize in manufacturing production as much as in the baseline. This can be seen in the smaller increase in manufacturing output relative to the baseline.

Finally, instead of assuming that the immobile landlords spend the land development profit, I assume that the land development profits are collected in a national portfolio and are equally redistributed across workers. As shown in Appendix Table A.15, Column 3, the changes in the main variables are quantitatively similar to those in the baseline outcome.

8 Policy Counterfactuals

In 2018, the Chinese central government announced that a cap-and-trade platform for farmland creation is under development (Notice of the General Office of the State Council [2018] No.16). On this trading platform, one location can pay another to create new farmland if the former location needs to convert farmland into urban land. This cap-and-trade platform guarantees that the nationwide amount of farmland does not decrease, while in each individual location, the quantity of farmland can change freely. This section evaluates the aggregate production and welfare change that would have occurred if a cap-and-trade platform had been launched instead.

Next, the central government plans to charge Beijing and Shanghai 4 times the listed price on the trading platform; the other locations in the more developed regions have to pay 1.6 to 3 times the price. This design essentially restricts urban land expansion and hence slows urbanization in more developed regions. In Subsection 8.2, I evaluate the welfare change if a national trading platform with price differentiation had been in use instead.

8.1 A Cap-and-Trade Platform

This subsection evaluates the change in GDP and workers' welfare if a cap-and-trade platform had been used to prevent any decrease in farmland at the national level. I first discuss how the cap-and-trade platform changes the land development decision and the rest of the equilibrium conditions. I then compare the simulated outcome in this scenario with reality.

When there is a cap-and-trade platform, the landlords receive additional payoff c_F from the trading platform for each unit of farmland above the minimum quantity $\bar{R}_n$. In contrast, if a landlord develops less farmland than the minimum quantity $\bar{R}_n$, she pays the platform c_F for each unit of shortage. With this cap-and-trade platform, the supply function of farmland becomes

$$c_{Rn} = p_{Rn} + c_F, \tag{23}$$

where c_F is the additional payoff from (payment to) the trading platform for each unit of farmland above (below) the minimum quantity. As long as c_F is positive, there is an overinvestment in farmland in all locations. However, the cap-and-trade platform reduces the aggregate cost compared to requiring each location to meet the minimum farmland quantity requirement. This is because the degree of distortion, represented by the gap between the marginal farmland development cost and farmland rent, is equalized across locations.

c_F is the new endogenous variable in this equilibrium. In equilibrium, c_F guarantees that

$$\sum_n R_n \geq \sum_n \bar{R}_n, c_F \geq 0,$$

$$\left(\sum_n R_n - \sum_n \bar{R}_n\right) c_F = 0. \tag{24}$$

Next, there are payments among landlords across locations, and the trade balance no longer holds. If a location has more farmland than the minimum requirement, the landlord receives an additional payment of $(R_n - \bar{R}_n)c_F$ in total. Therefore, the product market clearing condition becomes

$$p_{sn}Y_{sn} = \sum_{n'} \frac{(p_{sn}T_{nn'})^{1-\sigma_s}}{\tilde{p}_{sn'}^{1-\sigma_s}} p_{Mn'}Y_{Mn'} + \sum_{n'} \frac{(p_{sn}T_{nn'})^{1-\sigma_s}}{\tilde{p}_{sn'}^{1-\sigma_s}} \left(p_{Fn'}Y_{Fn'} + (R_{n'} - \bar{R}_{n'})c_F\right). \tag{25}$$

This new equilibrium is solved through iteration. Appendix B.5.2 explains the algorithm in detail.

The simulation indicates that approximately 60% of the aggregate cost incurred when implementing the Farmland Red Line Policy could have been saved if this cap-and-trade platform had been in use. As shown in Figure VI, in the counterfactual equilibrium with a cap-and-trade platform, the welfare of workers would have been 3.5% higher than in reality. Moreover, manufacturing output would have grown by 3.0%, and agricultural output would have been 1.7% lower. Finally, the urban population would have increased by 3.0%, and the urban land would have increased by 21.7%.

8.2 A Cap-and-Trade Platform with Price Differentiation

The central government is considering adopting a cap-and-trade platform and charging more developed locations 1.6 to 4 times the baseline price charged by the cap-and-trade platform. When more developed locations, such as Beijing and Shanghai, pay a higher price for each unit of farmland below the quantity requirement, urban land expansion will be more tilted towards less developed locations. This creates land misallocation and labor misallocation since less productive places become more affordable and even more workers choose to reside in less productive places. The modeling of this alternative cap-and-trade platform is similar to the procedure described in the previous section. A detailed explanation of the land development decisions in this setting is provided in Appendix B.5.3.

The simulation indicates that approximately 35% of the aggregate cost incurred when implementing the Farmland Red Line Policy could have been saved if this alternative cap-and-trade platform had been in use. As shown in Figure VII, compared to reality, the welfare of workers would have been 2.5% higher. Moreover, manufacturing output would have grown by 1.8%, and agricultural output would have been 1.5% lower. Finally, the urban population would have increased by 2.2%, and urban land would have increased by 17.1%.

9 Conclusion

This paper used China's Farmland Red Line Policy as a natural experiment to study the impact of land-use regulation on local economic development and the aggregate welfare of workers. At the local level, city jurisdictions with a lower barrier to rural-to-urban land conversion due to the policy had a significantly greater urban land supply, higher GDP, and larger population after the policy was adopted. At the aggregate level, the policy reduced worker welfare by 6% and generated a suboptimal spatial distribution of economic activities. Moreover, distortions from the policy on urbanization manifest mostly in the overcongestion of urban sectors as opposed to a decrease in urbanization. Finally, a cap-and-trade platform that allows local regions to exchange farmland preservation requirements can achieve the same aggregate level of farmland while costing 60% less in terms of workers' welfare compared to the Farmland Red Line Policy.

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Tables

Table I. Balance Test of the Land Conversion Barrier (C_u)

	C_u below the 50th percentile	C_u above the 50th percentile	Difference (SE)
Population growth rate (1982 to 1990)	0.177	0.169	0.00841
			(0.0374)
Employment growth rate (1982 to 1990)	0.286	0.273	0.0130
			(0.0396)
Non-agricultural employment growth rate (1982 to 1990)	0.508	0.530	-0.0227
			(0.0693)
Illiterate population growth rate (1982 to 1990)	-0.294	-0.311	0.0170
			(0.0369)
College graduates growth growth rate (1982 to 1990)	0.0972	0.127	-0.0296
			(0.0860)
Population (ln of)	13.42	13.24	0.176**
			(0.0608)
Illiteracy rate	14.97	14.84	0.123
			(0.409)
% college graduates	0.645	0.620	0.0259
			(0.0712)
Employment rate	83.85	81.54	2.311***
			(0.644)
% employment in non-agriculture sectors	43.12	41.53	1.598
			(1.918)
% employment in the construction sector	1.805	1.802	0.00235
			(0.117)
% in-migration	4.821	5.297	-0.476
			(0.407)

Notes. This table shows that city jurisdictions with different land conversion barriers have similar economic and demographic characteristics before the policy. I divide city jurisdictions into two groups depending on whether the land conversion barrier is above the 50th percentile or not and compare the differences between the two groups along various dimensions. First, locations with different land conversion barriers are quite similar in terms of population growth, employment, economic structural change (growth of employment in the non-agricultural sector), and human capital accumulation (change in illiterate population and college graduates) from 1982 to 1990. Second, they are also quite similar in terms of major local economic characteristics in 1990, including the employment structure, education, and in-migration. The conclusions are the same if directly regressing the corresponding variables against the land conversion barrier. Locations with a higher land conversion barrier had a slightly lower population size and a lower employment rate in 1990. The regression results in Sections 4 and 6 are robust to controlling the time-varying impacts of the population size and the employment rate in 1990. They are also robust to controlling for the time-varying effects of the other characteristics in 1990 reported in the balance test. The data are from the 1982 and 1990 Census. Standard errors are in parentheses: *** $p<0.01$, ** $p<0.05$, and * $p<0.1$.

Table II. The Causal Impact of the Land Conversion Barrier

	(1)	(2)	(3)	(4)	(5)	(6)
ln of	Urban land	$GDP_{Secondary}$	$GDP_{Service}$	$GDP_{Agriculture}$	GDP_{All}	Population
Panel A. Baseline						
Cu×Post99	-0.253***	-0.184***	-0.053	-0.106*	-0.111**	-0.109**
	(0.074)	(0.063)	(0.056)	(0.062)	(0.052)	(0.048)
Observations	12,044	13,552	13,552	13,552	13,552	2,524
R-squared	0.909	0.959	0.969	0.930	0.972	0.932
Panel B. Control for the time trends of location characteristics in 1990						
Cu×Post99	-0.187**	-0.204***	-0.076	-0.135**	-0.139**	-0.141***
	(0.072)	(0.066)	(0.059)	(0.063)	(0.054)	(0.049)
Observations	12,044	13,552	13,552	13,552	13,552	2,524
R-squared	0.914	0.960	0.970	0.932	0.972	0.934

Notes. This table shows that after the Farmland Red Line Policy was adopted, a higher land conversion barrier reduces the amount of urban land (Column 1), GDP (Column 5), and population size (Column 6). Next, the decrease in GDP is driven by the decrease in GDP in the secondary sector (Column 2), which is dominated by the manufacturing sector and hence uses urban land most intensively in production. In contrast, the declines in service sector GDP (Column 3) and agricultural GDP (Column 4) are mild. Panel A displays the regression outcome with baseline controls, including city jurisdiction fixed effects, year fixed effects, and region time-varying effects. The results are robust to including the time-varying effects of population and the employment rate in 1990, as shown in Panel B. The error terms are clustered at the city jurisdiction level. Robust standard errors are in parentheses: *** $p<0.01$, ** $p<0.05$, and * $p<0.1$.

Table III. The Causal Impact of the Land Conversion Barrier, Controlling for Confounding Factors

	(1)	(2)	(3)	(4)	(5)	(6)
ln of	Urban land	$GDP_{Secondary}$	$GDP_{Service}$	$GDP_{Agriculture}$	GDP_{All}	Population
Panel A. Control for the access to railways						
Cu×Post99	-0.188***	-0.203***	-0.075	-0.134**	-0.138**	-0.141***
	(0.072)	(0.066)	(0.059)	(0.063)	(0.054)	(0.049)
Observations	12,044	13,552	13,552	13,552	13,552	2,524
R-squared	0.915	0.960	0.970	0.932	0.972	0.934
Panel B. Control for the ruggedness of land close to existing urban land						
Cu×Post99	-0.288***	-0.216**	-0.060	-0.134	-0.137**	-0.136*
	(0.102)	(0.087)	(0.072)	(0.099)	(0.069)	(0.074)
Observations	12,044	13,552	13,552	13,552	13,552	2,524
R-squared	0.914	0.960	0.970	0.932	0.972	0.934
Panel C. Control for the distance to Beijing and the distance to ports						
Cu×Post99	-0.178**	-0.170**	-0.042	-0.122*	-0.104*	-0.141***
	(0.071)	(0.066)	(0.059)	(0.066)	(0.054)	(0.049)
Observations	12,044	13,552	13,552	13,552	13,552	2,524
R-squared	0.915	0.960	0.970	0.932	0.973	0.935

Notes. This table shows that the main regression results are robust to controlling for the time-varying effects of the access to railways (Panel A), the time-varying effects of the ruggedness of land near the existing urban area (Panel B), and the time-varying effects of the distance to Beijing and ports (Panel C). Panel A aims to address the concern that the presence of rugged land close to the administrative border might increase the transportation cost between this location and the rest of the country and hurt the local economy. If the negative effect varies across time, it would bias the estimation. I use the number of railway lines that passed through a city jurisdiction in 2000 to measure a city jurisdiction's access to the railway network. I then add its interaction with year fixed effects to the regression. In Panel B, I control for the time-varying effects of the ruggedness of the land within two kilometers of the existing urban area before 1999. This specification deals with the concern that the ruggedness of land close to the existing urban area might be correlated with the ruggedness of land close to the administrative boundary, and the former can directly affect the cost of urban land development after 1999 (Saiz, 2010). Finally, in Panel C, I add the distance to Beijing, interacted with year dummies, to approximate the time-varying effects of the efficiency of a local government. I also add the time-varying effects of the distance to the nearest port as a proxy for the time-varying effects of foreign market access. City jurisdiction fixed effects, year fixed effects, region time-varying effects, and the time-varying effects of the population size and employment rate in 1990 are always controlled for. The error terms are clustered at the city jurisdiction level. Robust standard errors are in parentheses: *** p<0.01, ** p<0.05, and * p<0.1.

Table IV. The Causal Impact of the Land Conversion Barrier, Long-Run Effects

	(1)	(2)	(3)	(4)	(5)	(6)
Δln of	Urban land	$GDP_{Secondary}$	$GDP_{Service}$	$GDP_{Agriculture}$	GDP_{All}	Population
Cu	-0.245***	-0.244***	-0.056	-0.272***	-0.192***	-0.182***
	(0.087)	(0.090)	(0.081)	(0.079)	(0.073)	(0.052)
Observations	631	631	631	631	631	631
R-squared	0.120	0.038	0.050	0.089	0.062	0.112

Notes. This table highlights the Farmland Red Line Policy's long-run effects on the urban land supply, GDP by sector, and population size. In the long run, the negative impacts of a higher land conversion barrier are more prominent than the baseline results in Table I, which is an average of the short-run and long-run effects. The dependent variable is the change in the outcome of interest from immediately before the policy to 2010. In particular, I choose 1990 as the pre-period for population size and 1996 as the pre-period for for the rest of the variables. Region fixed effects, the population size in 1990 and the employment rate in 1990 are controlled for. The error terms are clustered at the city jurisdiction level. Robust standard errors are in parentheses: *** p<0.01, ** p<0.05, and * p<0.1.

Table V. Land Conversion Barrier and the FAR of New Urban Land Plots

	(1)	(2)	(3)	(4)
ln of the FAR of	All	Residential land	Industrial land	Commercial land
Cu	0.053	0.049	0.058	-0.097
	(0.057)	(0.049)	(0.063)	(0.065)
Observations	4,881	4,650	4,393	4,235
R-squared	0.130	0.198	0.148	0.109
% of all	100%	12.35%	50.08%	37.57%

Notes. This table shows no association between the land conversion barrier and the FAR of the new urban land plots transacted since 2007. Each observation is a city jurisdiction-year. The outcome variable is defined as the average FAR across all the new urban land plots (weighted by land plot area) transacted in a given year and use category. The dependent variable exists only for the years between 2007 and 2015. Therefore, I cannot use DD analysis and control for location fixed effects. The identification instead relies on cross-sectional variation. To control as many local fundamentals as possible, all the regressions include the following controls: (a) region time-varying effects; (b) the time-varying effects of the population size, employment rate, illiteracy rate, percent of employment from the agricultural sector, percent of employment from construction sector, and percent of immigrants from other city jurisdictions in 1990; (c) the time-varying effects of GDP, GDP from non-agricultural sectors, and the urban land supply in 1996; and (d) the time-varying effects of land ruggedness close to the existing urban area. The last row reports the percentage of new urban land in each land-use category. The error terms are clustered at the city jurisdiction level. Robust standard errors are in parentheses: *** p<0.01, ** p<0.05, and * p<0.1.

Table VI. The Causal Impact of the Land Conversion Barrier on Government Service Provision

	(1)	(2)
ln of	N of hospital beds	Government expenditure per capita
Cu×Post99	0.011	-0.092*
	(0.040)	(0.052)
Observations	14,553	14,361
R-squared	0.933	0.948

Notes. This table shows no change in the number of hospital beds (Column 1) and a slight reduction in government expenditure per capita (Column 2) in response to a higher land conversion barrier after 1999. The Chinese government uses the number of hospital beds to measure the capacity of public health services. Next, government expenditures per capita can proxy for the social welfare of residents because most local government expenditures are spent on the provision of social security and public education. City jurisdiction fixed effects, year fixed effects, region time-varying effects, and the time-varying effects of the population size and employment rate in 1990 are always controlled for. The error terms are clustered at the city jurisdiction level. Robust standard errors are in parentheses: *** p<0.01, ** p<0.05, and * p<0.1.

Table VII. The Causal Impact of the Land Conversion Barrier on the Compactness of Urban Areas

Depvar: Urban area compactness	(1)	(2)
Cu×Post99	-0.001	-0.001
	(0.001)	(0.001)
Observations	1,188	1,188
R-squared	0.855	0.856
N of cities	594	594

Notes. This table shows that urban areas do not become less compact in city jurisdictions with a higher land conversion barrier. The compactness of an urban area is measured by the Polsby-Popper (PP) score, defined as the ratio of the area of the district to the area of a circle whose circumference is equal to the perimeter of the district (Polsby and Popper, 1991). Around 5% of the city jurisdictions are dropped from the analysis because the boundaries of the urban areas in 1995 and 2015 are constructed using urban land raster data, which are derived from satellite images. Weather conditions might make some urban land in a local region undetectable, and city jurisdictions in such situations in either 1995 or 2015 are dropped because the index cannot be calculated properly. Column 1 controls for location fixed effects, year fixed effects, and region time-varying effects. Column 2 also controls for the time-varying effects of the population size and employment rate in 1990. The error terms are clustered at the city jurisdiction level. Robust standard errors are in parentheses: *** p<0.01, ** p<0.05, and * p<0.1.

Table VIII. Land Conversion Barrier and Urban Land Use

% Urban land for	(1) Residency	(2) Public facilities	(3) Industrial and Commercial	(4) Transport and Green area
Cu	1.256	-0.001	-1.050	-0.473
	(1.561)	(1.004)	(1.406)	(1.404)
Observations	8,703	8,703	8,703	8,703
R-squared	0.151	0.126	0.149	0.060

Notes. This table suggests that there is no correlation between the land conversion barrier and the proportion of urban land used for residency, business, public facilities, or transportation plus green areas. I regress the percentage of urban land used for each purpose against the land conversion barrier. The dependent variable exists only for the years between 2002 and 2015. Therefore, I cannot use DD analysis and control for location fixed effects. The identification instead relies on the cross-sectional variation. To control as many local fundamentals as possible, all the regressions include the following controls: (a) region time-varying effects; (b) the time-varying effects of population size, employment rate, illiteracy rate, the percentage of employment from the agricultural sector, the percentage of employment from the construction sector, and the percentage of immigrants from other city jurisdictions in 1990; (c) the time-varying effects of GDP, GDP from the non-agricultural sector, and the urban land supply in 1996; and (d) the time-varying effects of land ruggedness close to the existing urban area. The error terms are clustered at the city jurisdiction level. Robust standard errors are in parentheses: *** p<0.01, ** p<0.05, and * p<0.1.

Table IX. Estimation of the Price Elasticity of Developed Land

Depvar: $\ln c_{Rnt}$	(1)	(2)	(3)	(4)
	IV Regression			OLS
$\ln\left(1-\frac{H_{nt}+R_{nt}}{(1-\phi_n)\tilde{R}_n}\right)$	-1.779***	-2.521***	-1.248***	0.011
	(0.323)	(0.447)	(0.227)	(0.070)
Wald-F	71.45	68.07	78.30	
Observations	4,728	4,734	5,135	4,728
	First Stage			
$(1-\hat{\phi}_n)\tilde{R}_n$	0.187***	0.162***	0.212***	
	(0.022)	(0.020)	(0.024)	
R-squared	0.929	0.889	0.908	

Notes. This table reports the IV estimation of the price elasticity of developed land. The baseline specification (Column 1) indicates that the supply elasticity of developed land, ζ, takes the value of 1.78. The dependent variable is the marginal cost of farmland development in location n in year t. The primary independent variable is the percentage of unused developable land. I use the percentage of undevelopable land in the area close to the administrative boundary, $\hat{\phi}_n$, to predict the percentage of undevelopable land within the entire city jurisdiction. Next, I use $(1-\hat{\phi}_n)\tilde{R}_n$, the predicted amount of developable land in location n, to instrument the independent variable. The identification relies on the cross-sectional variation. To control as many local fundamentals as possible, all the regressions include the following controls: (a) province time-varying effects; (b) the time-varying effects of the population size and employment rate; and (c) the time-varying effects of a series of average soil quality factors for rural land, including pH, organic carbon, gravel percentage, water storage capacity, water drainage, and soil electrical conductivity. The error terms are clustered at the city jurisdiction level. As shown in Column 2, the results are robust to controlling for region time-varying effects. Finally, to avoid the influence of locations with a very small or large percentage of unused developable land (due to measurement errors in the amount of urban land and farmland during this period detailed in Appendix A.4.3), I exclude the bottom and the top 5% of locations in terms of the value of the independent variable in the baseline regression. The results are robust to using the full sample, as shown in Column 3. Robust standard errors are in parentheses: *** p<0.01, ** p<0.05, and * p<0.1.

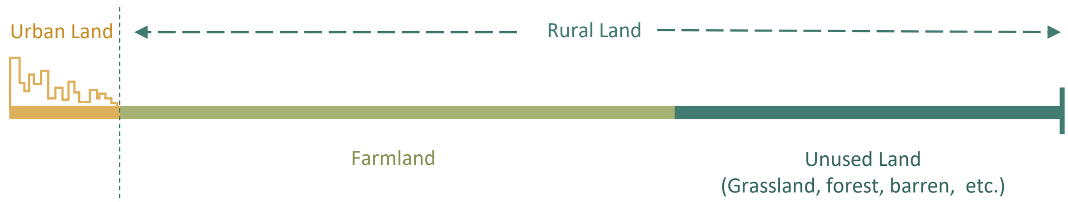
Table X. Simulated Long-Run Effects of the Farmland Red Line Policy

	(1)	(2)	(3)	(4)
	Urban land	GDP	$GDP_{\text{non-agriculture}}$	Population
Depvar: Δln of	Panel A. Simulated Outcome			
Cu	-0.194***	-0.058***	-0.080***	-0.032*
	(0.061)	(0.022)	(0.026)	(0.016)
Observations	631	631	631	631
R-squared	0.077	0.069	0.081	0.060
Depvar: Δln of	Panel B. Actual Outcome (taken from Table IV)			
Cu	-0.245***	-0.192***	-0.159**	-0.182***
	(0.087)	(0.073)	(0.078)	(0.052)
Observations	631	631	631	631
R-squared	0.120	0.062	0.038	0.112

Notes. This table suggests that the quantitative model can simulate the reduced-form results for the impact of the land conversion barrier on the urban land supply, GDP, and population size. The simulated causal impact of the land conversion barrier is close to the estimates based on the realized data. As shown in Panel A, Column 1, a one-standard-deviation decrease in the land conversion barrier increases urban land supply by 4.9%, which is quite close to the estimates using the realized data (Panel B, Column 1). Next, according to the simulation, a one-standard-deviation decrease in the land conversion barrier leads to a 1.4% decrease in GDP, which is driven by a 2.0% decrease in GDP from the non-agricultural sector and a 0.8% decrease in population size. Across all the regressions, I control for region fixed effects, the population size and employment rate in 1990. Standard errors are in parentheses: *** p<0.01, ** p<0.05, and * p<0.1.

Figures

Figure I. A Stylized City Jurisdiction



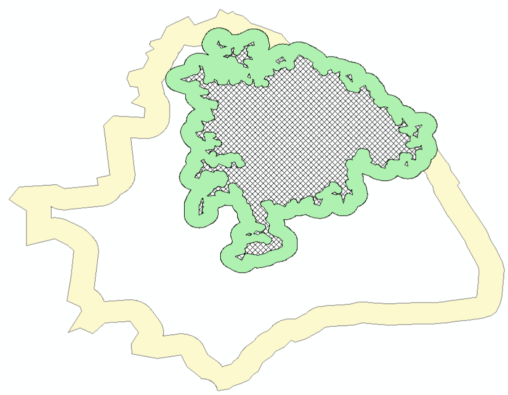
(a)

(b)

(c)

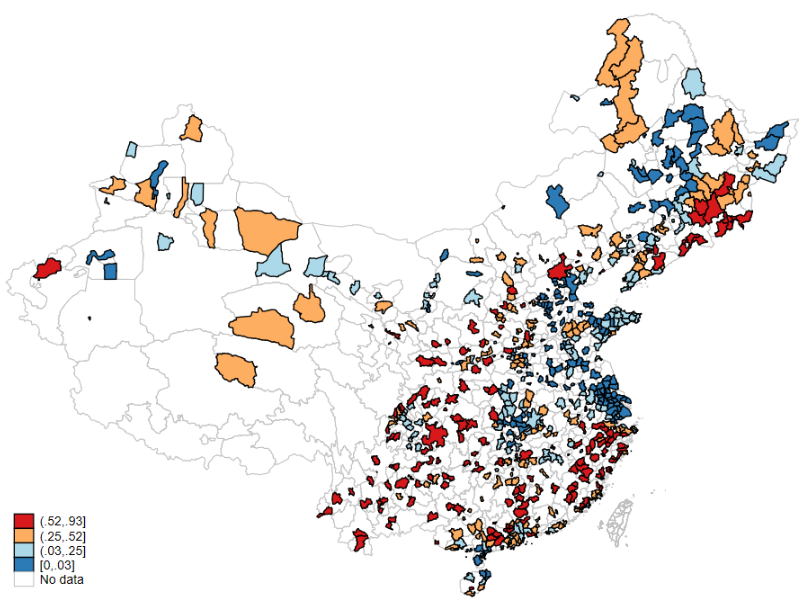
Notes. As shown in (a), a city jurisdiction in China is administratively categorized into urban and rural land. Rural land is then subdivided into farmland and unused land. Unused land refers to land that is neither cultivated into farmland nor converted into urban land, such as grassland, forest, barren land, etc. The left side of the figure represents the center of the urban area. The right side represents the administrative boundary of the city jurisdiction, which does not change in almost all city jurisdictions during the study period. Note that the figure illustrates only the overall spatial patterns of the three types of land, and the farmland plots do not have to be adjacent to each other in reality. Next, (b) shows that after the policy was adopted, if a local government converts farmland into urban land (indicated by the arrow on the left), it also has to convert an equivalent amount of unused land into farmland (indicated by the arrow on the right). Therefore, the policy requires the local government to pay an additional cost of cultivating unused land into farmland when converting farmland into urban land. The cost of converting an unused land plot into farmland depends on local geographical features and can vary across unused land plots both within and across city jurisdictions. The difference between subfigure (b) and subfigure (c) is that unused land in subfigure (c) is more rugged than unused land in subfigure (b). All else equal, the cost of farmland development, and hence the additional cost of urban land development, is higher in City B.

Figure II. The Region Used to Construct the Land Conversion Barrier



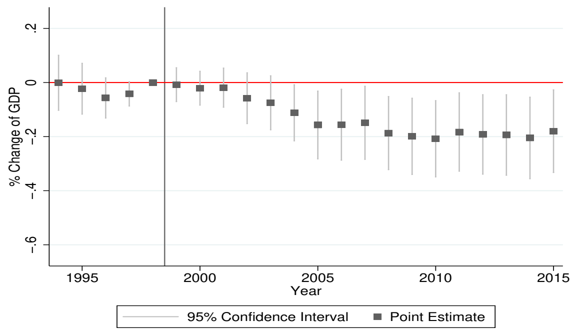
Notes. I use the Shanghai city jurisdiction as an example to illustrate the region I choose to measure land ruggedness. The crosshatched region represents the existing urban area before 1999. The green region is a 2-km outward buffer from the boundary of the existing urban area, and it represents the projected new urban area after 1999. The yellow region is a 5-km inward buffer from the administrative boundary of the city jurisdiction, and land within the existing (crosshatched region) or near future urban area (green region) is always excluded. In the baseline specification, I use the ruggedness of land in the yellow region to define the land conversion barrier. For a robustness check, I specify the inward buffer to be 10 kilometers. The results are also robust to using both the yellow region and the white region to calculate the land ruggedness. Finally, the results are robust to assuming that urban areas expand as a circle, with the current urban center as the center of the circle.

Figure III. The Spatial Distribution of the Land Conversion Barrier

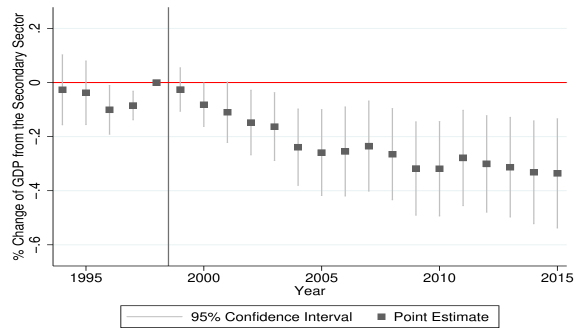


Notes. This figure shows that there is no clear regional pattern of the spatial distribution of the land conversion barrier. The value is higher towards the red end and lower towards the blue end. Regions with no data (except Taiwan) are rural counties that do not belong to any city jurisdiction.

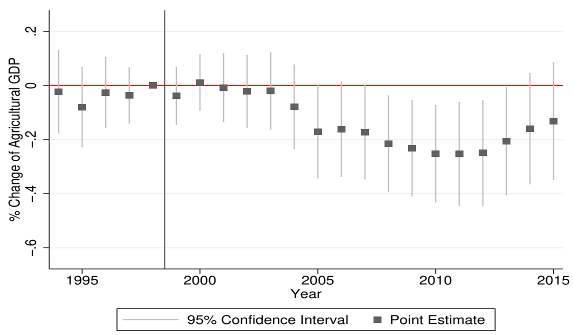
Figure IV. Impacts of the Land Conversion Barrier by Year



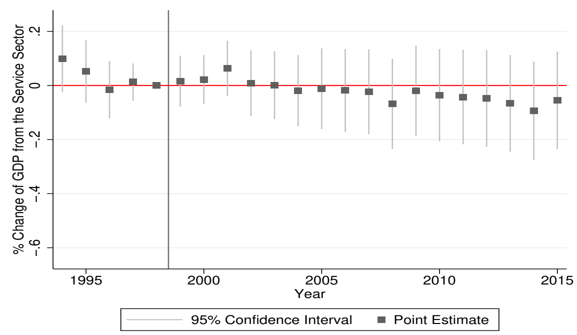
(a) Impacts on GDP



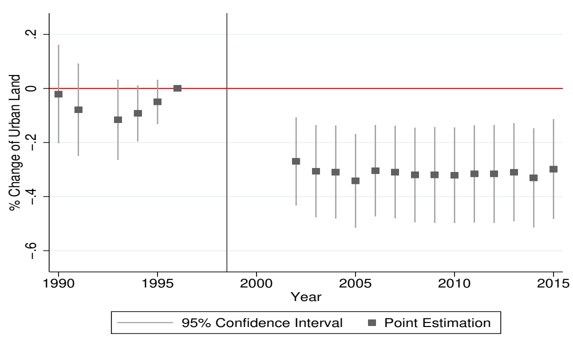
(b) Impacts on GDP from the secondary sector



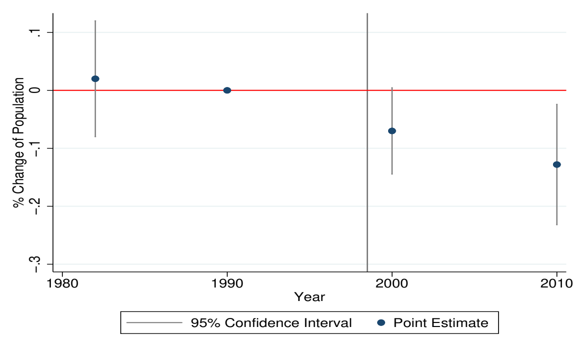
(c) Impacts on GDP from the agricultural sector



(d) Impacts on GDP from the service sector



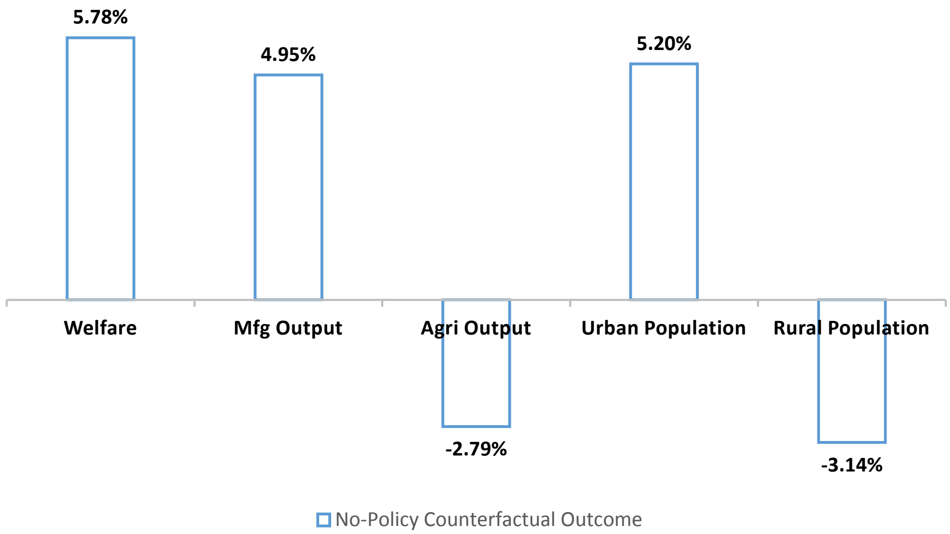
(e) Impacts on urban land supply



(f) Impacts on population

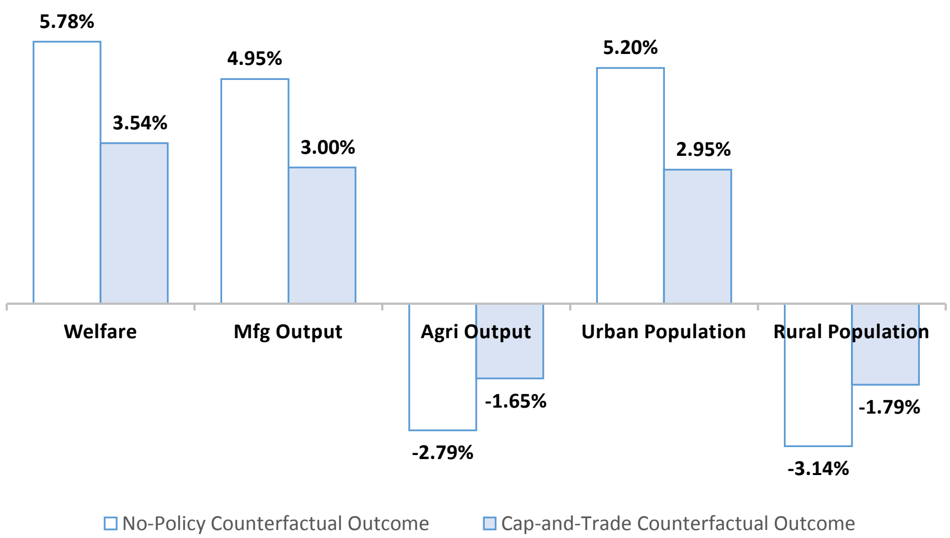
Notes. This figure shows that city jurisdictions with different land conversion barriers had parallel trends in GDP by sector, urban land supply and population before policy implementation; after 1999, the negative impacts of the land conversion barrier on GDP, urban land supply and population started to grow. Data on urban land supply are not available for 1992, and there are severe missing data issues for 1997 and 2001; hence, the coefficients for those years are dropped in (e). The results are robust to controlling for the time-varying impacts of population and employment rate in 1990, as shown in Appendix Figure A.5.

Figure V. No-Policy Counterfactual Outcomes



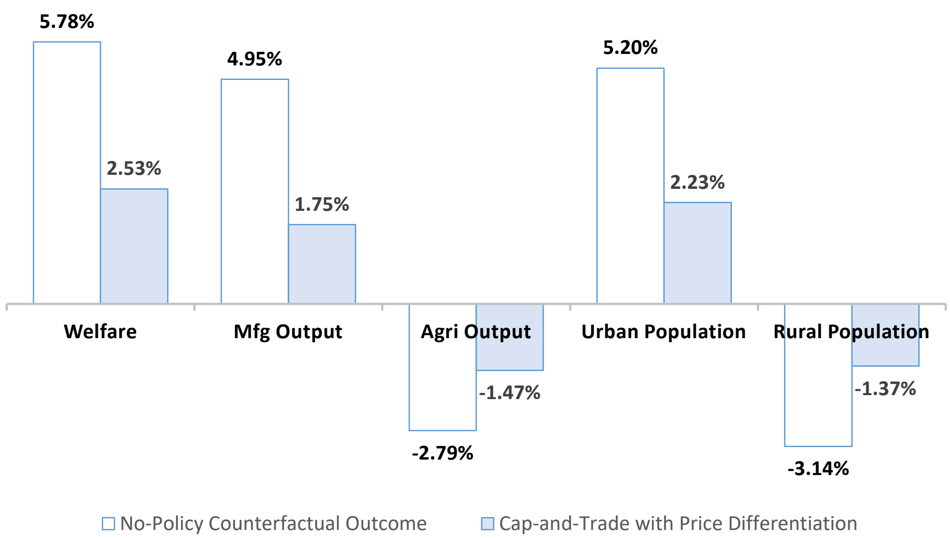
Notes. This figure suggests that the welfare of workers would have increased by 5.78% had the Farmland Red Line Policy not been implemented. The economy would have specialized more in the manufacturing sector relative to reality in 2010. There is a 4.95% increase in manufacturing sector output and a 2.79% decrease in agricultural sector output in the counterfactual world. The urban population size would have been 5.20% greater than that in reality in 2010.

Figure VI. Cap-and-Trade Counterfactual Outcomes



Notes. In the counterfactual equilibrium with a cap-and-trade platform, the welfare of workers would have been 3.54% higher relative to reality. Next, manufacturing output would have grown by 3.00%, and agricultural output would have been 1.65% lower. Finally, the urban population size would have increased by 2.95%.

Figure VII. Cap-and-Trade with Price Differentiation



Notes. In the counterfactual equilibrium with a cap-and-trade platform that has price differentiation, the welfare of workers would have been 2.53% higher relative to reality. Next, the manufacturing output would have grown by 1.75%, and the agricultural output would have been 1.47% lower. Finally, the urban population would have increased by 2.23%.

Online Appendix

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A Data Appendix

A.1 Additional Tables

Table A.1. Summary Statistics

Variables	(1) N of observations	(2) Mean	(3) SE
Land conversion barrier	631	0.303	0.276
ln(urban land)	12,044	3.392	0.923
ln(GDP)	13,552	4.700	1.344
ln(GDP$_{agriculture}$)	13,552	2.368	1.140
ln(GDP$_{non-agriculture}$)	13,552	4.525	1.436
ln(GDP$_{secondary}$)	13,552	3.914	1.511
ln(GDP$_{tertiary}$)	13,552	3.663	1.421
ln(population)	2,524	13.379	0.786
ln(N of hospital beds)	14,553	7.720	0.947
ln(government expenditure per capita)	14,361	7.103	1.308
FAR of commercial land	4,235	2.010	0.967
FAR of industrial land	4,648	0.705	0.322
FAR of residential land	4,650	2.356	0.751
% of urban land for residency	8,701	0.332	0.097
% of urban land for public facilities	8,701	0.156	0.062
% of urban land for transport and green area	8,701	0.251	0.088
% of urban land for industrial and commercial use	8,701	0.260	0.088
Compactness of urban area	1,188	0.340	0.187

Notes. This table provides the summary statistics for the main variables used in the empirical analysis. The land conversion barrier is measured as the percentage of land within 5 kilometers of the administrative boundary that has a local slope above 15 degrees. Land within or close to existing urban area before the policy is excluded, as illustrated in Figure II. The unit for urban land, GDP, urban land price, and government expenditure per capita are km^2, 10^8 yuan in current prices, and yuan in current prices, respectively. Data on FAR is at the city-year level, and FAR is defined as the plot area weighted floor-to-area ratios of newly transacted urban land plots in the corresponding year and use categories. More details on the data sources can be found in Appendix A.3.

Table A.2. Correlation between the Change in Urban Land and the Change in Farmland

Depvar: $\Delta R_{\text{2000 to 2010}}$	(1)	(2)
$\Delta H_{\text{2000 to 2010}}$	-0.031	-0.065
	(0.034)	(0.189)
Observations	631	631
R-squared	0.001	0.000

Notes. This table shows that there is little correlation between the change in urban land and the change in farmland across locations from 2000 to 2010. The results suggest that the Farmland Red Line Policy successfully stopped farmland decline in locations undergoing urbanization. The outcome variable in Column 1 is calculated using GeoExplorer II, while in Column 2, the outcome variable is calculated using the MODIS farmland raster data as a robustness check. The amount of urban land in 2000 is not directly available for about 70% of city jurisdictions. For these locations, I use a linear interpolation method based on data from 1996 and 2002 to impute the value for the year 2000. Standard errors are in parentheses: *** p<0.01, ** p<0.05, and * p<0.1.

Table A.3. Distance to the Administrative Boundary and the Amount of Unused Land

	(1)	(2)
Depvar	ln(Unused land)	Unused land
Distance (km)	-0.183***	-11.064***
	(0.002)	(0.355)
Distance^2		0.250***
		(0.024)
Observations	7,763	7,763
R-squared	0.895	0.948

Notes. This table shows that there is more unused land closer to the administrative boundary in a city jurisdiction. In particular, the baseline specification (Column 1) suggests that moving away from the administrative border by 1 kilometer reduces the amount of unused land by close to 20%. This finding indicates that, on average, land more than 5 kilometers away from the administrative boundary of a city jurisdiction is primarily unavailable for new farmland development. Therefore, in the main specification, I define the projected farmland creation region as within 5 kilometers from the administrative boundary of a city jurisdiction. In Column 2, I fit a quadratic relationship between the distance to the administrative boundary and the amount of unused land instead. The median amount of unused land within the 1-kilometer buffer of an administrative boundary is 67 square kilometers. Therefore, this alternative specification indicates that, for a median city, after approximately 7 kilometers ($67 - 11 * 7 + 0.25 * 7^2 \approx 0$) away from the administrative boundary of city jurisdiction, the land is mostly occupied and hence unavailable for new farmland development. Note that main regression results are robust to defining the projected farmland creation region land within 10 kilometers from the administrative boundary or all the rural land. Land within or close to existing urban area before the policy is always excluded, as illustrated in Figure II. The dependent variable is calculated using NASA MODIS, a land cover database at 500-meter resolution. The earliest year for which the database is available is 2000; hence, I use the land use patterns in 2000 for the analysis. It classifies every 500×500-meter land grid on the earth into one land use category, such as farmland, urban land, grassland, etc. In my analysis, unused land is defined as land grid not classified as urban land or farmland, and I further exclude all bodies of water and deserts. I then count the amount of unused land grids that are k kilometers away from the administrative boundary for each city jurisdiction and for $k = 0, 1, 2, ...$ The final regression is at city jurisdiction-distance bin level. City fixed effects are controlled for, and the error terms are clustered at the city jurisdiction level. Robust standard errors are in parentheses: *** p<0.01, ** p<0.05, and * p<0.1.

Table A.4. The Causal Impact of the Land Conversion Barrier, Additional Controls

ln of	(1) Urban land	(2) $GDP_{Secondary}$	(3) $GDP_{Service}$	(4) $GDP_{Agriculture}$	(5) GDP	(6) Population
Panel A. Control for city time varying effects						
Cu×Post99	-0.164**	-0.184***	-0.050	-0.063	-0.088*	-0.079**
	(0.067)	(0.065)	(0.058)	(0.063)	(0.053)	(0.035)
Observations	12,044	13,552	13,552	13,552	13,552	2,524
R-squared	0.918	0.959	0.970	0.931	0.972	0.951
Panel B. Control for city time varying effects and the province time varying effects						
Cu×Post99	-0.209***	-0.122*	-0.004	-0.026	-0.038	-0.146***
	(0.078)	(0.071)	(0.062)	(0.072)	(0.056)	(0.050)
Observations	11,965	13,465	13,465	13,465	13,465	2,508
R-squared	0.925	0.966	0.975	0.939	0.977	0.950
Panel C. Control for the government expenditure per capita						
Cu×Post99	-0.205***	-0.186***	-0.068	-0.135**	-0.129**	-0.133***
	(0.071)	(0.066)	(0.058)	(0.064)	(0.054)	(0.051)
Observations	11,473	13,431	13,431	13,431	13,431	1,690
R-squared	0.920	0.961	0.970	0.932	0.973	0.969

Notes. This table shows that the patterns found in the baseline regression specification (Table II) are robust to including additional control variables. In particular, a higher land conversion barrier leads to a relative decrease in urban land supply and population. Additionally, its negative impact on local GDP is the most prominent in the secondary sector. Panel A further includes the time-varying effects of the percentage of employment in the non-agricultural sector, the percentage of employment in the construction sector, the illiteracy rate, and the percentage of in-migration in 1990. In Panel B, both the controls used in Panel A and the province time-varying effects are included. Finally, in Panel C, I control the government expenditure per capita to show that the negative impacts of the land conversion barrier on local economic outcomes are not due to a reduction in social welfare provided to residences. Otherwise, the coefficients would be much closer to 0 after controlling for the government expenditure per capita, which is a proxy for social welfare. In all the regressions, I control city fixed-effects, year fixed-effects, region time-varying effects, and the time-varying effects of the population and employment rate in 1990. Error terms are clustered at the city jurisdiction level. Robust standard errors are in parentheses: *** $p<0.01$, ** $p<0.05$, and * $p<0.1$.

Table A.5. The Causal Impact of the Land Conversion Barrier, Additional Robustness Checks

	(1)	(2)	(3)	(4)	(5)	(6)
ln of	Urban land	$GDP_{Secondary}$	$GDP_{Service}$	$GDP_{Agriculture}$	GDP	Population
Panel A. Drop cities that incorporate at least one county during the study period						
Cu×Post99	-0.214***	-0.188***	-0.072	-0.094	-0.127**	-0.161***
	(0.078)	(0.070)	(0.062)	(0.060)	(0.056)	(0.050)
Observations	11,014	12,419	12,419	12,419	12,419	2,316
R-squared	0.894	0.956	0.965	0.948	0.970	0.926
Panel B. Use 1998 as the beginning year						
CuxPost98	-0.187**	-0.179***	-0.081	-0.118*	-0.125**	-0.141***
	(0.072)	(0.065)	(0.056)	(0.062)	(0.053)	(0.049)
Observations	12,044	13,552	13,552	13,552	13,552	2,524
R-squared	0.914	0.959	0.970	0.932	0.972	0.934
Panel C. Drop 26 provincial capital cities						
Cu×Post99	-0.176**	-0.194***	-0.064	-0.110*	-0.125**	-0.132***
	(0.074)	(0.068)	(0.060)	(0.064)	(0.055)	(0.049)
Observations	11,549	13,016	13,016	13,016	13,016	2,424
R-squared	0.896	0.956	0.965	0.934	0.969	0.926
Panel D. Drop 4 provincial-level cities						
Cu×Post99	-0.194***	-0.205***	-0.080	-0.140**	-0.142***	-0.143***
	(0.073)	(0.067)	(0.059)	(0.064)	(0.054)	(0.049)
Observations	11,965	13,465	13,465	13,465	13,465	2,508
R-squared	0.907	0.958	0.968	0.931	0.971	0.928
Panel E. Drop port cities						
Cu×Post99	-0.205***	-0.206***	-0.080	-0.120*	-0.142**	-0.157***
	(0.074)	(0.068)	(0.060)	(0.065)	(0.055)	(0.049)
Observations	11,769	13,252	13,252	13,252	13,252	2,468
R-squared	0.906	0.957	0.967	0.932	0.970	0.930

Notes. This table shows that the main regression results are robust to (a) excluding locations subject to potential measurement errors in the outcome variables; (b) using 1998 instead of 1999 as the beginning year of the post-period; and (c) excluding politically favored city jurisdictions, such as provincial capitals, provincial level cities and port cities. In Panel A, I exclude 8% of the city jurisdictions that have adjusted the administrative boundary through incorporating a neighbor county. For these city jurisdictions, time-consistent measures for urban land supply and GDP are not available because urban land supply and GDP are not available for the incorporated counties before 1997. I show that, after excluding these city jurisdictions, the results are similar to the baseline results. Therefore, the potential measurement errors caused by the boundary inconsistency of this subgroup are not a concern. In Panel B, I use 1998 instead of 1999 as the beginning year of the post-period to address the concern that local governments had to comply with the new policy right after its announcement in late 1998; therefore, part of 1998 should be treated as the post-period. The results in this alternative specification are almost the same as those in the baseline. Next, I exclude 26 provincial capital cities in Panel C, 4 provincial-level city jurisdictions in Panel D, and 14 coastal port city jurisdictions in Panel E. The coefficients from these subgroup regressions are very close to the baseline results. In all the regressions, I control for city fixed effects, year fixed effects, region time-varying effects, and the time-varying effects of the population and employment rate in 1990. Error terms are clustered at the city jurisdiction level. Robust standard errors are in parentheses: *** $p<0.01$, ** $p<0.05$, and * $p<0.1$.

Table A.6. Alternative Ways to Construct the Land Conversion Barrier

ln of	(1) Urban land	(2) $GDP_{Secondary}$	(3) $GDP_{Service}$	(4) $GDP_{Agriculture}$	(5) GDP	(6) Population
Panel A. Use the Terrain Ruggedness Index from Nunn and Puga (2012)						
Cu×Post99	-0.055***	-0.048***	-0.021	-0.035*	-0.035**	-0.031**
	(0.021)	(0.018)	(0.016)	(0.018)	(0.014)	(0.014)
Observations	12,044	13,552	13,552	13,552	13,552	2,524
R-squared	0.914	0.959	0.970	0.932	0.972	0.934
Panel B. Use the Average Slope from Nunn and Puga (2012)						
Cu×Post99	-0.056***	-0.048***	-0.021	-0.033*	-0.035**	-0.033**
	(0.021)	(0.018)	(0.016)	(0.018)	(0.014)	(0.014)
Observations	12,044	13,552	13,552	13,552	13,552	2,524
R-squared	0.914	0.959	0.970	0.932	0.972	0.934
Panel C. A 10-kilometer inward buffer as the projected farmland creation area						
Cu×Post99	-0.186**	-0.209***	-0.084	-0.132**	-0.143**	-0.146***
	(0.073)	(0.069)	(0.061)	(0.065)	(0.056)	(0.050)
Observations	12,044	13,552	13,552	13,552	13,552	2,524
R-squared	0.914	0.960	0.970	0.932	0.972	0.934
Panel D. All the rural land as the projected farmland creation area						
Cu×Post99	-0.170**	-0.204***	-0.074	-0.143**	-0.135**	-0.144***
	(0.074)	(0.069)	(0.061)	(0.067)	(0.055)	(0.052)
Observations	12,044	13,552	13,552	13,552	13,552	2,524
R-squared	0.914	0.960	0.970	0.932	0.972	0.934
Panel E. Assume a circular expansion of the urban area						
Cu×Post99	-0.195***	-0.205***	-0.074	-0.129**	-0.141**	-0.155***
	(0.073)	(0.068)	(0.060)	(0.064)	(0.055)	(0.048)
Observations	12,044	13,552	13,552	13,552	13,552	2,524
R-squared	0.914	0.960	0.970	0.932	0.972	0.935

Notes. This table shows that the main regression results are robust to using alternative ways to measure the land conversion barrier. Panels A and B use the terrain ruggedness index and the average slope measure developed in Nunn and Puga (2012) to represent the local land ruggedness. Note that the measures in Panels A and B have been normalized before being used in the regression, and hence, the values of the coefficients in Panels A and B are not directly comparable to the rest of the tables. In Panel C, I use a 10-kilometer inward buffer from the administrative boundary as the projected farmland creation region and calculate the percentage of land with a local slope greater than 15 degrees. In Panel D, I use all the rural land as the projected farmland creation region. In Panels C and D, I always exclude existing urban land and land less than 2 kilometers from existing urban land before the policy. In Panel E, I assume future urban land would expand in such a way that each urban area is a circle, with the current urban center as the center of the circle. I exclude this region when calculating the ruggedness of the land. The results in Panels C, D and E are very close to the baseline results. In all the regressions, I control for city fixed effects, year fixed effects, region time-varying effects, and the time-varying effects of population and employment rate in 1990. Error terms are clustered at the city jurisdiction level. Robust standard errors are in parentheses: *** p<0.01, ** p<0.05, and * p<0.1.

Table A.7. The Causal Impact of the Land Conversion Barrier with the HAC Spatial Clustering

ln of	(1) Urban land	(2) $\text{GDP}_{\text{Secondary}}$	(3) $\text{GDP}_{\text{Service}}$	(4) $\text{GDP}_{\text{Agriculture}}$	(5) GDP	(6) Population
Panel A. 500 Kilometers as the Cutoff Distance						
Cu×Post99	-0.187***	-0.204***	-0.076	-0.135**	-0.139***	-0.141***
	(0.066)	(0.063)	(0.058)	(0.060)	(0.052)	(0.039)
Observations	12,044	13,552	13,552	13,552	13,552	2,524
Panel B. 250 Kilometers as the Cutoff Distance						
Cu×Post99	-0.187***	-0.204***	-0.076	-0.135**	-0.139***	-0.141***
	(0.065)	(0.061)	(0.056)	(0.059)	(0.051)	(0.039)
Observations	12,044	13,552	13,552	13,552	13,552	2,524

Notes. This table shows that the main regression results are robust to using the Conley Spatial Clustering method to adjust for standard errors (Conley, 1999; Hsiang, 2010). Panel A uses 500 kilometers as the cutoff distance, while Panel B uses 250 kilometers. I control for city fixed effects, year fixed effects, region time-varying effects, and the time-varying effects of population and employment rate in 1990. Standard errors are in parentheses: *** p<0.01, ** p<0.05, and * p<0.1.

Table A.8. Estimation of the Price Elasticity of Farmland Supply

Depvar: lnc_{Rnt}	(1)	(2)	(3)	(4)	(5)
$ln\left(1-\frac{H_{nt}+R_{nt}}{(1-\phi_n)\bar{R}_n}\right)$	-1.779***	-1.779***	-1.778***	-1.755***	-1.824***
	(0.323)	(0.323)	(0.323)	(0.322)	(0.338)
Wald-F	71.45	71.46	71.43	71.45	69.68
Observations	4,728	4,728	4,728	4,728	4,728

Notes. This table shows that the IV estimation of the price elasticity of farmland supply is robust to alternative ways to impute data on the farmland supply during 2001 and 2004 and the urban land supply during 1999 and 2001 and alternative ways to construct farmland development costs, as discussed in Appendix A.4.3. Column 1 provides the baseline results from Table IX for comparison. In Column 2, I assume a constant change in the amount of farmland between 2000 and 2005 instead of a constant growth rate of farmland. In Column 3, I assume a constant increase in the amount of urban land between 1996 and 2002 for locations with missing data on urban land during 1997 and 2001 instead of a constant growth rate of urban land. In Column 4, I assume the interest rate to be 6.5% when calculating the present value of farmland rent instead of 5.8% as in the baseline. Calculated from the China Household Finance Survey (2011), 6.5% is the median interest rate faced by rural households. In Column 5, I take into account that in locations not binding on the constraint, the c_{Fnt} should be equal to 0 and show that the estimation results barely change. The control variables used in this table are the same as those in Table IX. Robust standard errors are in parentheses: *** p<0.01, ** p<0.05, and * p<0.1.

Table A.9. Simulated Long-Run Effects of the Farmland Red Line Policy, $\nu = 6$

	(1)	(2)	(3)	(4)
Depvar: Δln of	Urban land	GDP	$\text{GDP}_{\text{non-agriculture}}$	Population
Cu	-0.259***	-0.106***	-0.137***	-0.067**
	(0.077)	(0.036)	(0.042)	(0.027)
Observations	631	631	631	631
R-squared	0.079	0.071	0.083	0.064

Notes. This table shows the simulated impacts of the Farmland Red Line Policy on the urban land supply, GDP and population using a quantitative model that has a large labor supply elasticity. In this quantitative model, the labor supply elasticity is specified as 6, which is towards the high end of the estimates of the parameter in the literature Balboni (2019). The simulated impacts on GDP and population size are even closer to the estimates using the realized data, as reported in Table X. In this alternative specification, the simulated workers' welfare cost of the policy is 6.6%, which is greater than the baseline. Across all the regressions, I control for region fixed effects, the population size and the employment rate in 1990. Robust standard errors are in parentheses: *** p<0.01, ** p<0.05, and * p<0.1.

Table A.10. Correlation of the Calibrated Urban Sector Productivity with FDI and Human Capital

Depvar: $\ln \bar{A}_M$	(1)	(2)	(3)
ln(FDI per worker)	0.0781***		
	(0.00874)		
% college degree and above		2.924***	
		(0.350)	
Average years of education			0.209***
			(0.0240)
Observations	631	631	631
R-squared	0.113	0.100	0.108

Notes. This table shows that the calibrated urban sector productivity is strongly positively correlated with common proxies for local productivity, including the FDI per worker (Column 1) and the education level of workers in the non-agricultural sector (Columns 2 and 3). FDI is commonly used to explain the productivity, especially in developing countries, because it represents the local access to the frontier technology in production and management (Haskel et al., 2007). Similarly, labor skills are associated with the productivity of an urban area (Simon and Nardinelli, 2002). Standard errors are in parentheses: *** p<0.01, ** p<0.05, and * p<0.1.

Table A.11. Correlation of the Calibrated Urban Sector Amenities with the Number of Theaters and Library Books

Depvar: $\ln\bar{B}_M$	(1)	(2)
ln(N of library books)	0.103***	
	(0.0161)	
ln(N of theaters)		0.164***
		(0.0215)
Observations	620	586
R-squared	0.063	0.090

Notes. This table shows that the model-calibrated amenities of the urban sector is positively associated with the characteristics that make the location more desirable to live in, including the presence of theaters and the scale of public library collections. Column 1 suggests that the number of books collected by public libraries positively correlates with the calibrated local amenity level. Next, Column 2 shows that the number of theaters is positively associated with the location amenity level. Standard errors are in parentheses: *** p<0.01, ** p<0.05, and * p<0.1.

Table A.12. Correlation of Farmland Price based on the Model and the Rural Household Survey Data

Depvar: Expected farmland price	(1)	(2)	(3)
Calibrated farmland price	0.348***	0.699***	0.976***
	(0.100)	(0.161)	(0.230)
Constant	4.091***	1.898	-0.044
	(0.806)	(1.219)	(1.753)
Observations	5,902	3,078	354
R-squared	0.023	0.046	0.095

Notes. This table shows that the calibrated farmland price is close to its counterpart calculated using the Chinese Household Finance Survey. The survey asks each rural household to report both the amount of farmland it owns and the expected market value of the farmland, and the farmland price is the ratio between the two. Column 1 includes all the rural households who owned farmland, while in Column 2, I include rural households inside the city jurisdictions only. The relatively higher coefficient in Column 2 could have occurred because rural households closer to urban areas are better informed of the actual market value of their farmland. In Column 3, I further restrict the sample to those who rent out their farmland in the survey year since they are most aware of the updated market value of their farmland. The coefficient becomes even closer to 1 in this case. The error term is clustered at location level (city jurisdiction or rural region). Robust standard errors are in parentheses: *** p<0.01, ** p<0.05, and * p<0.1.

Table A.13. Correlation of Urban Land Price based on the Model and the Land Sales Data

Depvar: Calibrated urban land price	(1)	(2)	(3)	(4)
Average price of all sales	0.186***			
	(0.0284)			
Average price of land sold via auction		0.173***		
		(0.0301)		
Average price of new urban land			0.135***	
			(0.0241)	
Average price of existing urban land				0.163***
				(0.0235)
Observations	570	562	559	555
R-squared	0.070	0.056	0.053	0.080

Notes. This table shows that the model-calibrated urban land price is highly correlated with the price constructed using the land transaction data. The results are robust to the urban land price based on urban land plots sold through auction only (Column 2), newly developed urban land (Column 3), and existing urban land (Column 4). Standard errors are in parentheses: *** p<0.01, ** p<0.05, and * p<0.1.

Table A.14. Sensitivity of the Counterfactual Outcomes to Alternative Parameter Values

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Specification	Baseline	$\alpha = 0.02$	$\alpha = 0.08$	$\theta_M = 0.59$	$\theta_M = 0.76$	$\nu = 2$	$\nu = 4$
Workers' welfare	5.78	5.66	5.90	7.09	3.85	5.27	6.13
Manufacturing output	4.95	4.80	5.11	5.80	3.66	4.31	5.35
Agricultural output	-2.79	-2.79	-2.80	-3.22	-2.17	-2.51	-3.01
Urban population	5.20	5.18	5.22	6.19	3.75	4.40	5.78
Urban land	39.58	39.14	40.08	40.69	37.90	37.35	41.41
Farmland	-6.67	-6.68	-6.65	-6.57	-6.82	-6.60	-6.74
	(8)	(9)	(10)	(11)	(12)	(13)	(14)
Specification	$\zeta = 1.25$	$\zeta = 2.52$	$\sigma_M = 4$	$\sigma_M = 9$	$\sigma_F = 4$	$\sigma_F = 9$	$\sigma_F = 7$
Workers' welfare	5.07	6.33	5.65	5.82	5.59	5.74	5.79
Manufacturing output	4.69	5.16	4.85	4.99	4.72	4.91	4.97
Agricultural output	-2.64	-2.89	-2.54	-2.84	-2.80	-2.80	-2.79
Urban population	4.95	5.40	5.07	5.25	4.97	5.15	5.22
Urban land	35.31	43.07	37.84	40.24	37.87	39.26	39.72
Farmland	-8.02	-5.50	-6.69	-6.65	-6.44	-6.62	-6.69

Notes. The baseline results are reported in Column 1 for comparison. The counterfactual results are robust to the value of α in the range of $[0.02, 0.08]$ (Columns 2 and 3), θ_M in the range of $[0.59, 0.76]$ (Columns 4 and 5), ν in the range of $[2, 4]$ (Columns 6 and 7), ζ in the range of $\zeta \in [1.25, 2.52]$ (Columns 8 and 9), σ_M in the range of 4 to 9 (Columns 10 and 11), and σ_F in the range of 4 to 9 (Columns 12 and 13) as well as when it is specified to be the same as σ_M (Column 14).

Table A.15. Sensitivity of the Counterfactual Outcomes to Model Extensions

Specification	(1) Baseline	(2) Drop rural regions	(3) Re-distribute land profit
Workers' welfare	5.78	7.78	6.54
Manufacturing output	4.95	2.04	5.13
Agricultural output	-2.79	-6.83	-3.21
Urban population	5.20	2.33	5.86
Urban land	39.58	35.31	40.68
Farmland	-6.67	-11.22	-6.56

Notes. This table shows that the estimates of the aggregate cost of the policy are qualitatively similar when using alternative model specifications. **The first extension** is to drop the rural regions that only have an agricultural sector in it. By doing so, I prevent trade and migration flows between the city jurisdictions and the remaining rural regions and focus only on the welfare of workers inside city jurisdictions. The first consequence is that more urban land increases the utility of workers already residing in the city jurisdictions but does not increase the total population across city jurisdictions. As a result, the welfare increase is higher, but the urban population increase is smaller than the baseline outcome. The second consequence is that city jurisdictions cannot shift agricultural production to the remaining rural regions. Therefore, city jurisdictions cannot specialize in manufacturing production as much as in the baseline. This can be seen from a smaller increase in output from the manufacturing sector comparing to the baseline. Finally, although the decrease of agricultural output and farmland is larger, it is smaller than the corresponding change in city jurisdictions in the baseline. **The second extension** is to assume a national portfolio that collects all the land development profit and redistributes it equally among the workers. The counterfactual results based on the alternative model specification are quite similar to the baseline results.

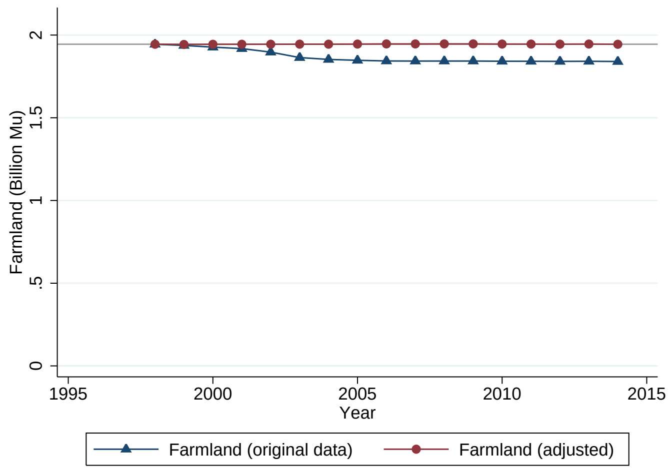
Table A.16. Sensitivity of the Counterfactual Outcomes to the Imputation of $c_{Rn,2010}$

Specification	Baseline	Specification 2	Specification 3
Workers' welfare	5.78	7.46	6.60
Manufacturing output	4.95	6.51	5.66
Agricultural output	-2.79	-3.67	-3.21
Urban population	5.20	6.50	6.00
Urban land	39.58	53.78	47.34
Farmland	-6.67	-7.20	-7.66
Mean of the farmland cost-to-rent ratio	1.43	1.56	1.54
SD of the farmland cost-to-rent ratio	0.62	0.82	0.96

Notes. This table shows that the estimates of aggregate effects of the policy are robust to alternative ways of imputing the marginal cost of farmland development in 2010. Across all the imputation methods, the baseline specification returns the lowest average farmland cost-to-rent ratio, which indicates the degree of land market distortions caused by the policy. Therefore, this method generates the most conservative estimates of workers' welfare loss caused by the policy. Column 1 reports the baseline specification for comparison. In **Specification 2**, I rely on the functional form of the supply of developed land to infer the marginal cost of farmland development in 2010. The counterfactual results based on this alternative imputation method predict a slightly larger welfare loss. **Specification 3** is the same as the baseline, except that the interest rate used to calculate the present value of farmland rent is 7.0% instead of the 5.8% rate in the baseline.

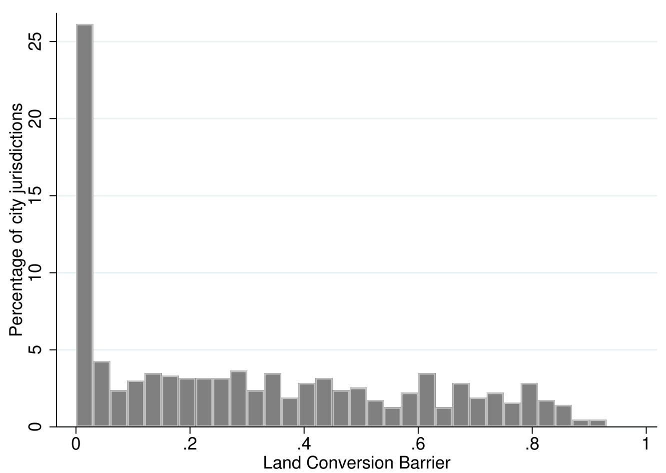
A.2 Additional Figures

Figure A.1. The Total Amount of Farmland in China



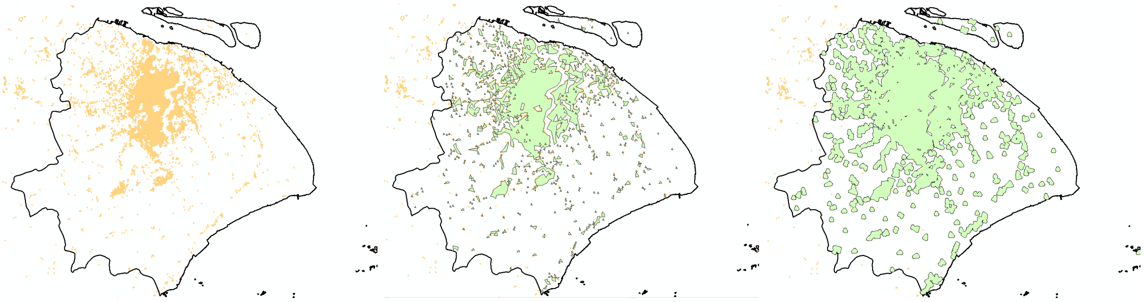
Notes. This figure shows that the total amount of farmland has barely changed at the national level since the policy's implementation, after accounting for the farmland reduction due to the Grain-for-Green National Project. In the figure, the blue line (original) represents the farmland stock by the end of the year, while the red line (adjusted) represents the farmland stock plus the amount of farmland converted back to unused land (such as grassland and forest) during that year as required by the Grain-for-Green Project. The Grain-for-Green National Project was announced in 1999 and implemented during the first half of the 2000s (Cao et al., 2009). The project aims to restore an ecological balance to the western parts of the country by converting farmland on mountainous land back to grassland and forest. The data used here come from the China Land Resource Yearbooks.

Figure A.2. Histogram of the Land Conversion Barrier

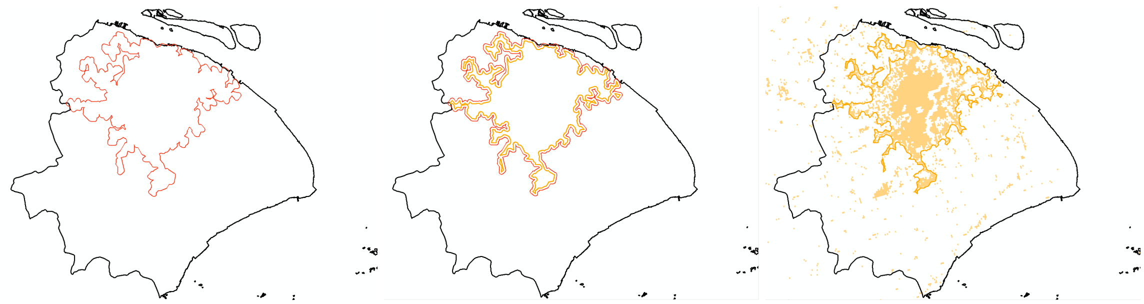


Notes. This figure shows that there is rich cross-sectional variation in the measure of the land conversion barrier.

Figure A.3. Construction of the Boundaries of Urban Areas



(a) Urban Land Cover Raster (b) Step 1 (c) Step 2



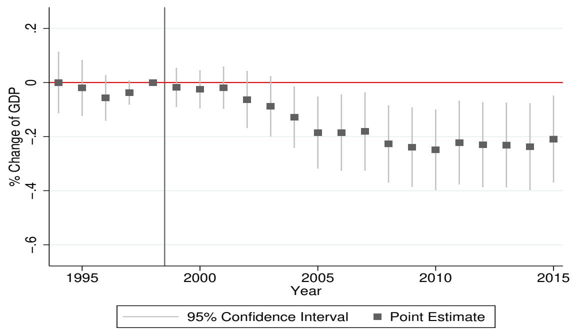
(d) Step 3 (e) Step 4 (f) Final Boundary

Notes. This figure illustrates the steps to draw the boundary of an urban area using urban land raster data. (a) shows the raw raster data, where each yellow dot represents a land grid classified as land occupied by man-made surfaces. In Step 1, I convert these grids from raster to polygons and merge all the adjacent polygons into one. Steps 2 to 4 deal with urban districts divided by a river, such as that in Shanghai. This guarantees that major urban districts that are less than one mile away from each other are treated as a united urban district. In particular, I expand the polygon boundaries outward by half a mile in Step 2 and merge the overlapped polygons into one in Step 3. In Step 4, I move all points on the boundary of the newly formed polygon backward by half a mile. I define the new boundary as the final urban area boundary. In (f), I compare the original urban land cover raster data with the boundary drawn to show that the urban area boundary properly captures the integrated urban area.

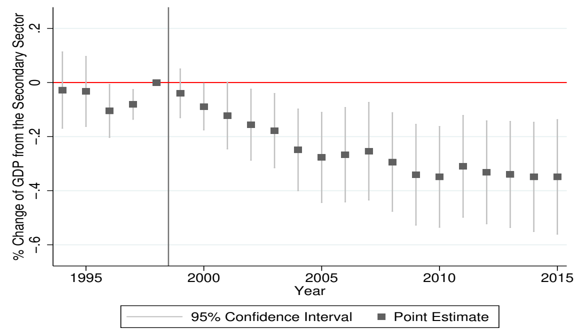
Figure A.4. Land Ruggedness and Farmland Development

Notes. This figure shows that on flat land, as in (a), low-cost standard cultivation techniques are applicable immediately. In the relatively rugged area, as in (b), flat surfaces along the slopes have to be created first to make the land cultivable, hence involving much more labor input and agricultural engineering techniques.

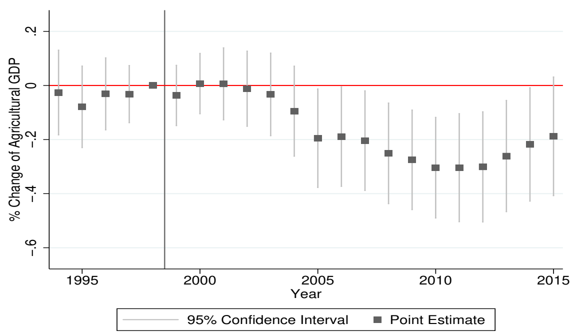
Figure A.5. Impacts of the Land Conversion Barrier by Year



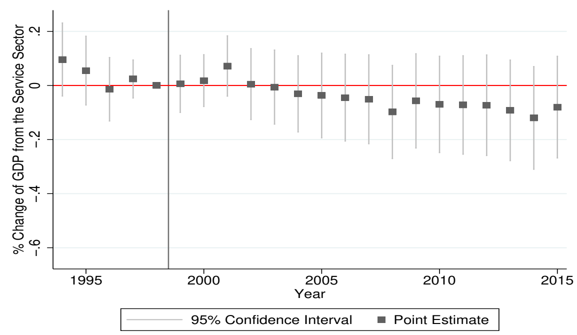
(a) Impacts on GDP



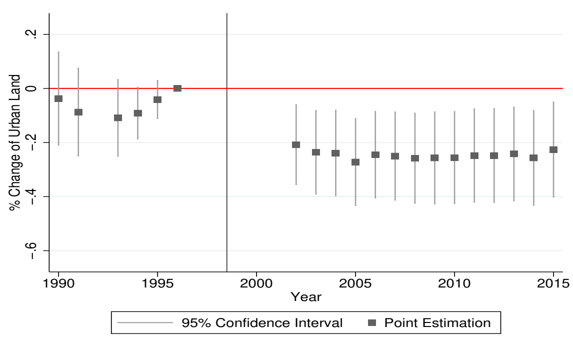
(b) Impacts on GDP from the secondary sector



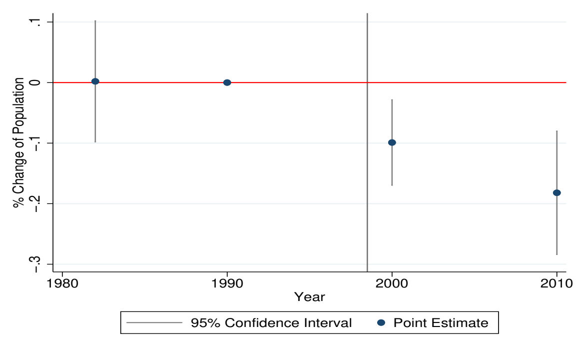
(c) Impacts on GDP from the agricultural sector



(d) Impacts on GDP from the service sector



(e) Impacts on Urban land supply



(f) Impacts on population

Notes. This figure shows that the parallel trends before the policy still hold after controlling for the time-varying impacts of population and employment rate in 1990.

A.3 Description of the Dataset

This subsection describes the datasets used in the empirical analysis.

First, to construct a panel dataset of city jurisdictions with their economic outcomes from 1990 to 2015, I assemble data from multiple yearbooks and census. They include the China City Statistical Yearbooks (1990 - 2015), the China City Development Yearbooks (2002 - 2015), China Data Online (1997 to 2015), and the Population Census (1982, 1990, 2000, and 2010). Variables in the panel data at the annual frequency include GDP by sector, urban land, government expenditure per capita, and the number of hospital beds, while data on population is at the decadal frequency.

Two city jurisdictions might merge into one over time if they become economically integrated. To make the geographical unit of analysis consistent over time, I use 2010, the latest census year, as the benchmark. If two city jurisdictions merged into one during 1990 and 2010, I treat them as one city jurisdiction throughout the period of my study and aggregate the data correspondingly. Next, 9% of city jurisdictions changed jurisdiction boundaries by incorporating a neighbor county during the period of study. Unavailability of county-level data at the annual frequency during the early 1990s makes it impossible to construct a time-consistent geographical unit of analysis for these 9% city jurisdictions. I show that results are robust to excluding these city jurisdictions from regression analysis. It suggests that potential measurement errors brought by these city jurisdictions is not a concern.

The population census has several advantages comparing to the population data reported in the City Statistical Yearbooks. First, the population census provides a more accurate accounting of the number of residents. Yearbooks only count people who register their Hukou in that city jurisdiction. Yet, working migrants may work in one city jurisdiction for a long time while keeping their Hukou registration at their birthplace. In contrast, in the population census, whoever stays in a city jurisdiction for more than six months by the time of census survey counts as a resident in that city jurisdiction. Next, the population census data always covers the entire country. Therefore, for a few city jurisdictions that changed the administrative boundary by incorporating a nearby county during 1990 and 2010, the population of that county is always added into the city jurisdiction throughout the time period of my study.

Second, several additional databases are used to construct variables for supplementary analysis. The first database is the transaction data of urban land sales published on the LandChina.com. This database covers the majority of the urban land transactions in China during 2007 and 2015. I use the database to construct the average FAR and urban land price at the level of city jurisdiction - year - land use (commercial land, industrial land, residential land, and others). The second dataset is the urban land use by category during 2002 and 2015 from the China City Development Yearbooks. The categories include business use (industrial use and commercial use), residential use, public facility (including schools, government buildings, hospitals, libraries, stadiums, etc), and transportation and green areas (such as roads, bus and train stations, and parks).[51] Third, I use the urban land-use raster data at 30-m resolution for 1995 and 2015 to draw the boundary of the urban area in each city jurisdiction. Appendix Figure A.3 illustrates the procedure to construct the urban boundary. The polygon of urban boundary is then used to calculate the compactness of the urban areas over

[51] The original classification has more than four categories and the classification adjust in 2008. To make the classification consistent across time, I aggregate them into four categories.

time. Finally, variables from the 1982 and 1990 Population Census are used to conduct the balance test for the land conversion barrier.

Next, land slope features at 90-m resolution and soil qualities at 1-km resolution come from the Harmonized World Soil Database (Fischer et al., 2008b). Data on slope features were collected by NASA and NGA during February, 2000. The soil data for China were collected by the Chinese Academy of Sciences during 1989 and 1993 (Fischer et al., 2008a; Nachtergaele et al., 2010).

Finally, I disclose the source of the variables used to test the model fit in Section 6.5. The percentage of the population with a college degree and above, and the average education years of population are calculated using the 2010 Population Census. Second, the number of theaters and the number of books collected by the public libraries in 2012 come from the China City Statistical Yearbook. Third, the FDI investment per capita in 2007 is also from the China City Statistical Yearbook. 2007 is the closest year to 2010 for which the data of FDI investment at the city jurisdiction level is provided. Next, I use the Chinese Household Finance Survey from 2012 to calculate the expected market value of the farmland in 210 locations (city jurisdictions and the rest of rural regions).

A.4 Construct Variables for Model Quantification

A.4.1 Geographical Features of a Location, $\{\phi_n, \Psi_n, \tilde{R}_n, R_n\}$

ϕ_n is the percentage of undevelopable land in location n. It is defined as the percentage of land grids in location n with a local slope above 15 degrees.[52] Next, Ψ_n is a vector of average soil qualities of land inside the administrative boundary of location n. The soil qualities capture the major factors that affect crop growth, including pH, organic carbon, gravel percentage, water storage capacity, water drainage, and soil electrical conductivity. Third, the total amount of land in a location, $\tilde{R}_n$, is calculated using the shapefile of administrative boundaries of counties in China in 2010. Finally, the amount of farmland in each location, R_n, in 2000, 2005, and 2010 comes from GeoExplorer II.

A.4.2 The Minimum Amount of Farmland, $\bar{R}_n$

The minimum amount of farmland that has to be maintained in each location equals the amount of farmland in location n immediately before the implementation of the policy. The nearest year for which the farmland quantity was available for all the locations was 2000. Therefore, I use the amount of farmland in 2000 to approximate the corresponding value in 1999.[53]

The quantity constraint on farmland is binding in a city jurisdiction if and only if the quantity of farmland in 2010 equals the minimum quantity of farmland and the amount of urban land increased during 1999 and

[52] It is technically difficult to develop land with a slope above 15 degrees into farmland or urban land (Saiz, 2010; Nunn and Puga, 2012).

[53] Starting in 1999, the Grain-for-Green program in China converted farmland in very mountainous regions back to unused land (such as grassland and forest). The program makes the change in farmland in the places involved in the program negative, even though this change is not due to urbanization. GeoExplorer reports the amount of farmland on each type of land. Therefore, I can detect the reduction in farmland on mountainous land during 2000 and 2010. I treat the reduction in farmland on mountainous land to be caused by this program and make a corresponding deduction on the amount of farmland in 2000. After the adjustment, any change in the farmland from 2000 to 2010 was due solely to the interaction of the Farmland Red Line Policy and the local governments' land development decisions.

2010.[54] For a few city jurisdictions, the amount of farmland in 2010 was lower than the amount of farmland before the policy, and their neighboring rural regions (rural counties that belong to the same prefecture as the city jurisdiction) had a quantity greater than the amount before the policy. This happens if the city jurisdiction asks the neighboring rural region within the same prefecture to help create some of the new farmland when the marginal land development cost in the city jurisdiction is relatively high.[55] As a result, the quantity constraint becomes permanently lower in the city jurisdiction, while it becomes permanently higher in the neighboring rural region. In such cases, I adjust the $\bar{R}_n$ for both the city jurisdiction and the rural region such that it equals the quantity of farmland in 2010.

A.4.3 Data for the Estimation of the Supply Elasticity of Developed Land

This subsection introduces the data used for estimating the supply elasticity of developed land.

First, data on the amount of farmland and urban land during 1999 and 2004 are needed. One challenge is that the farmland data, R_{nt}, are available only for 2000 and 2005. Furthermore, data on the amount of urban land were not available for 70% of city jurisdictions during 1997 and 2001. I use the amount of farmland in 2000 and 2005 to interpolate the amount of farmland for the years in between. In the baseline specification, I assume a constant growth rate across years; for a robustness check, I assume constant change in quantity across years (Appendix Table A.8, Column 2). Similarly, for the missing urban land data, I assume a constant growth rate of urban land between 1997 and 2001 to interpolate the amount of urban land in the corresponding year. The estimates are robust to assuming that the change in the amount of urban land is constant across years (Appendix Table A.8, Column 3).

The outcome variable is the marginal cost of land development, c_{Rnt}, which is equal to the marginal cost of farmland development in the model. The marginal cost of farmland development in a given year is approximately the same as the unit cost of developing new farmland in that year since the amount of newly developed farmland in a given year is small relative to the total farmland stock. Therefore, I use the unit cost of farmland development for a given year at location n to represent c_{Rnt}. Data on the unit cost of farmland development for a given year are very difficult to obtain in general. Fortunately, between 1999 and 2004, the China Land Resource Yearbooks reported the subsidy payed to rural households when they develop new farmland across locations.[56] Local governments subsidize local households that help new farmland development to meet the policy requirements.[57] Once the new farmland is developed, the rent generated from that farmland goes to rural households. Therefore, the unit cost of farmland development in year t can be calculated by adding the subsidy (c_{Fnt}) and the present value of farmland rent generated in all future

[54] If the amount of urban land did not change from 1999 to 2010, which accounts for 5.8% of the city jurisdictions, it is treated as not binding on the constraint. This makes the constraint condition assignment conservative.

[55] Typically, the city jurisdiction pays the rural region to help create new farmland, which distorts the farmland development decision and makes the marginal cost of land development higher than the farmland rent in those rural regions.

[56] The data are reported at the prefecture level, which includes two city jurisdictions and one rural region on average. Therefore, the observed prefecture-level data c^p_{Fgt} is a weighted average across all the locations within a prefecture: $c^p_{Fgt} = \sum_{n \in g} \omega_{nt} c_{Fnt}$, where ω_{nt} is the percentage of new farmland developed in location n to meet the policy requirement. In the baseline, I assume that $c_{Fnt} = c^p_{Fg(n)t}$ in all the locations. In Appendix Table A.8, Column 5, I take into account that in locations not binding on the constraint, c_{Fnt} should be equal to 0 and show that the estimation results barely change. The error terms are clustered at the prefecture level, as any measurement error in c^p_{Fgt} affects all the locations within the same prefecture.

[57] The local governments surveyed villages within their jurisdictions to learn how much it costs to develop a unit of new farmland.

periods:

$$c_{Rnt} = c_{Fnt} + PV_{Rt},$$

where $PV_{Rt} = \sum_{\tau=t}^{\infty} \frac{E(p_{Rn\tau})}{(1+r)^{\tau}}$. I specify the interest rate, r, to be 0.058, which is the average lending interest rate in China from 2000 to 2015.[58] Finally, I assume that the representative rural household uses the farmland rent from the current period to infer the future payoffs of the farmland rent. In particular, $E(p_{Rn\tau}) = p_{Rnt}$, and p_{Rnt} is recovered from the model: $p_{Rnt} = \frac{\theta_F E_{Fnt}}{R_{nt}}$.

A.4.4 The Marginal Cost of Farmland Development in 2010, $c_{Rn,2010}$

As discussed in A.4.3, the marginal cost of farmland development is available only up to 2004, and hence, the marginal cost of farmland development in 2010, $c_{Rn,2010}$, is not directly observable. However, this variable is needed to recover land price distortions from other sources, λ_{Hn}. This subsection introduces two ways to impute its value based on the values from earlier years.

I first define $\tau_{n,t}$ as the ratio of the marginal cost of farmland to the present value of all future farmland rents in year t:

$$c_{Rn,t} = \tau_{n,t} PV_{Rt}. \tag{26}$$

Without the Farmland Red Line Policy, $\tau_{n,t} = 1$. With the policy, it is greater than 1 if the constraint is strictly binding in location n. Moreover, conditional on the constraint binding, a larger τ_n means that a greater subsidy is needed to induce additional farmland development to meet the farmland quantity requirement and hence leads to more severe cross-sector land misallocation. Therefore, a higher $\tau_{n,t}$ indicates more distortions in land allocation as well as a larger welfare loss of workers as a result of the policy.

In the baseline specification, I assume that $\tau_{n,2010}$ is the same as $\tau_{n,2004}$ if the farmland quantity constraint is binding in location n.[59] For such locations,

$$c_{Rn,2010} = \tau_{n,2010} PV_{R,2010} = \frac{c_{Rn,2004}}{PV_{R,2004}} PV_{R,2010}.$$

$c_{Rn,2004}$ is available in the data, and $PV_{R,t}$ is computed in the same way as described in Appendix A.4.3. For locations that are not binding on the constraint, $c_{Rn,2010} = PV_{R,2010}$. This method likely provides a lower bound on the aggregate effect of the policy. Given that the urbanization rate continued to rise between 2005 and 2010, it is plausible to assume that $\tau_{n,2010}$ is weakly greater than $\tau_{n,2004}$. Therefore, this method leads to an underestimation of the distortions in the land market and hence the aggregate welfare loss. As shown in Appendix Table A.16, the baseline specification leads to the lowest aggregate welfare loss across all the specifications.[60]

[58] As a robustness check, I set the interest rate to be 0.070, which is the median interest rate faced by rural households calculated from the China Household Finance Survey. This result is reported in Appendix Table A.8, Column 4.

[59] The constraint binding condition is determined by comparing the total amount of farmland and the minimum quantity for each location, and the details are provided in Appendix A.4.2.

[60] This choice returns the lowest average $\tau_{n,2010}$ across locations, therefore generating the most conservative estimate of the aggregate cost of the policy.

For a robustness check, an alternative way of imputing $c_{Rn,2010}$ is to use the land supply function:

$$c_{Rn,2010} = c_{Rn,2004} \times \frac{\tilde{p}_{n,2010}}{\tilde{p}_{n,2004}} \left(\frac{(1-\phi_n)\tilde{R}_n - R_{n,2010} - H_{n,2010}}{(1-\phi_n)\tilde{R}_n - R_{n,2004} - H_{n,2004}} \right)^{-\zeta}.$$

The only unknowns are $\frac{\tilde{p}_{n,2010}}{\tilde{p}_{n,2004}}$. I assume it to be the same across locations and choose its value such that the average of $\frac{c_{Rn,2010}}{c_{Rn,2004}}$ is equal to the national average.[61]

As shown in Appendix Table A.16, the estimated workers' welfare loss is similar across different specifications. Note that the baseline specification yields the most conservative estimate of the increase in workers' welfare in the counterfactual equilibrium.

A.5 Model Fitness: Out-of-Sample Test

This subsection provides a detailed discussion on the fit of the model by testing the correlation between the recovered unobservables and out-of-sample proxy variables.

First, I show that FDI per worker around 2010 is strongly positively correlated with calibrated urban sector productivity (Appendix Table A.10, Column 1). FDI is commonly used to explain productivity, especially in developing countries, because it represents local access to frontier technology in production and management (Haskel et al., 2007). Next, labor skills are associated with the productivity of an urban area (Simon and Nardinelli, 2002). In Appendix Table A.10, Columns 2 and 3, I show that calibrated urban sector productivity is positively associated with the percentage of the population with a college degree and above and the average education years of the population.

Second, I show that the model-calibrated amenities of the urban sector are positively associated with the characteristics that make the location more desirable to live, including the presence of theaters and the scale of public library collections. Appendix Table A.11, Column 1 suggests that the number of books collected by the public libraries positively correlates with the calibrated local amenity level. Next, Appendix Table A.11, Column 2 shows that the number of theaters is positively associated with the location amenity level.

Third, the calibrated farmland price is close to its counterpart calculated using the Chinese Household Finance Survey. The survey asks each rural household to report both the amount of farmland it owns and the expected market value of the farmland, and the farmland price is the ratio between the two.[62] I regress the farmland price at the household level against the calibrated farmland price of that location and cluster the error term at the level of the location. Appendix Table A.12 shows that farmland prices are highly correlated with the model calibrations. The regression associated with Column 1 includes all the rural households that own farmland, while in Column 2, I include the rural households inside the city jurisdictions only. The relatively higher coefficient in Column 2 could mean that rural households closer to urban areas are better

[61] The national average growth rate of the farmland development cost is denoted as $\frac{c^{All}_{R,2010}}{c^{All}_{R,2004}}$, where $c^{All}_{R,t} = c^{All}_{F,t} + PV^{All}_{Rt}$. The national average subsidy for a unit of farmland in 2011 is available from the Land Resource Yearbook for 2011, which I use to approximate $c^{All}_{F,2010}$.

[62] The survey conducted in 2012 covers 210 out of 889 rural regions (631 in city jurisdictions) included in my analysis. Although this household survey began in 2010 and was conducted every two years, I do not use the first round of the survey because the unit of the expected market value of the farmland is not specified in that year, hence causing large measurement errors.

informed of the actual market value of their farmland.[63]

Finally, I test the correlation between the model-calibrated urban land price and the average urban land price based on urban land transaction data for 2010 from LandChina.com. As shown in Table A.13, Column 1, there is a strong positive correlation between the model-calibrated data and the actual data. The results are robust to the urban land price based on urban land plots sold through auction only (Column 2), newly developed urban land (Column 3), and existing urban land (Column 4).[64]

[63]In Column 3, I further restrict the sample to those who rent out their farmland in the survey year since they are most aware of the updated market value of the farmland. The coefficient becomes even closer to 1.

[64]Note that the calibrated price and the price calculated using the transaction data are not expected to be along a 45-degree line, and hence, the coefficient is not necessarily 1. This is because the calibrated urban land price refers to the average price across all the urban land plots in an urban area, yet the data are based on land plots transacted in that year, which accounts for less than 5% of total urban land in 2010.

B Model Appendix

B.1 Derivation of the Optimization Conditions of Workers

This subsection shows the derivation of a worker's optimization conditions of her utility maximization problem. A worker solves the utility maximization problem through backward induction. In Step 2, conditional on choosing location n and sector s, she optimally allocates her labor income to maximize her utility. Given income w_{sn}, she spends $\mu\theta$ on agricultural products, $(1-\mu)\theta$ on manufacturing products, and $1-\theta$ on housing. Therefore, the following conditions hold,

$$h(i,n,s)^* = \frac{(1-\theta)w_{sn}}{p_{H,sn}}, \tag{27}$$

$$T_{nj}p_{Fj}c_{Fj}(i,n,s) = \frac{(T_{nj}p_{Fj})^{1-\sigma_F}}{\tilde{p}_{Fn}^{1-\sigma_F}}\mu\theta w_{sn} \quad \forall j \in N, \tag{28}$$

$$T_{nj}p_{Mj}c_{Mj}(i,n,s) = \frac{(T_{nj}p_{Mj})^{1-\sigma_M}}{\tilde{p}_{Mn}^{1-\sigma_M}}(1-\mu)\theta w_{sn} \quad \forall j \in N \tag{29}$$

where

$$\tilde{p}_{sn} = \left(\sum_{n' \in N} (T_{nn'}p_{sn'})^{1-\sigma_s}\right)^{\frac{1}{1-\sigma_s}}.$$

From (28), the maximum consumption of agricultural goods bundle, $C_F(i,n,s)^*$, is

$$C_F(i,n,s)^* = \frac{\mu\theta w_{sn}}{\tilde{p}_{Fn}}.$$

From (29), the maximum consumption of manufacturing goods bundle, $C_M(i,n,s)^*$, is

$$C_M(i,n,s)^* = \frac{(1-\mu)\theta w_{sn}}{\tilde{p}_{Mn}}.$$

As a result, the maximum utility a worker can get conditional on choosing location n and sector s is

$$V_{sn}^* = \frac{\left(\frac{\mu\theta w_{sn}}{\tilde{p}_{Fn}}\right)^{\mu\theta}\left(\frac{(1-\mu)\theta w_{sn}}{\tilde{p}_{Mn}}\right)^{(1-\mu)\theta}\left(\frac{(1-\theta)w_{sn}}{p_{H,sn}}\right)^{1-\theta}B_{sn}z_{i,n,s}}{(\mu\theta)^{\mu\theta}((1-\mu)\theta)^{(1-\mu)\theta}(1-\theta)^{1-\theta}} = \frac{w_{sn}B_{sn}}{\tilde{p}_n^{\theta}p_{H,sn}^{1-\theta}}z_{i,n,s},$$

where

$$\tilde{p}_n = \tilde{p}_{Fn}^{\mu}\tilde{p}_{Mn}^{1-\mu}.$$

We derive the aggregate demand for residential land and consumption goods. By aggregating individual worker's demand for residential land in the urban sector, we have

$$(1-\theta)w_{Mn}L_{Mn} = p_{Hn}H_n,$$

where p_{Hn} is urban land price. Similarly, by aggregating individual worker's demand for farmland used for residential purpose in the rural sector, we have

$$(1-\theta)w_{Fn}L_{Fn} = p_{Rn}R_{Hn}. \tag{30}$$

where p_{Rn} is farmland price. Finally, the total demand from workers in location n for agricultural good produced in location n' is $\frac{(T_{nn'}p_{Fn'})^{1-\sigma_F}}{\tilde{p}_{Fn}^{1-\sigma_F}}\mu\theta\left(w_{Mn}L_{Mn}+w_{Fn}L_{Fn}\right)$. The total demand from workers in location n for manufacturing good produced in location n' is $\frac{(T_{nn'}p_{Mn'})^{1-\sigma_M}}{\tilde{p}_{Mn}^{1-\sigma_M}}(1-\mu)\theta\left(w_{Mn}L_{Mn}+w_{Fn}L_{Fn}\right)$.

In Step 1, a worker chooses the location and sector that offers her the highest utility. Given that $z_{i,n,s}$ follows Frechét distribution, the probability of one choosing location n and sector s is

$$\pi_{sn}^{L} = \frac{\left(w_{sn}\tilde{p}_n^{-\theta}p_{H,sn}^{\theta-1}B_{sn}\right)^{\tilde{\nu}}}{\sum_{n'}\sum_{s'}\left(w_{s'n'}\tilde{p}_{n'}^{-\theta}p_{H,s'n'}^{\theta-1}B_{s'n'}\right)^{\tilde{\nu}}}. \tag{31}$$

Correspondingly, the expected utility, $\tilde{V}$, is expressed as following,

$$\tilde{V} = \Gamma\left(1-\tilde{\nu}^{-1}\right)\left(\sum_{n'}\sum_{s'}\left(w_{s'n'}\tilde{p}_n^{-\theta}p_{H,s'n'}^{\theta-1}B_{s'n'}\right)^{\tilde{\nu}}\right)^{\frac{1}{\tilde{\nu}}}. \tag{32}$$

Define $\nu = \frac{\tilde{\nu}}{1-\beta\tilde{\nu}}$, (31) is equivalent to

$$\pi_{sn}^{L} = \frac{(w_{sn}\tilde{p}_n^{-\theta}p_{H,sn}^{\theta-1}\bar{B}_{sn})^{\nu}}{\sum_{n'}\sum_{s'}\left(w_{s'n'}\tilde{p}_{n'}^{-\theta}p_{H,s'n'}^{\theta-1}\bar{B}_{s'n'}\right)^{\nu}}. \tag{33}$$

This is because

$$\frac{L_{s'n'}}{L_{sn}} = \frac{(w_{s'n'}\tilde{p}_{n'}^{-\theta}p_{H,s'n'}^{\theta-1}\bar{B}_{s'n'}L_{s'n'}^{\beta})^{\tilde{\nu}}}{(w_{sn}\tilde{p}_n^{-\theta}p_{H,sn}^{\theta-1}\bar{B}_{sn}L_{sn}^{\beta})^{\tilde{\nu}}} = \frac{(w_{s'n'}\tilde{p}_{n'}^{-\theta}p_{H,s'n'}^{\theta-1}\bar{B}_{s'n'})^{v}}{(w_{sn}\tilde{p}_n^{-\theta}p_{H,sn}^{\theta-1}\bar{B}_{sn})^{\nu}}.$$

Therefore, $\frac{1}{\pi_{sn}^{L}}$ can be rewritten as

$$\frac{1}{\pi_{sn}^{L}} = \frac{\sum_{n'}\sum_{s'}(w_{s'n'}\tilde{p}_{n'}^{-\theta}p_{H,s'n'}^{\theta-1}\bar{B}_{s'n'})^{v}}{(w_{sn}\tilde{p}_n^{-\theta}p_{H,sn}^{\theta-1}\bar{B}_{sn})^{\nu}},$$

which is exactly (33).

It can be shown that $\bar{V}$ is a linear transformation of $\tilde{V}$, where $\bar{V} \equiv \left(\sum_{n'}\sum_{s'}(w_{s'n'}\tilde{p}_{n'}^{-\theta}p_{H,s'n'}^{\theta-1}\bar{B}_{s'n'})^{v}\right)^{\frac{1}{\nu}}$. To see this, replace $B_{sn} = \bar{B}_{sn}\left(\bar{L}\pi_{sn}\right)^{\beta}$ in (32), we have

$$\tilde{V}^{\tilde{\nu}} = \bar{L}^{\beta\tilde{\nu}}\Gamma\left(1-\tilde{\nu}^{-1}\right)\left(\sum_{n'}\sum_{s'}\left(w_{Mn'}\tilde{p}_{n'}^{-\theta}p_{H,s'n'}^{\theta-1}\bar{B}_{s'n'}\right)^{\tilde{\nu}}(\pi_{s'n'}^{L})^{\beta\tilde{\nu}}\right). \tag{34}$$

Replace $\pi^L_{s'n'}$ with (33), the following condition holds

$$\tilde{V}^{\tilde{\nu}} = \bar{V}^{-\nu\beta\tilde{\nu}} \bar{L}^{\beta\tilde{\nu}} \Gamma\left(1-\tilde{\nu}^{-1}\right) \sum_{n'} \sum_{s'} \left(w_{Mn'} \tilde{p}_{n'}^{-\theta} p_{H,s'n'}^{\theta-1} \bar{B}_{s'n'} \right)^{\tilde{\nu}+\nu\beta\tilde{\nu}} .$$

Since $\tilde{\nu} + \nu\beta\tilde{\nu} = \tilde{\nu}(1 + \frac{\tilde{\nu}\beta}{1-\beta\tilde{\nu}}) = \nu$,

$$\tilde{V}^{\tilde{\nu}} = \bar{V}^{-\nu\beta\tilde{\nu}} \bar{L}^{\beta\tilde{\nu}} \Gamma\left(1-\tilde{\nu}^{-1}\right) \sum_{n'} \sum_{s'} \left(w_{Mn'} \tilde{p}_{n'}^{-\theta} p_{H,s'n'}^{\theta-1} \bar{B}_{s'n'} \right)^{\nu} = \bar{V}^{\tilde{\nu}} \bar{L}^{\beta\tilde{\nu}} \Gamma\left(1-\tilde{\nu}^{-1}\right)$$

Therefore, we get the following equation:

$$\tilde{V} = \bar{V} \bar{L}^{\beta} \Gamma\left(1-\tilde{\nu}^{-1}\right)^{\frac{1}{\nu}} . \tag{35}$$

As $\bar{L}^{\beta} \Gamma\left(1-\tilde{\nu}^{-1}\right)^{\frac{1}{\nu}}$ is a constant, $\bar{V}$ is a linear transformation of $\tilde{V}$.

Note that (33) can be further simplified to

$$\pi^L_{sn} = \bar{V}^{-\nu} (w_{Mn} \tilde{p}_n^{-\theta} p_{H,sn}^{\theta-1} \bar{B}_{sn})^{\nu}. \tag{36}$$

Therefore, the labor supply in sector s, location n is

$$L_{sn} = \bar{L} \bar{V}^{-\nu} (w_{sn} \tilde{p}_n^{-\theta} p_{H,sn}^{\theta-1} \bar{B}_{sn})^{\nu}. \tag{37}$$

B.2 Impacts of the Farmland Red Line Policy on Land Markets

This subsection studies the impacts of the Farmland Red Line Policy on land markets through a partial equilibrium version of the model. In the partial equilibrium, the supply functions of urban land and farmland are derived from the landlord's profit maximization problem, while the demand for urban land and farmland are taken as given and are subject to demand shocks.

I first discuss the condition under which the constraint binds since only then the supply of urban land and farmland deviate from the no-policy market equilibrium. I define the state of the economy right before policy implementation as the *initial equilibrium*. The minimum farmland quantity $\bar{R}_n$ is the optimal amount of farmland chosen by the landlord in location n in the initial equilibrium. If demands for urban land or farmland do not change after policy implementation, the profit-maximizing quantity of farmland always equals the optimal amount of farmland in the initial equilibrium. As a result, the constraint is not binding. Proposition 1 summarizes the condition for the minimum farmland quantity constraint to bind in a location.

Proposition 1 *The minimum farmland quantity constraint is binding in a location if after policy implementation, the increase in local demand for urban land is large relative to the increase in demand for farmland, such that it is profitable to reduce farmland supply.*

Intuitively, the constraint is binding if and only if without the policy, it is profitable for the landlord to reduce farmland supply. Moreover, the landlord would want to reduce farmland to supply more urban land if the increase in demand for urban land is large relative to the increase in demand for farmland.

To see the second point through the model, we rewrite the demand function of urban land at the initial equilibrium as $p_{Hn}H_n = E_{Hn}$ and the demand function of farmland as $p_{Rn}R_n = E_{Rn}$. E_{Hn} represents the total payment to urban land, while E_{Rn} represents the total payment to farmland. In this subsection, E_{Hn} and E_{Rn} are taken as given and are subject to exogenous shocks.[65] Suppose demand shocks to urban land and farmland occurs to the location. Without the Farmland Red Line Policy, the change in farmland, $d\ln R_n$ can be expressed as a function of the demand shock to urban land $d\ln E_{Hn}$ and the demand shock to farmland $d\ln E_{Rn}$:

$$d\ln R_n = k_{1n} d\ln E_{Rn} - k_{2n} d\ln E_{Hn}. \tag{38}$$

where $k_{1n} \equiv \frac{(1-\phi_n)\tilde{R}_n+(\zeta-1)H_n-R_n}{(1-\phi_n)\tilde{R}_n+(\zeta-1)(H_n+R_n)}$ and $k_{2n} \equiv \frac{\zeta H_n}{(1-\phi_n)\tilde{R}_n+(\zeta-1)(H_n+R_n)}$.[66] The minimum farmland quantity constraint is binding if without the policy, the landlord reduces the farmland supply after the demand shocks: $d\ln R_n < 0$. Therefore, the condition under which the constraint is binding is derived:

$$d\ln E_{Hn} - \frac{k_{1n}}{k_{2n}} d\ln E_{Rn} \geq 0. \tag{39}$$

This relation indicates that the constraint is binding if the urban land demand shock is large relative to the farmland demand shock.

The constraint binding condition is likely to be met in many locations in China for multiple reasons. First, many places had a rapid urbanization process after 1999. It works as a positive demand shock to urban land and negative demand shock for farmland, hence making the constraint bind. Moreover, joining WTO also brings business opportunities that primarily benefit the manufacturing sector. It serves as a positive demand shock to urban land demand while there is no change in demand for farmland, which again makes the constraint bind. Finally, the initial difference in the real wage between the rural sector and urban sector and the further relaxation of Hukou restriction during 2000 and 2005 also make more rural populations move to urban sectors. It is a positive demand shock to urban land demand and negative demand shock for farmland. It again guarantees that the constraint is binding.

Next, I discuss the impact of the Farmland Red Line Policy on the quantity of urban land and farmland when the constraint binds. First of all, the quantity of farmland in the new equilibrium is greater than in the no-policy case. It is because the farmland supply cannot decrease as in no-policy case after demand shocks happen. Second, there is an under-supply of urban land because the policy increases the percent of land development and drives up the marginal land development cost.[67] As a result, the urban land price is higher and less urban land is supplied. Therefore, we get the following proposition.

[65] Note that in general equilibrium, both E_{Hn} and E_{Rn} are determined by the total income in the urban sector and rural sector, hence endogenous.

[66] This expression is derived by log differentiating the demand and supply functions of urban land and farmland around the initial equilibrium. Appendix B.3 provides detailed derivation.

[67] Suppose the percent of land development is weakly lower when there is the policy. It indicates that p_{Hn} is weakly lower and at least the same amount of H_n or even more is consumed than in the no-policy case. But farmland is also greater than in the no-policy case. This suggests that the percent of land development, $\frac{H_n+R_n}{(1-\phi_n)\tilde{R}_n}$, must be higher than when there is no policy, which is a contradiction.

Proposition 2 *If the constraint is binding, there is an over-supply of farmland and an under-supply of urban land.*

At the end of this subsection, I discuss how the percentage of undevelopable land, ϕ_n, affects the likelihood of the constraint to be binding and the degree of the under-supply of urban land when the constraint binds. Intuitively, a higher ϕ_n indicates a lower price elasticity of developed land. As a result, at a given positive demand shock for urban land, the landlord is more likely to reduce farmland to increase urban land supply without the policy. Therefore, the constraint is more likely to be binding under the policy. Next, given that the constraint is binding, an extra unit of farmland drives up the marginal cost of land development further when the supply elasticity of developed land is smaller. This further increases the urban land price and decreases the quantity of urban land.

Proposition 3 *A higher percent of undevelopable land, ϕ_n, makes the farmland quantity constraint more likely to be binding. Moreover, given that the constraint is binding, a higher ϕ_n causes a more severe under-supply of urban land.*

Proof. Suppose the urban land demand shock and the farmland demand shock are drawn from a joint probability distribution $F_{X_h,X_r}(x_h, x_r)$. The probability that the constraint is binding is

$$Pr\left(d\ln E_{Hn} \geq a_n d\ln E_{Rn}\right) = \int_{-\infty}^{+\infty}\int_{-\infty}^{\frac{x_h}{a_n}} f_{X_h,X_r}(x_h, x_r)dx_r dx_h$$

where $a_n = \frac{(1-\phi_n)\tilde{R}_n+(\zeta-1)H_n-R_n}{\zeta H_n}$ and a_n decreases with ϕ_n. Therefore, at any given x_h, a higher ϕ_n increases $\frac{x_h}{a_n}$ and hence $\int_{-\infty}^{\frac{x_h}{a_n}} f_{X_h,X_r}(x_h, x_r)dx_r$. As a result, a higher ϕ_n leads to a higher probability for the constraint to be binding.

Next, we show that a higher ϕ_n causes a more severe under-supply of urban land given that the constraint is binding. To see this, the difference of urban land supply with and without the policy after the demand shocks is:

$$d\ln H_n' - d\ln H_n = -\frac{R_n}{H_n}k_{2n}\left(\frac{k_{2n}}{k_{1n}}d\ln E_{Hn} - d\ln E_{Rn}\right)$$

Both k_{2n} and $\frac{k_{2n}}{k_{1n}}$ increases with ϕ_n, which indicates that the difference of new urban land supply after demand shocks is more negative. Hence a higher ϕ_n causes a more severe under-supply of urban land. Q.E.D.

Proposition 3 indicates that ceteris paribus, a location with a higher percentage of undevelopable land has a smaller increase in urban land supply after policy implementation. This is consistent with the empirical findings from Section 4 that locations with a higher land ruggedness in the area where new farmland is likely to be developed have less urban land supply after the policy began.

B.3 Derivation of the Change in Land Use in Response to Land Demand Shocks

By log differentiating the demand functions of urban land and farmland around the initial equilibrium, we have

$$d\ln p_{Hn} + d\ln H_n = d\ln E_{Hn}, \tag{40}$$

$$d\ln p_{Rn} + d\ln R_n = d\ln E_{Rn}. \tag{41}$$

When there is no Farmland Red Line Policy, we log differentiate the corresponding urban land supply function and farmland supply function and get

$$d\ln p_{Hn} = d\ln p_{Rn}, \tag{42}$$

$$d\ln p_{Rn} = \frac{\zeta H_n}{(1-\phi_n)\tilde{R}_n - R_n - H_n} d\ln H_n + \frac{\zeta R_n}{(1-\phi_n)\tilde{R}_n - R_n - H_n} d\ln R_n. \tag{43}$$

Combining (40), (41), (42), and (43), we have 4 equations with 4 unknowns: $dlnR_n$, $dlnH_n$, $dlnp_{Rn}$, and $dlnp_{Hn}$. Therefore, $dlnR_n$ can be expressed as a function of $dlnE_{Hn}$ and $dlnE_{Rn}$:

$$dlnR_n = \frac{\Big((1-\phi_n)\tilde{R}_n + (\zeta-1)H_n - R_n\Big)\, dlnE_{Rn} - \zeta H_n dlnE_{Hn}}{(1-\phi_n)\tilde{R}_n + (\zeta-1)(H_n+R_n)}. \tag{44}$$

Denote $k_{1n} = \frac{(1-\phi_n)\tilde{R}_n + (\zeta-1)H_n - R_n}{(1-\phi_n)\tilde{R}_n + (\zeta-1)(H_n+R_n)}$ and $k_{2n} = \frac{\zeta H_n}{(1-\phi_n)\tilde{R}_n + (\zeta-1)(H_n+R_n)}$, (44) can be rewritten as

$$dlnR_n = k_{1n} dlnE_{Rn} - k_{2n} dlnE_{Hn}. \tag{45}$$

Similarly, $dlnH_n$ can be expressed as:

$$dlnH_n = \frac{(1-\phi_n)\tilde{R}_n + (\zeta-1)\,R_n - H_n}{(1-\phi_n)\tilde{R}_n + (\zeta-1)\,(R_n+H_n)} dlnE_{Hn} - \frac{\zeta R_n}{(1-\phi_n)\tilde{R}_n + (\zeta-1)\,(R_n+H_n)} dlnE_{Rn}. \tag{46}$$

Next, we derive the change in urban land and farmland in response to the demand shocks for urban land and farmland when the Farmland Red Line Policy intervenes with the land development decisions. At the initial equilibrium, the policy is announced first, and the demand shocks $dlnE_{Hn}$ and $dlnE_{Rn}$ happen afterward. Denote the change in farmland and urban land quantities as $dlnR_n'$ and $dlnH_n'$.

If the demand shocks make the farmland weakly increasing without the policy requirement, which means $dlnR \geq 0$, the constraint is not binding, and $dlnR_n'$ and $dlnH_n'$ are the same as $dlnR_n$ and $dlnH_n$ correspondingly. If $dlnR < 0$, without the policy, it is profitable for the landlord to reduce farmland. Therefore, with the policy, the constraint is binding and $dlnR_n' = 0$. Next, $dlnH_n'$ is expressed as

$$dlnH_n' = \frac{(1-\phi_n)\tilde{R}_n - R_n - H_n}{\zeta H_n + (1-\phi_n)\tilde{R}_n - R_n - H_n} dlnE_{Hn}. \tag{47}$$

Finally, the difference of urban land supply after the demand shocks with and without the policy is simply

$$dlnH_n'-dlnH_n=-\frac{\zeta R_n}{(1-\phi_n)\,\tilde{R}_n+(\zeta-1)\,(R_n+H_n)}\left(\frac{\zeta H_n}{(1-\phi_n)\,\tilde{R}_n+(\zeta-1)\,H_n-R_n}dlnE_{Hn}-dlnE_{Rn}\right).$$

Note that $\frac{\zeta R_n}{(1-\phi_n)\tilde{R}_n+(\zeta-1)(R_n+H_n)}=\frac{R_n}{H_n}k_{2n}$ and $\frac{\zeta H_n}{(1-\phi_n)\tilde{R}_n+(\zeta-1)H_n-R_n}=\frac{k_{2n}}{k_{1n}}$. The expression above can be written as

$$dlnH_n'-dlnH_n=-\frac{R_n}{H_n}k_{2n}\left(\frac{k_{2n}}{k_{1n}}dlnE_{Hn}-dlnE_{Rn}\right)\tag{48}$$

B.4 Recover the Unobservables

This subsection introduces the procedure to recover the unobserved variables that rationalize the observed data from 2010 as an equilibrium. The recovery of unobservables takes five steps.

In Step 1, I solve the set of wages, $\{w_{Mn}, w_{Fn}\}$, and land prices, $\{p_{Hn}, p_{Rn}\}$, that are consistent with the data according to the equilibrium conditions. The observed data include output from the manufacturing and agricultural sector in location n, $\{E_{Mn}, E_{Fn}\}$, working population from the manufacturing and agricultural sector in location n, $\{L_{Mn}, L_{Fn}\}$, and urban land and farmland, $\{H_n, R_n\}$, correspondingly.[68] Specifically, they are recovered using the following conditions:

$$\begin{aligned}w_{Mn}&=E_{Mn}/L_{Mn},\\ w_{Fn}&=\gamma E_{Fn}/L_{Fn},\\ p_{Hn}&=(1-\theta_M)E_{Mn}/H_n,\\ p_{Rn}&=(1-\gamma\theta_F)E_{Fn}/R_n.\end{aligned}$$

In Step 2, I recover the prices of manufacturing and agricultural products from across locations. I first parameterize bilateral trade cost as the bilateral trade data is not available at city jurisdiction level. Therefore, the bilateral trade cost within China is parameterized as a function of bilateral distances between two locations, as in Redding (2016):

$$T_{nn'}^{-\sigma_M}=d_{nn'}^{-D_M},$$

where $d_{nn'}$ is the distance between the centroid of the two locations n and n'. The distance decay elasticity for trade in manufacturing goods is specified as 1, following the literature (Faber and Gaubert, 2019).

I then use the market clearing condition for the manufacturing goods (18) and the price index of the manufacturing goods (3) to recover $\{p_{Mn}, Y_{Mn}, \tilde{p}_{Mn}\}$ that are consistent with the observed output by sector

[68] For rural regions, all the working population is classified as agricultural workers. This is a realistic simplification because, according to the population census and City Statistical Yearbook in 2010, 73% of employment belongs to the agricultural sector. Correspondingly, all the final output is classified as agricultural output.

and calibrated trade costs $\{T_{nn'}\}$. p_{Mn} and $\tilde{p}_{Mn}$ are solved by iterating over (49) and (50).[69]

$$\tilde{p}_{Mn} = \left(\sum_{n'} (T_{nn'} p_{Mn'})^{1-\sigma_M} \right)^{\frac{1}{1-\sigma_M}}, \tag{49}$$

$$p_{Mj}^{\sigma_M - 1} = \frac{1-\mu}{E_{Mj}} \sum_n \frac{(T_{jn})^{1-\sigma_M}}{\tilde{p}_{Mn}^{1-\sigma_M}} (E_{Mn} + E_{Fn}). \tag{50}$$

In Step 3, I calculate $\{\bar{A}_{Mn}, \bar{A}_{Fn}\}$ using the production function of the manufacturing and agricultural sectors:

$$\bar{A}_{Mn} = \frac{w_{Mn}}{p_{Mn} L_{Mn}^{1+\alpha}},$$
$$\bar{A}_{Fn} = \frac{E_{Fn}}{p_{Fn} L_{Fn}^{\gamma} R_{Fn}^{1-\gamma}},$$

where $R_{Fn} = \frac{1-\gamma}{1-\theta_F \gamma} R_n$.

In Step 4, $\{\bar{B}_{Mn}, \bar{B}_{Fn}\}$ and $\bar{V}$ can be solved up to a constant using labor supply functions (5) and labor clearing condition (4). I specify the measure of utility such that at equilibrium, the expected utility of a representative worker is 1. Therefore, $\bar{B}_{Mn}$ is uniquely determined by

$$\bar{B}_{Mn} = \left(\frac{L_{Mn}}{\bar{L}} \right)^{\frac{1}{\nu}} \bar{V} w_{Mn}^{-1} \tilde{p}_{Fn}^{\mu\theta_M} \tilde{p}_{Mn}^{(1-\mu)\theta_M} p_{Hn}^{1-\theta_M},$$

and $\bar{B}_{Fn}$ is uniquely determined by

$$\bar{B}_{Fn} = \left(\frac{L_{Fn}}{\bar{L}} \right)^{\frac{1}{\nu}} \bar{V} w_{Fn}^{-\theta_F} \tilde{p}_{Fn}^{\mu\theta_F} \tilde{p}_{Mn}^{(1-\mu)\theta_F} p_{Rn}^{1-\theta_F}.$$

In Step 5, I calibrate the markup for urban land, λ_{Hn}. By definition,

$$\lambda_{Hn} = \frac{p_{Hn}}{c_{Rn}},$$

where c_{Rn} is the marginal cost of farmland development in 2010. p_{Hn} has been recovered in Step 1 and c_{Rn} for 2010 comes from the external data as introduced in Appendix A.4.4.

B.5 Solve the Counterfactual Equilibrium

B.5.1 Remove the Farmland Red Line Policy

I apply the hat algebra to simulate the counterfactual outcome without the Farmland Red Line Policy in 2010. By expressing the equilibrium conditions of the model in changes relative to their baseline values ($\hat{x} = \frac{x'}{x}$)

[69] At interation round t = 0, I specify $p_{Mn}^0 = 1$ for all n. Plug $\{p_{Mn}^0\}$ into (49), we solve $\tilde{p}_{Mn}^1$ that satisfy the set of equations. Next, by pluging $\tilde{p}_{Mn}^1$ into (50), we get $\{p_{Mn}^1\}$, which is an update of product prices. Iterate until $p_{Mn}^t \rightarrow p_{Mn}^{t+1}$ and $\tilde{p}_{Mn}^t \rightarrow \tilde{p}_{Mn}^{t+1}$. $\{p_{Fn}, Y_{Fn}, \tilde{p}_{Fn}\}$ are recovered in the same way. Finally, $\tilde{p}_n$ can be recovered once $\tilde{p}_{Mn}$ and $\tilde{p}_{Fn}$ are available.

and expressing $\left\{\hat{Y}_{Fn}, \hat{Y}_{Mn}, \hat{p}_{Fn}, \hat{p}_{Mn}, \hat{\tilde{p}}_n, \hat{p}_{Hn}, \hat{p}_{Rn}, \hat{R}_{Hn}, \hat{R}_{Fn}\right\}$ as functions of the rest of variables, there are 9 equilibrium conditions with 9 unknown vectors $\{\hat{L_{Mn}}, \hat{w_{Mn}}, \hat{R}_n, \hat{L_{Fn}}, \hat{w_{Fn}}, \hat{H}_n, \hat{\tilde{p}}_{Fn}, \hat{\tilde{p}}_{Mn}, \hat{\tilde{V}}\}$.

$$\left(\hat{\tilde{p}}_{Fn}\right)^{1-\sigma_F} = \sum_{n'\in N} \pi_{pFnn'} \left(\hat{w_{Fn'}}\right)^{1-\sigma_F} \left(\hat{L_{Fn'}}\right)^{(1-\gamma)(1-\sigma_F)} \left(\hat{R_{n'}}\right)^{(\gamma-1)(1-\sigma_F)}, \tag{51}$$

where $\pi_{pFnn'} = \frac{\left(T_{nn'}(\gamma A_{Fn'})^{-1} w_{Fn'} L_{Fn'}^{1-\gamma} R_{n'}^{\gamma-1}\right)^{1-\sigma_F}}{\tilde{p}_{Fn}^{1-\sigma_F}}$.

$$\left(\hat{\tilde{p}}_{Mn}\right)^{1-\sigma_M} = \sum_{n'\in N_c} \pi_{pMnn'} \left(\hat{w_{Mn'}}\right)^{1-\sigma_M} \left(\hat{L_{Mn'}}\right)^{-\alpha(1-\sigma_M)}, \tag{52}$$

where $\pi_{pMnn'} = \frac{\left(T_{nn'}\left(\bar{A}_{Mn'}\right)^{-1} w_{Mn'} L_{Mn'}^{-\alpha}\right)^{1-\sigma_M}}{\tilde{p}_{Mn}^{1-\sigma_M}}$.

$$\left(\hat{L_{Mn}}\right)^{\frac{1}{\nu}+1-\theta_M} = \left(\hat{\tilde{V}}\right)^{-1} \left(\hat{w_{Mn}}\right)^{\theta_M} \left(\hat{\tilde{p}}_{Fn}\right)^{-\mu\theta_M} \left(\hat{\tilde{p}}_{Mn}\right)^{-(1-\mu)\theta_M} \left(\hat{H}_n\right)^{1-\theta_M}. \tag{53}$$

$$\left(\hat{L_{Fn}}\right)^{\frac{1}{\nu}+1-\theta_F} = \left(\hat{\tilde{V}}\right)^{-1} \left(\hat{w_{Fn}}\right)^{\theta_F} \left(\hat{\tilde{p}}_{Fn}\right)^{-\mu\theta_F} \left(\hat{\tilde{p}}_{Mn}\right)^{-(1-\mu)\theta_F} \left(\hat{R}_n\right)^{1-\theta_F}. \tag{54}$$

$$\left(\hat{w_{Mn}}\right)^{\sigma_M} \left(\hat{L_{Mn}}\right)^{1-\alpha(\sigma_M-1)} = \sum_{j\in N_c} \pi_{M1nj} \left(\hat{\tilde{p}}_{Mj}\right)^{\sigma_M-1} \hat{w_{Mj}} \hat{L_{Mj}} + \sum_{j\in N} \pi_{M2nj} \left(\hat{\tilde{p}}_{Mj}\right)^{\sigma_M-1} \hat{w_{Fj}} \hat{L_{Fj}}, \tag{55}$$

where $\pi_{M1nj} = (1-\mu)\left(T_{nj}\right)^{1-\sigma_M} \frac{\tilde{p}_{Mj}^{\sigma_M-1} E_{Mj}}{p_{Mn}^{\sigma_M-1} E_{Mn}}$ and $\pi_{M2nj} = (1-\mu)\left(T_{nj}\right)^{1-\sigma_M} \frac{\tilde{p}_{Mj}^{\sigma_M-1} E_{Fj}}{p_{Mn}^{\sigma_M-1} E_{Mn}}$.

$$\left(\hat{w_{Fn}}\right)^{\sigma_F} \left(\hat{L_{Fn}}\right)^{\sigma_F(1-\gamma)+\gamma} \left(\hat{R}_n\right)^{-(1-\gamma)(\sigma_F-1)} = \sum_{j\in N_c} \pi_{F1nj} \left(\hat{\tilde{p}}_{Fj}\right)^{\sigma_F-1} \hat{w_{Mj}} \hat{L_{Mj}} + \sum_{j\in N} \pi_{F2nj} \left(\hat{\tilde{p}}_{Fj}\right)^{\sigma_F-1} \hat{w_{Fj}} \hat{L_{Fj}}, \tag{56}$$

where $\pi_{F1nj} = \mu\left(T_{nj}\right)^{1-\sigma_F} \left(E_{Fn}^{-1} p_{Fn}^{1-\sigma_F}\right) \tilde{p}_{Fj}^{\sigma_F-1} E_{Mj}$ and $\pi_{F2nj} = \mu\left(T_{nj}\right)^{1-\sigma_F} \left(E_{Fn}^{-1} p_{Fn}^{1-\sigma_F}\right) \tilde{p}_{Fj}^{\sigma_F-1} E_{Fj}$.

$$\begin{aligned} \hat{\tilde{V}}^{\nu} = &\sum_n \pi_{VMn} \left(\hat{w_{Mn}}^{\theta_M} \left(\hat{\tilde{p}}_{Fn}\right)^{-\mu\theta_M} \left(\hat{\tilde{p}}_{Mn}\right)^{-(1-\mu)\theta_M} \left(\hat{L_{Mn}}\right)^{\theta_M-1} \hat{H_n}^{1-\theta_M}\right)^{\nu} \\ &+ \sum_n \pi_{VFn} \left(\hat{w_{Fn}}^{\theta_F} \left(\hat{\tilde{p}}_{Fn}\right)^{-\mu\theta_F} \left(\hat{\tilde{p}}_{Mn}\right)^{-(1-\mu)\theta_F} \left(\hat{L_{Fn}}\right)^{\theta_F-1} \hat{R_n}^{1-\theta_F}\right)^{\nu}, \end{aligned} \tag{57}$$

where $\pi_{VFn} = \frac{L_{Fn}}{\bar{L}}$ and $\pi_{VMn} = \frac{L_{Mn}}{\bar{L}}$.

$$\frac{\hat{w_{Mn}} \hat{L_{Mn}}}{\hat{H}_n} = \left(\hat{\tilde{p}}_{Fn}\right)^{\mu} \left(\hat{\tilde{p}}_{Mn}\right)^{(1-\mu)} \left(\pi_{r1n} - \pi_{r2n}\hat{R}_n - \pi_{r3n}\hat{H}_n\right)^{-\zeta}, \tag{58}$$

where $\pi_{r1n} = \frac{(1-\phi_{n2})\tilde{R}_n}{(1-\phi_{n2})\tilde{R}_n - R_n - H_n}$, $\pi_{r2n} = \frac{R_n}{(1-\phi_{n2})\tilde{R}_n - R_n - H_n}$ and $\pi_{r3n} = \frac{H_n}{(1-\phi_{n2})\tilde{R}_n - R_n - H_n}$.

$$\left(\hat{\tilde{p}}_{Fn}\right)^{\mu}\left(\hat{\tilde{p}}_{Mn}\right)^{(1-\mu)}\left(\pi_{r1n} - \pi_{r2n}\hat{R_n} - \pi_{r3n}\hat{H_n}\right)^{-\zeta} = \pi_{r4n}\frac{\hat{w_{Fn}}\hat{L_{Fn}}}{\hat{R_n}}, \tag{59}$$

where $\pi_{r4n} = \frac{\frac{1-\theta_F\gamma}{\gamma}\delta w_{Fn}L_{Fn}}{\tilde{p}_{Fn}^{\mu}\tilde{p}_{Mn}^{(1-\mu)}c_n\left(1-\frac{R_n+H_n}{(1-\phi_{n2})\tilde{R}_n}\right)^{-\zeta}\tilde{R}_n + \frac{1-\theta_F\gamma}{\gamma}\frac{w_{Fn}L_{Fn}}{R_n}\delta\left(R_n-\bar{R}_n\right)}$.

In the extended model that incorporates N_r rural regions, there are 5 unknown variables $\{\hat{R_n}, \hat{L_{Fn}}, \hat{w_{Fn}}, \hat{\tilde{p}}_{Fn}, \hat{\tilde{p}}_{Mn}\}$ for each location pinned down by (51),(52),(54), (56), and the farmland supply function:

$$\left(\pi_{r6n} - \pi_{r7n}\hat{R_n}\right)^{-\zeta} - \pi_{r8n}\frac{\hat{w_{Fn}}\hat{L_{Fn}}\left(\hat{\tilde{p}}_{Fn}\right)^{-\mu}\left(\hat{\tilde{p}}_{Mn}\right)^{\mu-1}}{\hat{R_n}} = 0, \tag{60}$$

where $\pi_{r6n} = \frac{(1-\phi_n)\tilde{R}_n}{(1-\phi_n)\tilde{R}_n - R_n}$, $\pi_{r7n} = \frac{R_n}{(1-\phi_n)\tilde{R}_n - R_n}$, and $\pi_{r8n} = \frac{\frac{1-\theta_F\gamma}{\gamma}\delta w_{Fn}L_{Fn}}{\delta p_{Rn}\left(R_n-\bar{R}_n\right)+\tilde{p}_{Fn}^{\mu}\tilde{p}_{Mn}^{(1-\mu)}c_n\left(1-\frac{R_n}{(1-\phi_n)\tilde{R}_n}\right)^{-\zeta}\tilde{R}_n}$.

Next, I outline the iterative algorithm used to solve for the equilibrium of the model.

1. Guess the initial values of $[\hat{\tilde{p}}_{Fn}, \hat{\tilde{p}}_{Mn}, \hat{L_{Mn}}, \hat{w_{Mn}}, \hat{L_{Fn}}, \hat{w_{Fn}}]^0$.

2. At given values of $[\hat{\tilde{p}}_{Fn}, \hat{\tilde{p}}_{Mn}, \hat{L_{Mn}}, \hat{w_{Mn}}, \hat{L_{Fn}}, \hat{w_{Fn}}]$, use (58) and (59) (and (60) in the extended model) to solve for the unique solution of $[\hat{R_n}, \hat{H_n}]^*$.

3. Given $[\hat{R_n}, \hat{H_n}]^*$, search for $[\hat{\tilde{p}}_{Mn}, \hat{\tilde{p}}_{Fn}, \hat{L_{Mn}}, \hat{w_{Mn}}, \hat{L_{Fn}}, \hat{w_{Fn}}, \hat{\bar{V}}]^*$ that satisfy the rest of equilibrium conditions.

4. Stop iteration if

   $||[\hat{\tilde{p}}_{Mn}, \hat{\tilde{p}}_{Fn}, \hat{L_{Mn}}, \hat{w_{Mn}}, \hat{L_{Fn}}, \hat{w_{Fn}}, \hat{H_n}, \hat{R_n}]^{t+1} - [\hat{\tilde{p}}_{Mn}, \hat{\tilde{p}}_{Fn}, \hat{L_{Mn}}, \hat{w_{Mn}}, \hat{L_{Fn}}, \hat{w_{Fn}}, \hat{H_n}, \hat{R_n}]^{t}|| < \epsilon_{tol}$.

   Otherwise, set $[\hat{\tilde{p}}_{Mn}, \hat{\tilde{p}}_{Fn}, \hat{L_{Mn}}, \hat{w_{Mn}}, \hat{L_{Fn}}, \hat{w_{Fn}}]^{t+1} = \epsilon_{iter}[\hat{\tilde{p}}_{Mn}, \hat{\tilde{p}}_{Fn}, \hat{L_{Mn}}, \hat{w_{Mn}}, \hat{L_{Fn}}, \hat{w_{Fn}}]^{t} + (1-\epsilon_{iter})[\hat{\tilde{p}}_{Mn}, \hat{\tilde{p}}_{Fn}, \hat{L_{Mn}}, \hat{w_{Mn}}, \hat{L_{Fn}}, \hat{w_{Fn}}]^{*}$ for some $\epsilon_{iter} \in (0,1)$ and go back to step 2.

Note that the equilibrium system is only defined to scale (it is homogenous of degree zero), I normalize the geometric mean of change in CPI to one.

B.5.2 Adding a Trading Platform to the Economy

Having the trading platform introduces one more equilibrium condition and the system cannot be directly solved using hat algebra. Therefore, I simulate the counterfactual outcome by using the equilibrium conditions of the new setting directly. After expressing $[p_{Fn}, p_{Mn}, \tilde{p}_n, p_{Hn}, p_{Rn}, R_{Hn}, R_{Fn}]$ as functions of the other variables, there are 10 equilibrium conditions with 10 vectors: $[\bar{V}, \tilde{p}_{Fn}, \tilde{p}_{Mn}, L_{Mn}, L_{Fn}, w_{Mn}, w_{Fn}, H_n, R_n, c_F]$. I denote the upper bound of c_F as $c_{F,u}$ and set it to be the maximum of $c_{Rn} - p_{Rn}$ in the data. Correspondingly, the lower bound of c_F is denoted as $c_{F,l}$ and set to be the minimum of $c_{Rn} - p_{Rn}$ in the data. I outline the steps to search for the solution below.

1. Start with an initial guess of c_F between $c_{F,u}$ and $c_{F,l}$.

2. At given c_F, search for $[\bar{V}, \tilde{p}_{Fn}, \tilde{p}_{Mn}, L_{Mn}, L_{Fn}, w_{Mn}, w_{Fn}, H_n, R_n]^*$ that meet all the equilibrium conditions except (24).

   (a) Start with an initial guess of $[\tilde{p}_{Fn}, \tilde{p}_{Mn}, L_{Mn}, L_{Fn}, w_{Mn}, w_{Fn}]$.

   (b) At given $[\tilde{p}_{Fn}, \tilde{p}_{Mn}, L_{Mn}, L_{Fn}, w_{Mn}, w_{Fn}]$, solve for the unique $[R_n, H_n]^{**}$ using (21) and (23).

   (c) At given $[R_n, H_n]^{**}$, update $[\tilde{p}_{Fn}, \tilde{p}_{Mn}, L_{Mn}, L_{Fn}, w_{Mn}, w_{Fn}]$ using (25), (3), (5), (10) and (11).

   (d) Given $[\tilde{p}_{Fn}, \tilde{p}_{Mn}, L_{Mn}, L_{Fn}, w_{Mn}, w_{Fn}]^{**}$, update $\bar{V}$ using (4).

   (e) If $||[\bar{V}, \tilde{p}_{Fn}, \tilde{p}_{Mn}, L_{Mn}, L_{Fn}, w_{Mn}, w_{Fn}, H_n, R_n]^{**} - [\bar{V}, \tilde{p}_{Fn}, \tilde{p}_{Mn}, L_{Mn}, L_{Fn}, w_{Mn}, w_{Fn}, H_n, R_n]^t|| < \epsilon_{tol2}$, set $[R_n]^* = [R_n]^{**}$ and stop iteration. Otherwise, set $[\bar{V}, \tilde{p}_{Fn}, \tilde{p}_{Mn}, L_{Mn}, L_{Fn}, w_{Mn}, w_{Fn}]^{t+1} = [\bar{V}, \tilde{p}_{Fn}, \tilde{p}_{Mn}, L_{Mn}, L_{Fn}, w_{Mn}, w_{Fn}]^*$ and go back to step b.

3. Stop iteration if $|| \sum_n R_n^* - \sum_n \bar{R}_n|| < \epsilon_{tol}$. Otherwise, update $[c_{F,l}, c_{F,u}, c_F]^{t+1}$ through the following algorithm and go back to Step 2.

   (a) If $\sum_n R_n \leq \bar{R} - \epsilon_{tol}$, update $c_{F,l}^{t+1} = c_F^t$, $c_{F,u}^{t+1} = c_{Fu}^t$ and $c_F^{t+1} = \frac{1}{2}\left(c_{F,u}^t + c_F^t\right)$.

   (b) If $\sum_n R_n \geq \bar{R} + \epsilon_{tol}$, update $c_{F,l}^{t+1} = c_{F,l}^t$, $c_{F,u}^{t+1} = c_F^t$ and $c_F^{t+1} = \frac{1}{2}\left(c_F^t + c_{F,l}^t\right)$.

B.5.3 Add a Trading Platform with Price Differentiation Feature

To model the cap-and-trade platform with a price differentiation feature, I denote κ_n as the price premium faced by location n. κ_n follows the specification announced in Notice of the General Office of the State Council [2018] No.16. As before, the landlords receive additional payoff c_F from the trading platform for each unit of farmland above the minimum quantity $\bar{R}_n$. What is different is that, if the landlord develops less farmland than the minimum quantity of $\bar{R}_n$, she pays the platform $\kappa_n c_F$ for each unit of shortage. The price differentiation feature indicates that there is a positive profit left on the platform as long as at least one location facing $\kappa_n > 1$ buys farmland. I assume that the profit from the cap-and-trade platform is uniformly re-distributed between landlords, such that it does not affect the land development decision at the margin.

In this alternative equilibrium, a location is in one of the following three cases. The first case is that the quantity of farmland is below the minimum quantity and she pays $\kappa_n c_F$ for each unit of farmland developed by another location:

$$c_{Rn} = p_{Rn} + \kappa_n c_F. \tag{61}$$

The second case is that she creates more than the required minimum amount of farmland and receives c_F for each extra unit of farmland:

$$c_{Rn} = p_{Rn} + c_F. \tag{62}$$

The last case is that it is not profitable either to create extra farmland or to reduce farmland to below the minimum quantity. In this case, the landlord just creates the minimum amount of farmland as required, and the following condition holds:

$$p_{Rn} + \kappa_n c_F > c_{Rn} > p_{Rn} + c_F. \tag{63}$$

c_F makes the total amount of farmland across locations equal the targeted minimum amount of farmland at the national level, and therefore (24) holds. Next, there is payment between landlords and I denote the payment to location n as E_{Rn}:

$$E_{Rn} = \left(R_n - \bar{R}_n\right)\left((\kappa_n - 1)1_{R_n < \bar{R}_n} + 1\right)c_F + e_R, \tag{64}$$

where e_R is the uniform redistribution of profit from the trading platform.

The algorithm to solve the new equilibrium is similar to the one when all the locations pay the same price. The only difference is at Step 2 (b). The farmland supply function depends on whether a location is selling, buying or neither buying or selling. I calculate both the farmland quantity if the location buy farmland hence use (61) to choose the farmland supply and the farmland quantity if the location sell farmland hence use (62) to choose the farmland supply. If farmland quantity in the first case is lower than the minimum level, the location buy on the platform. If farmland quantity in the second case is greater than the minimum level, the location sell on the platform. If none is the case, this location chooses the amount of farmland right at the minimum level. The amount of urban land can be derived once the farmland quantity is solved.

B.6 Model Extension: Landlord as a Monopoly in the Urban Land Market

In this model extension, I assume that the representative landlord in a location is a monopoly in the local urban land market. When making the urban land development decision, she takes into account that a lower urban land price would attract more workers to come to the local urban sector. This is to approximate the reality that the local government - the decision-maker of urban land development - would like to keep the urban land price low to attract firms to open new business (Yang et al., 2015). I assume that the representative landlord takes the farmland price as given, as in the baseline model.

For the representative landlord in location n, the demand for urban land is $p_{Hn}H_n = w_{Mn}L_{Mn}$. The landlord takes into account that the number of urban workers in a location, L_{Mn}, is endogenous to p_{Hn}. Specifically, from (5), $L_{Mn} = \bar{L}\bar{V}^{-\nu}\left(w_{Mn}\tilde{p}_n^{-\theta}\bar{B}_{Mn}\right)^{\nu}p_{Hn}^{-(1-\theta)\nu}$. Therefore, the demand for urban land becomes

$$p_{Hn}H_n^{\frac{1}{1+(1-\theta)\nu}} = k_n, \tag{65}$$

where $k_n \equiv \left(\bar{L}\bar{V}^{-\nu}\tilde{p}_n^{-\theta\nu}\bar{B}_{Mn}^{\nu}w_{Mn}^{1+\nu}\right)^{\frac{1}{1+(1-\theta)\nu}}$. k_n is assumed to be exogenous to the representative landlord, because all the components either depend on exogenous local fundamentals or the economic conditions of other locations in the economy.[70]

Without the Farmland Red Line Policy, the landlord's problem is to choose H_n and R_n to maximize the total land profit Π_n:

$$\Pi_n = p_{Hn}H_n + p_{Rn}R_n - \int_0^{H_n+R_n} \tilde{p}_n f(\psi_n)\left(1 - \frac{x}{(1-\phi_n)\tilde{R}_n}\right)^{-\zeta} dx, \tag{66}$$

[70] (65) is derived by plugging the supply function of the manufacturing labor into the urban land demand function.

subject to the urban land demand function (65) and the exogenous value of farmland price p_{Rn}. The first order conditions lead to the following urban land and farmland supply decisions:

$$p_{Hn} = \frac{1 + (1-\theta)\,\nu}{(1-\theta)\,\nu}\tilde{p}_n f(\psi_n)\left(1 - \frac{H_n + R_n}{(1-\phi_n)\tilde{R}_n}\right)^{-\zeta}, \tag{67}$$

and

$$p_{Rn} = \tilde{p}_n f(\psi_n)\left(1 - \frac{H_n + R_n}{(1-\phi_n)\tilde{R}_n}\right)^{-\zeta}. \tag{68}$$

Therefore, to model the landlord in location n as a monopolist is equivalent to assuming that in the extended model discussed in Section 5.3, $\lambda_{Hn} = \frac{1+(1-\theta)\nu}{(1-\theta)\nu}\bar{\lambda}_{Hn}$, where $\bar{\lambda}_{Hn}$ represents the price distortion due to other land-use regulations.

B.7 Model Extension: Redistribute Land Development Profit between Workers

In this model extension, I assume a national portfolio that aggregates the land rents of the whole economy. The profit in the national portfolio is re-distributed equally among workers. This is an alternative way of incorporating the general equilibrium effects of the land profit without introducing heterogeneous wealth effects or inefficiencies due to the externalities in the labor migration (Redding and Rossi-Hansberg, 2017).

With this alternative assumption, the labor income now becomes

$$\tilde{w}_{sn} = w_{sn} + \pi_r, \tag{69}$$

where π_r is the transfer from the national portfolio. π_r satisfies the following relation:

$$\pi_r \bar{L} = \sum_n \left(p_{Rn}R_n + p_{Hn}H_n - CC_n\right), \tag{70}$$

and CC_n represents the total land development cost in location n:

$$CC_n = \int_0^{R_n+H_n} \tilde{p}_n c_n \left(1 - \frac{x}{(1-\phi_n)\,\tilde{R}_n}\right)^{-\zeta} dx. \tag{71}$$

The labor supply function becomes

$$L_{sn} = \bar{L}\bar{V}^{-\nu}\left(\tilde{w}_{sn}\tilde{p}_n^{-\theta}p_{H,sn}^{\theta-1}\bar{B}_{sn}\right)^{\nu}, \tag{72}$$

and the expected utility of a representative worker now is

$$\bar{V} = \left(\sum_{s'\in\{F,M\}}\sum_{n'\in N}\left(\tilde{w}_{s'n'}\tilde{p}_{n'}^{-\theta}p_{H,s'n'}^{\theta-1}\bar{B}_{sn}\right)^{\nu}\right)^{\frac{1}{\nu}}. \tag{73}$$

The aggregate demand for urban land in location n is

$$(1-\theta)\tilde{w}_{Mn}L_{Mn} = p_{Hn}H_n. \tag{74}$$

The aggregate demand for farmland used for residential purpose in location n is

$$(1-\theta)\tilde{w}_{Fn}L_{Fn} = p_{Rn}R_{Hn}. \tag{75}$$

Last, the tradable goods market clearing condition becomes

$$\frac{p_{Fn}Y_{Fn}}{\mu} = \theta\sum_{j\in N}\frac{(T_{jn})^{1-\sigma_F}}{\tilde{p}_{Fj}^{1-\sigma_F}}\tilde{w}_{Mj}L_{Mj} + \theta\sum_{j\in N}\frac{(T_{jn})^{1-\sigma_F}}{\tilde{p}_{Fj}^{1-\sigma_F}}\tilde{w}_{Fj}L_{Fj} + \sum_{j\in N}\frac{(T_{jn})^{1-\sigma_F}}{\tilde{p}_{Fj}^{1-\sigma_F}}CC_j, \tag{76}$$

$$\frac{p_{Mn}Y_{Mn}}{1-\mu} = \theta\sum_{j\in N}\frac{(T_{jn})^{1-\sigma_M}}{\tilde{p}_{Mj}^{1-\sigma_M}}\tilde{w}_{Mj}L_{Mj} + \theta\sum_{j\in N}\frac{(T_{jn})^{1-\sigma_M}}{\tilde{p}_{Mj}^{1-\sigma_M}}\tilde{w}_{Fj}L_{Fj} + \sum_{j\in N}\frac{(T_{jn})^{1-\sigma_M}}{\tilde{p}_{Mj}^{1-\sigma_M}}CC_j. \tag{77}$$

I take this alternative model to data and simulate the counterfactual equilibrium without the Farmland Red Line Policy. The quantitative results are shown in Appendix Table A.15.