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The effect of land use regulations on farmland protection and non-agricultural land conversions in China*

Man Li[†]

This paper examines the effect of the Prime Farmland Protection Regulation in protecting high quality farmland from urban development and the subsequent effect on non-farmland conversion in China in the first decade after the Regulation came into effect (1995-2005). The empirical evaluation is conducted with geo-referenced panel data for the entire country. Results indicate that the rate of farmland conversion was reduced during 1995-2000. About two-fifths of the reduction results from the protection of farmland with high grain productivity. There is no evidence of the effectiveness of the Regulation in protecting farmland during the period 2000–2005, regardless of land quantity or quality. Farmland development was accompanied by a reduction in forests and grasslands during the period from 1995 through to 2005.

Key words: China, farmland protection, land use conversion, urban development.

JEL classifications: Q24, R52

1. Introduction

Farmland protection is among the top priorities for the Chinese government. Food security and food staples self-sufficiency enhance national security and the social stability of the country. Rapid urbanisation that accompanies China's remarkable economic growth has created intense competition for agricultural land in both urban fringe and rural areas. Two and a half decades have passed since China first enacted legislation to protect farmland from conversion to non-agricultural used, especially high quality cultivated land. Yet hundreds of thousands of hectares of agricultural land are still converted to urban uses each year, raising the question of whether the legislation is effective in preserving farmland. Addressing the issue has important implications for formulating relevant policy recommendations regarding the trade-off between urban growth and farmland retention. This paper provides empirical insights into this question by focusing on the Prime Farmland Protection Regulation.

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[†] Man Li (e-mail: manlichn@gmail.com) is Assistant Professor at the Department of Applied Economics, Utah State University, Logan, Utah, USA .

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The Prime Farmland Protection Regulation (hereafter the Regulation), passed in 1994 and amended in 1999, is one of the most stringent policies on farmland conversion in China. As stipulated in the Regulation, every province sets up ordinance that requires local governments at the county level or higher to designate a *prime farmland protection zone* in every village or township (see Table S1). Conversion of prime farmland to non-agricultural uses is prohibited. When a conversion is unavoidable, it must be approved by the central or the provincial governments and the loss of farmland must be offset by the same amount of newly converted farmland (from non-agricultural uses) of the same quality somewhere else in the same county (State Council 1994).[1] The offset was later named *no net loss* and was reinforced in the amendments to Land Administration Law in 1999 (Standing Committee 1999). The Regulation applies to land planted to food grains, cotton, oilseeds, and vegetables; to land with good irrigation, drainage, and erosion control; and to experimental plots for agricultural research and development. In practice, governments use three indicators to monitor the implementation of these policies: the acreage of total farmland (including prime farmland and non-prime farmland); the area of prime farmland; and the ratio of the second indicator to the first indicator. The amendments to Land Administration Law requires that prime farmland cover at least 80 per cent of total farmland in each provincial level administrative district.

While the purpose of the Regulation is clear, the effects of the policy are ambiguous. The reasons are at least twofold. First, a prime farmland protection zone is not a geographic entity but rather a virtual space of planning concept aiming at the mandatory protection of high quality farmlands (Xia *et al*. 2016). Consequently, boundaries of protection zones have never been revealed. Under such circumstances, county government officials are more likely to target the quantity than the quality of the land to which they apply the Regulation. Second, in the process of economic liberalisation to achieve higher economic growth rates, China implemented several fiscal and governance reforms. There reforms force local officials to take on the role of land developer (Lichtenberg and Ding 2009), which conflicts with their responsibility under the Regulation.

In this paper, a modelling framework is developed which is based on a comprehensive nationwide geo-referenced database. It is used to empirically examine the effect of the Regulation on protecting farmland from urban development and the subsequent effect on forests and grassland conversions in the first decade after the Regulation came into effect (1995-2005). The model is built on the classic monocentric city model (Alonso 1964; Mills 1967;

[1] If it is infeasible to offset, the new land user must pay a fee to cover the cost of reclaiming the same amount of new farmland.

Muth 1969) and spatial urban growth model (Capozza and Helsley 1989) and is modified to accommodate farmland protection policy intervention. The database contains accurate measurement of land use change in each 1 km grid-cell over three land use transition periods (1988-1995, 1995-2000, and 2000-2005). The land use data was merged with a set of detailed land quality indicators most relevant to the criteria targeted by the Regulation and with extensive economic data which capture the revenue and opportunity cost of farmland conversion.

This paper makes two contributions to the literature. First, the structure of the long-term land use data provides an opportunity to assess the effects of China's farmland protection policy. The preferred specification includes quasi-township fixed effects and county-by-period fixed effects in the quasi-township-level models for the rate of farmland conversion. Consequently, the estimated regulation effects are purged of all permanent township characteristics that determine farmland conversion and all transitory differences in the mean conversion rate of townships across counties. These controls are important for two reasons. First, China's land use and land use change are characterised by significant spatial heterogeneity; second, the first post-Regulation decade was a period of dramatic change in economic growth and urban development, including housing monetisation reform and substantial investment in road construction. While an extensive literature has been dedicated to public policies for managing urban growth and protecting agricultural land (see Bengston *et al.* (2004) for a systematic review), only a limited number of empirical studies examined the effectiveness of those policies (Howe 1994; Pfeffer and Lapping 1994; Daniels 1998; Kline and Alig 1999; Wu and Cho 2007). Most of the studies have a narrow focus, targeting a specific program in a specific area. The lack of the counterfactual poses a significant challenge to isolating the effects of a specific program. Further, the changing social context complicates evaluation.

A second contribution is this paper combines location-specific land quality indicators with multiple land use conversion periods to measure the effects of the Regulation. The detailed land quality indicators allow for an examination of these Regulation effects across a number of criteria, such as land productivity and irrigation condition. It therefore overcomes a major obstacle—the lack of data useful for identifying the prime farmland protection zones (which do not actually exist). In the existing literature, several studies have documented the issue (Yang and Li 2000; Ding 2003; Lichtenberg and Ding 2008). Building on their work, the present paper systematically evaluates the effect of China's farmland protection policies using national-scale empirical data. Urban development is arguably the most pervasive socio-economic force affecting national food security in China, which in turn induced the conversion of non-agricultural lands, especially natural forests and grasslands, for agriculture in frontier areas. This conversion has caused growing environmental and ecological problems (Li *et al*. 2016). Solving these issues requires a renewed perspective on the effects of farmland protection policies.

The remainder of this paper is organised as follows: Section 2 presents the theoretical framework to evaluate the effect of farmland protection policy. Section 3 describes the data and empirical methods. Section 4 discusses the results. Section 5 interprets the magnitude of the Regulation's effect and discusses the policy implication. Section 6 concludes this paper.

2. Modelling urban development and land protection in China

When adapting the urban spatial model to a developing country such as China, it is important to consider how land institutions work.[2] Land tenure in China is regulated by the Constitution, making the state the sole owner of urban lands and villagers the joint owners of rural lands. Land conversion from rural to urban use is possible only when local governments (county level or higher) requisition land for development and other special uses by compensating villagers based on the land's agricultural productivity. Previous studies demonstrated that urban spatial expansions in China have become more responsive to economic incentives, even though the allocation of land between urban and rural uses is determined primarily by administrative forces (Deng *et al*. 2008; Lichtenberg and Ding 2009).

2.1 *Theoretic model*

Consider how a local social planner makes decisions to convert land from agricultural to urban use. Without the Regulation, a parcel will be developed if:

$$\pi(q, w) > 0 \tag{1}$$

where $\pi(\cdot)$ is the net returns of the parcel to urban development, derived by subtracting the opportunity costs of land conversion from its potential urban rent; q represents a set of land quality variables, selected based on the criteria of designation of prime farmland such as land productivity of targeting crops and irrigation condition; w consists of the average urban household income, the distance from central business district (CBD) and land agricultural rent. The classic urban spatial model suggests that the bid rent for urban land increases with urban household income and decreases with the distance from CBD; the coincidence of bid rent and agricultural rent at equilibrium implicitly defines the boundary of urban area (Alonso 1964; Mills 1967; Muth 1969; Capozza and Helsley 1989).

[2] China has five levels of government: central, provincial, prefectural, county, and township. Township officials rank lowest in China's government hierarchy; they have little power to make land use conversion decisions. Village is an informal subdivision under township, serving as a basic organisational unit for rural population.

In practice, π is difficult to observe. Instead, it is often the status of farmland development or more precisely, the acreage of farmland conversion that can be observed. Let y represents the percentage of farmland converted to urban use; y is non-negative as urban development is typically irreversible. Before the Regulation came into effect, the probability of $y > 0$ equals the probability of $\pi > 0$ and the expected value of y can be written as:

$$E_0(y|q,w) = \Pr(\pi > 0|q,w) \cdot E(y|q,w;y > 0) \tag{2}$$

where the subscript 0 represents the period without the intervention of the Regulation, namely the pre-regulation period. Equation (2) serves as a counterfactual model when the Regulation takes effect.

The ideal situation to evaluate the policy involves a treatment group of prime farmland and a control group in which farmland conversion is not subject to the Regulation. In the absence of data useful for identifying the prime farmland, an alternative strategy is to introduce a latent variable s indicating whether a parcel is the prime farmland. Let $f(q,w)$ represent the probability of $s = 1$ and let $f_q(\cdot)$ be the partial derivative of $f(\cdot)$ with respect to q; $f_q(\cdot) > 0$. The underlying rationale for introducing $f(\cdot)$ is, if the Regulation was in effect, land parcels with higher agricultural productivity would be more likely to be classified into prime farmland and we would expect a positive $f_q(\cdot)$. Otherwise, the policy would fail in the end. Unlike q, it is not conceptually clear whether and how w influences $f(\cdot)$; I will speculate this effect from empirical evidence.

Under the Regulation, a parcel will be developed if:

$$\pi(q,w) > 0 \text{ and } s = 0 \tag{3}$$

Accordingly, $y > 0$ with probability $[1 - f(q,w)]\Pr(\pi > 0)$ and $y = 0$ with probability $\Pr(\pi < 0) + f(q,w)\Pr(\pi > 0)$. This distribution manifests the reduced farmland conversion area arising from the Prime Farmland Protection Regulation—a splitting mechanism for excess zeros in y. One can derive the expectation of y from its probability density distribution:

$$E_1(y|q,w) = [1 - f(q,w)] \cdot \Pr(\pi > 0|q,w) \cdot E(y|q,w,y > 0) \tag{4}$$

where the subscript 1 represents the post-regulation period. Equation (4) serves as a theoretical framework of land development when the Regulation takes effect. It competes with expression (2) in the evaluation of the policy.

2.2 Evaluate the effectiveness of the policy

In theory, one can test the effectiveness of the Regulation using two necessary conditions. First, expression (2) is rejected in favour of expression (4) under the Regulation, that is, $f(q,w) > 0$. Second, land parcels with higher land quality are more likely classified into prime farmland, that is, $f_q(\cdot) > 0$. The two conditions yield the following results.

Proposition. The Prime Farmland Protection Regulation is effective only if:

$$E_1(y|q,w) - E_0(y|q,w) < 0 \tag{5}$$

and:

$$\frac{\partial \ln E_1(y|q,w)}{\partial q} - \frac{\partial \ln E_0(y|q,w)}{\partial q} < 0 \tag{6}$$

The proof for this Proposition follows simply from deriving $f(q,w)$ from Equations (2) and (4) and then taking derivative with respect to q (see Appendix S1).

Intuitively, all else being equal, we expect to observe more land parcels retaining agricultural use under the Regulation, which yields the condition expressed in Equation (5). By reserving some farmland, the Regulation reduces the total area of land available for development and therefore *lowers* the marginal effects of all variables including land quality on the percentage of farmland conversion in any given area. On the other hand, lands with higher quality are more likely to be protected, which tends to *enlarge* the negative effect of land quality on the percentage of farmland conversion. Under these two opposite influences on the effect of land quality, we expect that the condition expressed in Equation (6) holds.

The effect of the Regulation on farmland protection can be assessed from two aspects: quantitatively, total farmland conversion declines; qualitatively, the higher productivity farmland is developed less or more slowly. These two principles correspond to the theoretical conditions expressed in equations (5) and (6). We address the first principle through summarising farmland conversions and the associated land characteristics. To address the overall change in farmland quality, we must rely on statistical models to establish a link between the rate of farmland conversion and land quality.

3. Data and methods

One of the strengths of this study is that it brings together a variety of comprehensive data files for analysis. The data files include the 1×1 km high quality land use data that is used to identify urban core and to calculate the quantity of farmland converted to urban use over time; the location-specific land productivities of grain and oil-crops as the important crops targeted by the Regulation; the extensive long time-series, county-level socio-economic data used to measure urban rent; and the opportunity costs of farmland conversion. Interested readers can find further information about the data in Appendix S2.

3.1 Is total conversion of farmland reduced after the regulation came into effect?

Table 1 reports summary information on farmland characteristics by the type of land use change, including farmland converted to urban (column 1), farmland not changed (column 2), and new farmland created (column 3). The three panels correspond to the three land use conversion periods, respectively.

The statistics can be summarised into four points. First, at the national level, farmland development slowed down in the first 5 year period after the Regulation came into effect but increased in the second 5 year period. Approximately 0.60 million ha of farmland were converted to urban use from 1988 to 1995. The area of farmland development decreased by half during 1995-2000 and increased to 1.89 million ha during 2000-2005, triple the amount converted to urban land in the pre-regulation period. Spatially,

Table 1 Means of farmland characteristics by land use change status

	Developed (1)	Unchanged (2)	New farmland (3)
1988-1995			
Total area (million ha)	0.60	165.80	9.10
Grain productivity (tonne/ha)	5.05	6.08	4.33
Oil-crops productivity (tonne/ha)	1.20	1.55	0.99
Distance from urban boundary (km)	3.25	17.38	20.44
Distance from cities (km)	33.20	81.90	100.70
Per ha urban GDP (million ¥/ha)	0.81	0.70	0.49
Per ha agricultural revenue (thousand ¥/ha)	3.90	1.95	1.34
Government revenue (thousand ¥)	35.70	7.40	5.60
No. of 1-km land grid cells	43,180	3,592,584	1,795,254
1995-2000			
Total area (million ha)	0.32	167.60	11.60
Grain productivity (tonne/ha)	5.13	6.05	4.81
Oil-crops productivity (tonne/ha)	1.37	1.54	1.20
Distance from urban boundary (km)	3.69	16.85	19.24
Distance from cities (km)	50.20	82.20	123.50
Per ha urban GDP (million ¥/ha)	1.53	1.36	1.09
Per ha agricultural revenue (thousand ¥/ha)	3.08	1.92	1.65
Government revenue (thousand ¥)	27.30	10.80	8.60
No. of 1-km land grid cells	33,035	3,559,548	1,116,134
2000-2005			
Total area (million ha)	1.89	169.00	10.20
Grain productivity (tonne/ha)	6.64	6.07	4.01
Oil-crops productivity (tonne/ha)	1.49	1.54	0.92
Distance from urban boundary (km)	8.25	16.61	20.05
Distance from cities (km)	43.00	84.00	131.30
Per ha urban GDP (million ¥/ha)	2.04	1.86	1.45
Per ha agricultural revenue (thousand ¥/ha)	7.30	1.82	1.45
Government revenue (thousand ¥)	51.30	15.40	13.40
No. of 1-km land grid cells	382,524	3,635,669	1,774,536

Note: Total area is reported at the national level; other variables are weighted arithmetic means across land grid cells in each group of land use change status by period and the weight is the percentage of grid-cell that was developed/unchanged/new farmland in the initial year of each conversion period.

farmland development began with the North China Plain, the Pearl River Delta, and the Yangtze River Delta, centred around Beijing, Guangzhou, and Shanghai—three metropoles of China—respectively. By 2005, the conversion had expanded to the Northeast China Plain, the Jianghan Plain in Central China, and the Sichuan Basin in Southwest China (see Figures S1–S3 in Appendix S4). Along with the spatial expansion, the number of counties developing farmland increased from 1,604 (out of 2,418 counties in total) in the pre-regulation period to 1,689 in the first post-regulation period and to 2,067 in the second post-regulation period.

Second, despite the loss of traditional farmland due to urbanisation during the entire study period, the total acreage of farmland increased from 176.5 million ha in 1988 to 179.2 million ha in 2005. The increase was largely due to the conversion of grasslands (primarily in Northwest China) and woody areas (primarily in Northeast China) to crop production (Li *et al.* 2016). Out of 2,418 counties in the sample, 1,386 counties had met the no net-loss necessity required by the Regulation during 1995-2000. But the number of 'no net-loss' counties declined to 943 in the period 2000-2005.

Third, land quality, location, and the economic characteristics associated with farmland conversion differ with the type of land use change. Among the three types, land parcels converted to urban use are closest to urban boundary and cities; these parcels are typically located in counties with the highest government budgetary revenue and hectare-based urban GDP and agricultural revenue. In contrast, the newly created farmland is more likely from remote areas with the lowest government revenue and per ha urban GDP and agricultural revenue; these parcels have the lowest productivity of grain and oil crops. These heterogeneous patterns remain unchanged over time.

Fourth, more land parcels with better quality were gradually converted to urban use. For example, during 1988-1995, the average grain productivity of parcels under development was 5.05 t/ha (metric tonnes per ha) which was slightly lower than the productivity of undeveloped parcels during the same period. The value increased to 6.64 t/ha during 2000-2005, highest among all three land-use change types.

In summary, farmland conversion to urban use was moderated in terms of both the conversion rate and the spatial extent in the first post-regulation period, but it was not the case in the second 5 year period. The loss of farmland was typically offset by new farmland with lower land productivity in remote areas. Yet one cannot reach a conclusion of whether better farmland was developed less, which must be addressed by using statistical models to establish a link between farmland development and land quality and to purge likely sources of bias.

3.2 Empirical strategy

To empirically explore whether better farmland was developed less, time-series, cross-sectional data was fitted to the following equation:

$$\sinh^{-1} y_{it} = \boldsymbol{q}_{it}\boldsymbol{\beta}_t + \varepsilon_{it} \tag{7}$$

where $\varepsilon_{it} = \alpha_i + \theta_{ct} + u_{it}$, representing the stochastic error term, and $\boldsymbol{q}_{it}$ represents a vector of land quality variables. The term y_{it} represents the percentage points of farmland converted to urban use (i.e. the rate of farmland conversion) in polygon i over period t. Here polygon is a proxy measure of township (details on the how the polygons are delineated can be found in Appendix S2).[3] The subscript $t = 0$ represents the pre-regulation period, that is, 1988-1995; $t = 1, 2$ represents the post-regulation periods, that is, 1995-2000 and 2000-2005, respectively. To correct the skewed distributions of y_{it}, I adopt the inverse hyperbolic sine transformation, where the estimated coefficients can be interpreted in the same way as with a log-transformed dependent variable. Such a transformation gives results identical to using the logarithm for non-zero observations while also being able to handle the zeroes with no crude transformation of the data (Gibson *et al.* 2017).

Of primary interest is the vector of land quality variables $\boldsymbol{q}_{it}$ whose effects vary by period; $\boldsymbol{q}_{it}$ = (land productivity of grain, land productivity of oil crops, irrigation percentage), evaluated at the initial year of period t. These variables are most relevant to the standards designated by the Regulation. A comparison of the parameter $\boldsymbol{\beta}_t$ between different periods reflects the extent to which the Regulation affected farmland conversion. Specifically, $(\boldsymbol{\beta}_1 - \boldsymbol{\beta}_0)$ captures the effects of the Regulation 1994 and $(\boldsymbol{\beta}_2 - \boldsymbol{\beta}_0)$ captures the accumulated effects of the Regulation 1994 and the Amendments 1999. These Amendments tightened the standards for prime farmland conversion and reinforced the implementation of *no net-loss* strategy to offset the loss of farmland. A negative value of the difference (i.e. $\boldsymbol{\beta}_t - \boldsymbol{\beta}_0, \forall\, t = 1, 2$) indicates that the Regulation can help reduce the rate of farmland conversion.

One might expect that farmland conversion rate and its dependence on land quality would have changed over time for reasons unrelated to the implementation of the Regulation, given China's dramatic economic growth since 1995. As such, we cannot simply attribute to the Regulation the difference in conversion rates and the parameter $\boldsymbol{\beta}_t$ between the pre-regulation and post-regulation periods. Since those confounding factors are most likely socio-economic shocks typically measured at the county level or higher, there are several ways to model them with the available data. One possibility is to include a full set of county-by-period indictors, θ_{ct} (as specified in ε_{it}) where the subscript c references county, to non-parametrically control for time-varying shocks common to conversion of farmland with various quality level within the same county. Such a control is essential to infer causality from the

[3] County is not used as the analysis unit for two reasons. First, a county can have multiple urban cores. This is especially the case in metropolitan areas. As a result, land development in a county is likely to surround multiple urban centres. Second, county, as an analysis unit, is too large to capture the heterogeneous characteristics of land quality, a key variable to an analysis.

analysis. In addition to θ_{ct}, the error term contains polygon fixed effects α_i. Including a full set of fixed effects in the sample greatly reduces the degrees of freedom, but it absorbs polygon-specific, time-invariant unobserved factors such as terrain characteristics that affects permanent conversion rates and might be correlated with land quality.

Another possibility to control for transitory determinants of farmland conversion that are unrelated to the adoption of the Regulation is to include a set of county-level economic variables $\boldsymbol{w}_{ct}$ and allow their effects to vary over time:

$$\sinh^{-1} y_{it} = \boldsymbol{q}_{it}\boldsymbol{\beta}_t + \boldsymbol{w}_{ct}\boldsymbol{\gamma}_t + \xi_{it} \tag{8}$$

where $\xi_{it} = \alpha_i + \eta_{pt} + v_{it}$; the subscript p indexes provinces. The vector $\boldsymbol{w}_{ct}$ = (per ha agricultural revenue, per ha urban GDP, government budgetary revenue, road density), evaluated at the initial year of period t. These variables are hypothesised to influence urban spatial expansion.

Road density was used to measure transportation cost, and per ha agricultural revenue to measure the expected opportunity costs of farmland conversion, derived from dividing the net revenue from total crop production by total farmland area in a county. Data on urban household income at the county level are generally lacking. Recent studies suggest that changes in urban areas increase with the value of urban land (Lichtenberg and Ding 2009; Li *et al.* 2013). Following the literature, per ha urban GDP—the division of GDP in manufacturing and services by urban area in a county—is used as a proxy for the expected economic returns to urban development.

The variable government budgetary revenue captures the economic incentives of local authorities in making land development decisions. The revenue sources partly from local government's share of value-added taxes on urban sectors, and partly from profit from land conversion as local government receives conveyance fees from leasing land use rights to requisitioned farmland. As a major source of fiscal income, urban GDP is highly collinear with government revenue and the correlation coefficient equals 0.6. Details about the revenue are not reported at the county level, making it infeasible to analyse the fiscal revenue from newly developed land. Here the hectare-based revenue is replaced with a county-based value measured in thousands of yuan. This strategy greatly reduces the collinearity with per ha urban GDP (the correlation coefficient reduces to 0.1).

Analogously, the polygon fixed effects α_i are specified in ξ_{it}, aiming to control for unobserved, permanent determinants of farmland conversion specific to each polygon. Since Equation (8) replaces county-by-period fixed effects with county-level economic variables, I include a full set of province-by-period indicators, denoted by η_{pt}, to adjust for transitory shocks common to polygons within the same province. Yet conditioning on $\boldsymbol{w}_{ct}$ and η_{pt} cannot capture all time-varying confounding factors that determines farmland conversion but are unrelated to the implementation of the Regulation, an advantage of Equation (8) lies in its ability to draw inferences about the Regulation's multidimensional influences from a comparison of the parameter γ_t between different periods.

Missing data reduced the usable sample to 20,653 polygons for the period 1988-1995, to 20,538 polygons for the period 1995-2000, and to 20,623 polygons for the period 2000-2005. Table S2 reports summary statistics of these variables by land use conversion period. Equations (7) and (8) were estimated using pooled linear regression. In a flat panel data sample, the pooled estimator is consistent and asymptotically normal even in the presence of serially correlated errors (Wooldridge 2002). Robust standard errors that allow serial correlations are reported in the subsequent tables.

3.3 Substitution effect and land use spillovers

Urbanisation has many secondary ripple effects on land use change. When some farmland is converted to urban use, farmers may either voluntarily convert non-farmland, especially forests and grassland, to agricultural use because of economies of scale, fixed input effects, market schemes (Wu 2000), or be required by the administrative order to offset the loss by the same amount of new farmland somewhere else in the same county, that is, no net loss in prime farmland.

To explore the potential effect of farmland development on the conversion of rural non-farmland (forests or grasslands),[4] I fit the data to the following equation:

$$\Delta \mathrm{NF}_{it} = D_{it}\delta_{1t} + D_{ct}^{-i}\delta_{2t} + \boldsymbol{w}_{ct}\boldsymbol{\lambda}_t + \xi_{it} \tag{9}$$

where D_{it} and $\Delta \mathrm{NF}_{it}$ are, respectively, the acreage of farmland converted to urban use and the acreage of non-farmland change in polygon i over period t. The variable D_{ct}^{-i} is the total acreage of farmland converted to urban use in all polygons except i of county c, that is, $D_{ct}^{-i} = D_{ct} - D_{it}$. The terms $\boldsymbol{w}_{ct}$ and ξ_{it} are defined the same way as in Equation (8), representing a set of county-level economic variables and a full set of polygon fixed effects α_i and province-by-period indicators η_{pt}, respectively.

I use δ_{1t} to measure substitution effect of farmland development on non-farmland conversion within the polygon and use δ_{2t} to measure spillover effect arising from the development of farmland in surrounding polygons of the same county. If a substitution or spillover effect exists, we expect a negative value of δ_{1t} or δ_{2t}. Farmland development may not only affect the conversion of non-farmland within each polygon, but also generate

[4] This study only considers the conversion of forests and grassland to crop production. Another type of non-farmland land is unused land, representing the rest of all other lands, including sandy desert, Gobi desert, salinised land, bare soil, bare rock and tundra. Those types of land are unsuitable for agricultural production.

externalities on non-farmland conversion in other polygons. For instance, if forests or grassland supply is insufficient or unsuitable to offset the loss of farmland in a polygon, a land use planner may resort to farming on non-agricultural land in other areas of the county to meet the no-net-loss requirement.

Including a full set of county-by-period fixed effects θ_{ct} in the error term of Equation (9) is a preferred strategy to capture transitory unobserved factors at the county level or higher. But doing so will absorb the majority of D_{ct}^{-i} since D_{ct} and θ_{ct} are perfectly collinear. Alternatively, the substitution and spillover effects can be jointly estimated:

$$\Delta \mathrm{NF}_{it} = D_{it}\delta_t + \varepsilon_{it} \tag{10}$$

where $\delta_t = \delta_{1t} - \delta_{2t}$, derived from $D_{it}(\delta_{1t} - \delta_{2t}) + D_{ct}\delta_{2t}$, a reduced form of $D_{it}\delta_{1t} + D_{ct}^{-i}\delta_{2t}$ in Equation (9). Theory provides no clarity about the sign of δ_t. Whether substitution and spillover effects coexist is an empirical question considered in the next section. The term ε_{it} is defined the same way as in Equation (7), that is, $\varepsilon_{it} = \alpha_i + \theta_{ct} + u_{it}$. This specification non-parametrically absorbs all transitory shocks common to polygons within the same county (including $D_{ct}\delta_{2t}$) in addition to all permanent, polygon-specific unobservables.

Analogously, Equations (9) and (10) are estimated using pooled linear regressions. The empirical strategy proposed in this subsection aims to qualitatively understand the correlation between farmland development and non-farmland conversions rather than to identify their causal relationship. Causal mechanisms can be explored further in future research.

4. Results

This section comprises three subsections. Subsection 4.1 reports estimation results for Equations (7) and (8). Subsection 4.2 presents the estimated effects of the Regulation on the conversion of farmland to urban use based on the estimation results. Subsection 4.3 examines substation and spillover effects on non-farmland conversions.

4.1 Empirical estimation

Table 2 presents the results from the estimation of Equations (7) and (8), using data from all polygons over the three periods. The specification in column 1 includes a full set of polygon fixed effects and period fixed effects, in addition to land quality variables. Column 2 reports the results from adding four county-level economic variables. The specification in column 3 adds another full set of province-by-period fixed effects. The last column reports the estimates from replacing the county-level economic variables with county-by-period fixed effects. *F*-tests reject the null that the additional sets of

Table 2 Estimated regression model for farmland development

	Farmland conversion to urban use							
	(1)		(2)		(3)		(4)	
Before regulation (1988-1995)								
Grain	−5.44	(1.19)***	−6.62	(1.16)***	−7.89	(1.10)***	−7.93	(1.08)***
Oil-crops	−15.72	(3.93)***	−14.22	(3.83)***	−14.71	(3.63)***	−7.61	(3.64)**
Irrigation	−0.54	(5.06)	−1.27	(4.95)	−5.73	(4.86)	−8.55	(5.43)
Per ha agricultural revenue			−1.39	(0.25)***	−0.81	(0.25)***		
Per ha urban GDP			11.58	(0.92)***	9.05	(0.91)***		
Government revenue			−0.25	(0.06)***	−0.26	(0.06)***		
Road density			12.76	(3.06)***	16.45	(3.87)***		
After regulation (1995-2000)								
Grain	−6.12	(1.19)***	−7.19	(1.16)***	−8.40	(1.10)***	−8.37	(1.08)***
Oil-crops	−15.38	(3.94)***	−13.47	(3.84)***	−14.02	(3.64)***	−6.45	(3.66)*
Irrigation	−3.94	(4.92)	−2.08	(4.80)	−6.78	(4.66)	−5.35	(5.18)
Per ha agricultural revenue			−1.38	(0.17)***	−1.08	(0.16)***		
Per ha urban GDP			5.39	(0.36)***	4.22	(0.36)***		
Government revenue			−0.47	(0.03)***	−0.40	(0.04)***		
Road density			13.94	(2.84)***	16.27	(3.58)***		
After regulation (2000-2005)								
Grain	−3.77	(1.19)***	−4.93	(1.16)***	−7.40	(1.10)***	−7.30	(1.08)***
Oil-crops	−17.58	(3.92)***	−16.31	(3.82)***	−15.88	(3.62)***	−8.30	(3.64)**
Irrigation	10.31	(5.07)**	3.27	(4.96)	0.02	(4.84)	−1.07	(5.43)
Per ha agricultural revenue			−0.026	(0.004)***	−0.021	(0.004)***		
Per ha urban GDP			3.49	(0.31)***	2.26	(0.31)***		
Government revenue			0.14	(0.02)***	0.08	(0.02)***		
Road density			10.83	(2.38)***	15.34	(3.04)***		
R^2	0.663		0.680		0.716		0.789	
County-by-period fixed effects	No		No		No		Yes	
Province-by-period fixed effects	No		No		Yes		No	
Polygon fixed effects	Yes		Yes		Yes		Yes	
Period fixed effects	Yes		Yes		Yes		Yes	

Note: The sample includes 20,653 polygon observations in 2,084 counties over three periods. The magnitudes of all estimates are enlarged by 100 times. Standard errors in parentheses are robust and allow for within-polygon serial correlation. *, **, and *** indicate statistical significance at the 10%, 5%, and 1% levels, respectively.

controls are jointly equal to zero. Therefore, the specification in column 4 is the preferred one and variables listed in column 3 supplement the analysis of the effects of economic variables on farmland conversion.

Overall, the estimation results are robust across various specifications and can test the three fundamental assumptions of the classic urban spatial model. After controlling for unobserved, polygon-specific permanent determinants of farmland development and unobserved transitory factors common to all polygons, the rate of farmland conversion decreases with grain and oil-crop productivities and agricultural revenue, and increases with urban GDP and road density. These estimates are statistically significant at the 1 per cent level over the entire study period. The effects of these variables on farmland conversion persist when adding additional controls from column 2 through column 4 as noted at the bottom of the table. There is no evidence that the rate of farmland conversion is associated with the proportion of farmland under irrigation during the three periods.

The effect of government budgetary revenue on farmland conversion is worth discussing. The conversion rate decreases with government revenue from 1988 through 2000; after that, the effect becomes positive. This dynamic inconsistency could be partly attributed to the housing monetisation reform launched in 1998, which replaced the long-standing, socialist welfare housing system with a market-oriented regime (Lee and Zhu 2006). Consequently, local officials have more incentive to increase fiscal income from requisitioning farmland for urban development.

4.2 Is higher productivity farmland developed less?

Since the essence of the Regulation is to protect high quality farmland from conversion to non-agricultural use, the Regulation's effects on farmland protection can be assessed by evaluating $(\hat{\boldsymbol{\beta}}_1 - \hat{\boldsymbol{\beta}}_0)$ and $(\hat{\boldsymbol{\beta}}_2 - \hat{\boldsymbol{\beta}}_0)$ based on the estimates reported in Table 2. That is, if the Regulation was in effect, land parcels with higher agricultural productivity would be developed less. Table 3 presents the estimated regulation effects for variables whose coefficient estimates are statistically significant at the 5 per cent level or better (i.e. irrigation is excluded). The results for the two post-regulation periods are in separate panels, where columns 1-4 correspond to specifications aligning to those in Table 2.

Overall, the estimated effects of regulation for grain productivity are robust across the four specifications over the entire post-regulation period. But the estimated regulation effects for oil-crop productivity are sensitive to unobserved, county-specific transitory determinants of farmland development even though the county-level economic variables are controlled for. In other words, county-by-period shocks to farmland conversion potentially bias the effect of regulation.

The results in column 4 of panel A indicate that during 1995-2000, the Regulation can protect farmland with high productivity of grain from

Table 3 Estimated effects of the farmland protection regulation

	Regulation effects							
	(1)		(2)		(3)		(4)	
A. 1995-2000								
Grain	−0.684	(0.182)***	−0.574	(0.178)***	−0.512	(0.191)***	−0.436	(0.226)*
Oil-crops	0.335	(0.502)	0.750	(0.491)	0.691	(0.519)	1.163	(0.633)*
Per ha agricultural revenue			0.009	(0.174)	−0.264	(0.171)		
Per ha urban GDP			−6.190	(0.734)***	−4.826	(0.734)***		
Government revenue			−0.225	(0.035)***	−0.140	(0.037)***		
Road density			1.184	(0.706)*	−0.176	(0.729)		
B. 2000-2005								
Grain	1.662	(0.182)***	1.690	(0.178)***	0.482	(0.191)**	0.635	(0.226)***
Oil-crops	−1.862	(0.500)***	−2.088	(0.490)***	−1.169	(0.516)**	−0.692	(0.630)
Per ha agricultural revenue			1.363	(0.243)***	0.793	(0.243)***		
Per ha urban GDP			−8.097	(0.744)***	−6.785	(0.744)***		
Government revenue			0.387	(0.046)***	0.337	(0.048)***		
Road density			−1.931	(0.914)**	−1.114	(1.036)		
County-by-period fixed effects	No		No		No		Yes	
Province-by-period fixed effects	No		No		Yes		No	
Polygon fixed effects	Yes		Yes		Yes		Yes	
Period fixed effects	Yes		Yes		Yes		Yes	

Note: The magnitudes of all estimates are enlarged by 100 times. Standard errors in parentheses are robust and allow for within-polygon serial correlation. *, **, and *** indicate statistical significance at the 10%, 5%, and 1% levels, respectively.

conversion to urban use. Before the Regulation was implemented, a one metric tonne/ha increase in grain productivity would reduce the farmland conversion rate by 7.93 per cent (column 4 of Table 2). When the Regulation took effect, the reduction increases by 0.44 percentage points. In contrast, the negative effect of oil-crop productivity on farmland conversion is weakened by 1.16 percentage points during this period.

Unlike the period 1995-2000, there is no evidence that the Regulation was effective in protecting high productivity farmland from urban development during 2000-2005. As shown in column 4 of panel B, the estimated regulation effect for grain productivity is significantly positive. This finding implies that the role of grain productivity in protecting farmland from conversion was instead weakened in the second 5 year period after the regulation came into effect. As for oil-crop productivity, there was no significant change in its effect on farmland conversion before and after the adoption of the Regulation.

One can draw inferences about the Regulation's effects on the role of economic variables in determining farmland development. All economic variables except road density contributed to the decreased rate of farmland conversion during 1995-2000. A one million ¥/ha increase in urban GDP accelerated the rate of farmland conversion by 9.05 per cent prior to the Regulation (column 3 of Table 2). This positive effect declined by 4.83 percentage points during 1995-2000 and further decreased by to 1.96 percentage points during 2000-2005. In comparison, a one thousand ¥/ha increase in agricultural revenue reduced the farmland conversion rate by 0.81 per cent prior to the Regulation (column 3 of Table 2). This negative correlation was significantly weakened during 2000-2005. This result implies that in the second post-regulation period, agricultural rent became less important for a land use planner to consider when deciding whether to convert farmland to urban use. A similar dynamic pattern is found in the case of government budgetary revenue, underscoring the fact that the housing monetisation reform potentially undermined the effect of Regulation on farmland protection. As for road density, there was no significant change in its effect on farmland conversion from pre-regulation to post-regulation periods. It is important to note that the estimated Regulation's effects for economic variables are admittedly coarse due to the potential presence of unobserved confounding transitory shocks to farmland development but unrelated to the regulation. Thus, the implications must be interpreted with caution.

In addition to the identification efforts presented above, the potential heterogeneity of the coefficient estimates and the Regulation's effects in irrigation status were explored. The interested readers can find further information and estimation results in Appendix S3. Robustness testing was undertaken by replacing the inverse hyperbolic sine transformation of y_{it} with the log-transformed y_{it} while adding a small number to handle the zeros. The finding persists across alternative transformation of the dependent variable.

4.3 Are non-farmland conversions associated with farmland development?

To examine whether substitution and spillover effects exist and change over time, Equations (9) and (10) were estimated using data from all polygons over the three periods. Table 4 separately reports the primary regression results for forests and grassland conversions in two panels. Column 1 of Table 4 presents the point estimates of δ_{1t} and δ_{2t}. Column 2 presents the point estimates of δ_t. The specification in column 3 replaces county-by-period fixed effects in Equation (10) with county-level economic variables and province-by-period indicators. Such a substitution is informative. It helps detect to what extent the unobserved, county-level transitory determinants of non-farmland conversion would bias the estimation of δ_t. It also provides an opportunity to examine whether the potential collinearity between D_{it} and D_{ct}^{-i} in Equation (9) is a concern.

Focusing first on forestland change. There is a significant correlation between farmland development and forestland conversion from 1988 through to 2005 and the correlation changes over time. *F*-test rejects the null hypothesis that the spillover effects are jointly equal to zero (*P*-value is 0.066). The potential collinearity between D_{it} and D_{ct}^{-i} is not a major concern;[5] the coefficient estimates for δ_{1t} in columns 1 and 3 are similar. A comparison of results between columns 2 and 3 indicates that omitting some county-specific, transitory determinants of forestland conversion slightly changes the magnitude of estimates, but it does not undermine the major conclusion drawn from the analyses below.

Results suggest that forests increase with farmland development before the implementation of the Regulation. The increase coincides with ecosystem restoration stimulated by government policy. The Chinese government launched the Three-North Shelterbelt Program in 1978 with the proposed outcome of raising northern China's forest cover from 5 per cent to 15 per cent by 2050 in 559 counties within 13 provinces (Li *et al.* 2016). The government also launched the Taihang Mountains Afforestation Project in 1986 and the Coastal Shelterbelt Project in 1990 to prevent soil erosion. Although there is debate on the effectiveness of these projects, Landsat images confirm an increase in forest cover in northern China, Liaodong Peninsula, Southeast coastal area and the Taihang Mountains (which form the western side of the triangular North China Plain and the eastern edge of the Loess Plateau) during the period 1988-1995 (see Figure S4 in Appendix S4).

Forestland decreases with farmland development during 1995-2000, the first 5 years after the Regulation came into effect. All else being equal, a one ha decrease in forestland is associated with an almost equal amount increase of farmland development. The substitution effect over this period differs

[5] The associated variance inflation factors are less than four, lower than the level of five typically recommended for high multicollinearity.

Table 4 Estimated effects of farmland development on non-farmland conversions

	(1)		(2)		(3)	
Change in forestland area						
Area of farmland development (1988-1995)	0.366	(0.190)*	0.418	(0.170)**	0.335	(0.189)*
Area of farmland development of all *other* polygons in the same county (1988-1995)	–0.069	(0.037)*				
Area of farmland development (1995-2000)	–0.785	(0.407)*	–0.999	(0.383)***	–0.792	(0.405)**
Area of farmland development of all *other* polygons in the same county (1995-2000)	0.107	(0.096)				
Area of farmland development (2000-2005)	1.238	(0.126)***	1.060	(0.115)***	1.206	(0.89)***
Area of farmland development of all *other* polygons in the same county (2000-2005)	–0.030	(0.018)*				
R^2	0.211		0.498		0.211	
Change in grassland area						
Area of farmland development (1988-1995)	–0.043	(0.345)	–0.003	(0.309)	–0.006	(0.344)
Area of farmland development of all *other* polygons in the same county (1988-1995)	0.044	(0.067)				
Area of farmland development (1995-2000)	0.541	(0.740)	0.242	(0.695)	0.639	(0.735)
Area of farmland development of all other polygons in the same county (1995-2000)	0.089	(0.175)				
Area of farmland development (2000-2005)	–0.461	(0.228)**	–0.568	(0.210)***	–0.398	(0.225)*
Area of farmland development of all *other* polygons in the same county (2000-2005)	0.055	(0.033)				
R^2	0.180		0.479		0.180	
County-by-period fixed effects	No		Yes		No	
County-level economic variables	Yes		No		Yes	
Province-by-period fixed effects	Yes		No		Yes	
Polygon fixed effects	Yes		Yes		Yes	

Note: The sample includes 20,653 polygon observations in 2,084 counties over three periods. Standard errors in parentheses are robust and allow for within-polygon serial correlation. *, **, and *** indicate statistical significance at the 10%, 5%, and 1% levels, respectively.

statistically significantly from that in the pre-regulation period at the 1 per cent level, implying that local land use planners plausibly began to consider the no-net-loss requirement when they converted farmland to urban use.

In contrast to the first post-regulation period, forest cover increases again with farmland development during 2000-2005, due largely to the Sloping Land Conversion Program (SLCP) initiated by the Chinese government in 1999. The SLCP is a nationwide payment-for-ecosystem-service project with dual goals of ecological restoration and poverty alleviation by paying farmers to increase forest cover on highly erodible cropland (typically sloped land) and barren hillsides. The program has expanded to over 2,000 counties in 25 provinces across China, with approximately 7.2 million ha of cropland being enrolled by the end of 2003 (Xu *et al*. 2010).

There is evidence for a negative spillover effect on forestland conversion over the pre-regulation and the second post-regulation periods, where forest cover is positively associated with farmland development within a polygon. Such evidence is absent for the period 1995-2000. This result implies that if non-farmland is unsuitable to offset the loss of farmland in a polygon, a local land use planner may consider cultivating non-farmland from other polygons to at least partially meet the no-net-loss necessity.

Turning next to grassland change, the effect of farmland development is different. There is no significant correlation between farmland development and grassland conversion except the period 2000-2005 during which evidence is significant for the presence of substitution effect at the 5 per cent level or better. Associated with a one ha increase in farmland development is a decrease of 0.57 ha in grasslands during this period, all else being equal. Not surprisingly, in the absence of evidence of positive correlation between grassland conversion and farmland development (as is the case with forestland conversion during 1988-1995 and 2000-2005), *F*-test fails to reject the null hypothesis that the spillover effects are jointly equal to zero (*P*-value is 0.407).

In summary, results from exploring substitution and spillover effects suggest that farmland development was accompanied by reduction in forests or grasslands to various extent after the no-net-loss requirement was enforced. There is suggestive evidence of a negative spillover effect on forestland change but little evidence of such an effect for grassland conversion countrywide.

5. The magnitude of the regulation's effects and policy implication

The analysis above indicates that farmland development, especially on land characterised by high productivity of grain, was retarded in the first 5 years after the Regulation came into effect. But the conversion rate was accelerated in the second 5 year period. This section provides answers to two questions about the estimated effects of the Regulation. What is the largest source of the change in the farmland conversion rate? To what extent can the Regulation protect high productivity farmland from urban development?

Addressing the two questions just posed requires a decomposition of changes in farmland conversion rate, which needs two steps. First, I calculate the aggregate measure of change in farmland conversion rate and report it in the last row of panel A in Table 5. The measure is obtained by subtracting the mean value of $\sinh^{-1} y_{i0}$ (i.e. the dependent variable in Equation (7) for $t = 0$) from the mean value of $\sinh^{-1} y_{i1}$. Second, I decompose this measure into four components as shown on the right-hand side of Equation (7). The first three components relate to land quality variables and equal the product of the sample mean of the corresponding land quality variable and the associated estimated regulation effect (column 4 of Table 2). Subtracting these components from the change measure yields the residual. Since differencing between the post-regulation and pre-regulation periods wipes out the polygon fixed effects α_i, the residual is primarily composed of county-by-period fixed effects θ_{ct}.

Column 1 of Table 5 presents the decomposition results. Given these estimates, it is easy to calculate their relative contribution to the total change in farmland conversion as well as the 95 per cent confidence interval of the contribution, as presented in columns 2 and 3 of Table 5, respectively. Calculation reveals that the average rate of farmland conversion decreased by −0.06 units from the pre-regulation period to the period 1995-2000. This number translates to a national reduction of 0.28 million ha (column 1 of Table 1). Approximately 38.9 per cent of the decrease (−0.7 per cent to 78.6 per cent at the 95 per cent confidence interval) results from the protection of farmland with high grain productivity. This contribution, however, is offset by oil-crop productivity and irrigation proportion. Transitory shocks common to the conversion of farmland within the same county are another

Table 5 The magnitude of the regulation effects and its composition

	Regulation effects	Contribution (%)		
		Mean	95% confidence interval	
	(1)	(2)	(3)	
A. 1995-2000				
Grain	−0.024	38.9	−0.7	78.6
Oil-crops	0.016	−26.3	−54.4	1.8
Irrigation	0.011	−18.2	−52.0	15.5
Residual	−0.066	105.6	n.a.	n.a.
Total	−0.063	100.0	n.a.	n.a.
B. 2000-2005				
Grain	0.036	7.0	2.1	11.9
Oil-crops	−0.010	−1.9	−5.4	1.5
Irrigation	0.027	5.2	1.1	9.4
Residual	0.456	89.7	n.a.	n.a.
Total	0.508	100.0	n.a.	n.a.

Note: The 95% confidence intervals in column 3 are calculated based on robust standard errors that are heteroskedastic-consistent to address within-polygon serial correlation.

important factor affecting the decreased rate of farmland conversion. These shocks explain almost 105.6 per cent of the reduction.

The effects of the Regulation during the period 2000-2005 are different. An analogous decomposition indicates that the average rate of farmland conversion increased by 0.51 units from the pre-regulation period to this period, equivalent to a national increase of 1.29 million ha (column 1 of Table 1). Like the preceding decomposition, time-varying shocks common to the conversion of farmland within the same county are the largest source of the increase (89.7 per cent). In comparison, grain productivity and irrigation percentage jointly explain a small proportion of the increase (12.2 per cent), and the negative impact of oil-crop productivity on the increase is almost negligible (−1.9 per cent).

The analysis reveals a stark difference of the policy effectiveness between the two post-regulation periods, which brings up the question of what factors induced this difference. As the county-by-period shocks are the dominant factors affecting change in farmland conversion rate during both periods, the lack of success of the Regulation during 2000-2005 was less likely due to this policy instrument itself but rather, to the socio-economic context that did not favour the policy.

The period 2000-2005 coincides with the implementation of several economic development policies. For example, China launched housing monetisation reform in 1998 to replace the long-standing in-kind housing subsidy and targeted the housing industry as ‘a new growth focus’ (Lee and Zhu 2006). China also made a major investment in road construction. The country’s total road length increased almost 2.5-fold from 1.4 million kilometres in 2000 to 3.46 million kilometres in the 2006 (NBSC 2010). Further investigation of the impacts of those development strategies on farmland protection is beyond the scope of this study. Nonetheless, those development strategies appear to strengthen the role of local officials in land development, making the top-down farmland protection policy less effective.

The findings described in this paper seem to be consistent with Jacobs (1999) and Alterman’s (1997) analyses of agricultural land protection strategies in Western countries. Both noted that success in agricultural land protection is weakly related to the characteristics of particular approaches taken and instead is more a factor of the sociopolitical environment that supports those land policies. Successful approaches require comprehensive planning by local governments, a system of strict land use regulation, and a means to purchase agricultural land threatened with conversion (Jacobs 1999; Bengston *et al.* 2004). Thus, creating a socio-economic and political-policy environment that can reconcile the conflict between economic development and farmland retention is a key consideration for policymakers.

The effects of urban spatial expansion and the associated farmland protection policy on rural non-farmland conversion also merit discussion. Changing land use is costly. The economic literature on land use change has been strongly influenced by von Thünen's land rent hypothesis; that is, land use is changed when the potential rent from the converted use is higher than the opportunity cost of land use change (including the conversion cost and the rent from the original use). Farmland development may not necessarily induce farming on non-agricultural land. Instead, if some ecosystem restoration programs coexist, one can see an increase in forests and grassland coverage, as evidenced over the period 1988-1995.

The intervention of farmland protection policy changes the incentive mechanism of land resource allocation. With the no-net-loss requirement, we observe an almost one-to-one reduction in forests cover during 1995-2000 and a decrease of grasslands during 2000-2005. These changes have deteriorated ecosystems and resulted in significant carbon loss from both soil and biomass across the country. Li *et al.* (2016) found a net soil carbon loss of 1.4 per cent (147 TgC) in forestlands over 1995-2000 and of 2.6 per cent (395 TgC) in grasslands over 2000-2005 due to land use changes. Whether forests or grasslands constitute a primary source of new farmlands depends on many factors, such as what is the primary type of land use in the focused areas and how much efforts the government makes in ecosystems restoration. Yet designing land use policy is a multi objective decision making process in which policies target food security for instance while other goals such as restoring ecosystems are preserved. The analysis on forests and grassland changes reinforces the importance of creating a favourable policy environment to reconcile conflicts between multiple objectives.

This study has several limitations. First, it relies on time-series variation across three periods to examine the policy impact and assumes that the rate of farmland conversion over the pre-policy period is the counterfactual. This is because a prime farmland protection zone is a virtual space of planning concept rather than a geographic entity. From a policymaking perspective, what matters is that under the policy: (i) less farmland is converted to urban use; and (ii) the better farmland is developed more slowly. Therefore, this paper relies on these two principles to assess the policy impact. A recent study by Xia *et al.* (2016) made similar hypotheses to demarcate the protection zones in a small area of eastern China with satellite images and farmland quality. Moreover, including a full set of county-by-period indictors in the specification helps address the absence of a real counterfactual group to represent significant changes occurring over the study period. Another limitation of this study is there is limited discussion about the source of polygon-specific variations in the rate of farmland conversion. Part of the variations are time-invariant factors (e.g. geophysical variables) which have been assimilated by polygon fixed effects. County-by-period indictors and county-level economic variables also capture many time-varying factors. The third limitation is that this study does not identify the causal relationship between farmland development and non-farmland conversions. Understanding causal mechanisms requires effort in gathering data related to multiple ecosystems restoration projects and is thus a theme of future research.

6. Conclusions

This paper evaluates the effectiveness of China's Prime Farmland Protection Regulation and the subsequent effect on forests and grassland conversions. In the first 5 years after the Regulation took effect (1995–2000), farmland conversion to urban use was alleviated in both conversion rate and the spatial extent. Approximately 38.9 per cent of the alleviation results from the protection of farmland with high grain productivity. Agricultural revenue, urban GDP, and government budgetary revenue also contributed to the decreased rate of farmland conversion. There is little evidence that the alleviation was associated with preserving lands having high productivity of oil-crops or lands with high irrigation coverage. These findings are derived from the most comprehensive data available including the high quality land use data, the highly detailed land quality indicators and the extensive economic data. The estimated effects of the Regulation are robust across a variety of specifications.

The policy effects are different in the second 5 years (2000-2005). I found that farmland conversion to urban use was intensified during 2000-2005. A heterogeneous analysis suggests that the Regulation can protect high-oil-crop-productivity farmland predominantly irrigated and high-grain-productivity farmland without irrigation. But these two land productivity variables together only explain 5.1 per cent of the change in farmland conversion rate. In contrast, time-varying shocks common to farmland development within the same county are the largest source of the increased farmland conversion. To gain a clearer understanding of the lack of success of this policy, it is crucial to understand what those unobserved factors are and how they undermine the effect of the policy. Previous research has pointed to the joint influence of China's fiscal reform and housing monetisation reform on land development. This paper's findings highlight the importance of creating a favourable socio-economic environment to support farmland protection policies.

References

Alonso, W. (1964). *Location and Land Use*. Harvard University Press, Cambridge, MA.

Alterman, R. (1997). The challenge of farmland preservation: lessons from a six-nation comparison, *Journal of the American Planning Association* 63, 220–243.

Bengston, D.N., Fletcher, J.O. and Nelson, K.C. (2004). Public policies for managing urban growth and protecting open space: policy instruments and lessons learned in the United States, *Landscape and Urban Planning* 69, 271–286.

Capozza, D.R. and Helsley, R.W. (1989). The fundamentals of land prices and urban growth, *Journal of Urban Economics* 26, 295–306.

Daniels, T. (1998). The purchase of development rights, agricultural preservation and other land use policy tools: the Pennsylvania experience, in Ernstes, D.P. and Hicks, D.M. (eds), *Increasing Understanding of Public Problems and Policies–1998*. Farm Foundation, Oak Brook, IL.

Deng, X., Huang, J., Rozelle, S. and Uchida, E. (2008). Growth, population and industrialization, and urban land expansion of China, *Journal of Urban Economics* 63, 96–115.

Ding, C. (2003). Land policy reform in China: assessment and prospects, *Land Use Policy* 20, 109–120.

Gibson, J., Datt, G., Murgai, R. and Ravallion, M. (2017). For India's rural poor, growing towns matter more than growing cities, *World Development* 98, 413–429.

Howe, D.A. (1994). A research agenda for Oregon planning: problems and practices for the 1990s, in Abbott, C., Howe, D.A. and Adler, S. (eds), *Planning the Oregon Way: A Twenty-Year Evaluation*. Oregon State University Press, Corvallis, OR, pp. 275–290.

Jacobs, H.M. (1999). Protecting agricultural lands under the threat of urbanization: Lessons for developing countries from developed countries, Proceedings of International Seminar on Land Policy and Economic Development. International Center for Land Policy Studies and Training, Taoyuan, Taiwan, pp. 210–227.

Kline, J.D. and Alig, R. (1999). Does land use planning slow the conversion of forest and farmlands? *Growth and Change* 30, 3–22.

Lee, J. and Zhu, Y. (2006). Urban governance, neoliberalism and housing reform in China, *Pacific Review* 19, 39–61.

Li, M., Wu, J. and Deng, X. (2013). Identifying the drivers of land use change in China: a spatial multinomial logit model analysis, *Land Economics* 89, 632–654.

Li, M., Wu, J. and Deng, X. (2016). Land use change and soil carbon sequestration in China: where does it pay to conserve? *Regional Environmental Change* 16, 2,429–2,441.

Lichtenberg, E. and Ding, C. (2008). Assessing farmland protection policy in China, *Land Use Policy* 25, 59–68.

Lichtenberg, E. and Ding, C. (2009). Local officials as land developers: urban spatial expansion in China, *Journal of Urban Economics* 66, 57–64.

Mills, E.S. (1967). An aggregative model of resource allocation in a metropolitan area, *The American Economic Review* 57, 197–210.

Muth, R.F. (1969). *City and Housing*. The University of Chicago Press, Chicago, IL.

NBSC (National Bureau of Statistics of China) (2010). *China Statistical Yearbook*. China Statistical Press, Beijing.

Pfeffer, M.J. and Lapping, M.B. (1994). Farmland preservation, development rights and the theory of the growth machine: the views of planners, *Journal of Rural Studies* 10, 233–248.

Standing Committee of the Ninth National People's Congress of the People's Republic of China (1999). Land Administration Law of the People's Republic of China (first amended version). The National People's Congress of the People's Republic of China, Beijing.

State Council of the People's Republic of China (1994). *Prime Farmland Protection Regulation*. State Council of the People's Republic of China, Beijing.

Wooldridge, J.M. (2002). *Econometric Analysis of Cross Section and Panel Data*. The MIT Press, Cambridge, MA.

Wu, J. (2000). Slippage effects of the conservation reserve program, *The American Journal of Agricultural Economics* 82, 979–992.

Wu, J. and Cho, S. (2007). The effect of local land use regulations on urban development in the Western United States, *Regional Science and Urban Economics* 37, 69–86.

Xia, N., Wang, Y., Xu, H., Sun, Y., Yuan, Y., Cheng, L., Jiang, P. and Li, M. (2016). Demarcation of prime farmland protection areas around a metropolis based on high-resolution satellite imagery, *Scientific Reports* 6, 37634.

Xu, J., Tao, R., Xu, Z. and Bennett, M.T. (2010). China's Sloping Land Conversion Program: does expansion equal success? *Land Economics* 86, 219–244.

Yang, H. and Li, X. (2000). Cultivated land and food supply in China, *Land Use Policy* 17, 73–88.

Supporting Information

Additional Supporting Information may be found in the online version of this article:

Appendix S1. Proof of Proposition.

Appendix S2. Data and unit of analysis.

Appendix S3. Examining heterogeneity in the regulation's effects across irrigation status.

Appendix S4. Additional figures.

Table S1. Effective dates of the implementing acts of the Prime Farmland Regulation and the Amendments to Land Administration Law by province.

Table S2. Means of county and polygon characteristics.