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Are There Any Undesired Effects of Anti-Land Fragmentation Programs on Farm Production Practices and Farm Input Use?

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Abstract: Most policies designed to reduce land fragmentation involve land consolidation. However, research examining the relationship between agricultural zoning and land fragmentation has not yet been explored. This paper considers the causal impact of an anti-land fragmentation policy on farmland use and farm production inputs relevant to environmental quality using a population-based census survey of farm households in Taiwan. Using the regression discontinuity method, we found that the anti-land fragmentation policy reduced the proportion of farmland used in farm production and environmental conservation by 2.4% and 2.6%, respectively. The policy also impacted the proportion of farmland using fertilizers, irrigation systems, and underground water. Our results show that anti-land fragmentation policies must be carefully designed to avoid negatively impacting farmland use and the environment.

Keywords: land fragmentation; farm production; fertilizer; underground water; farm household

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1. Introduction

There is an extensive debate on the relationship between farm size and agricultural productivity, including one frequently discussed hypothesis where smaller farms are more productive than larger farms [1,2]. Research on this relationship is ongoing and inconclusive. On the one hand, Fan and Chan-King [3] explain that small farms could face lower labor costs than large farms based on their factor endowments relying on family labor. Hefland and Taylor [4] and Rada et al. [5] found that small farms have high land productivity and total factor productivity in Brazil. On the other hand, some studies suggest that measurement error in reported crop yields and omitted variables such as soil quality makes it challenging to discern the statistical direction and magnitude of this relationship [6,7].

Land size is also an essential component of other issues affecting agricultural outcomes, such as land fragmentation. This scenario is common when farmland is dispersed over vast areas [8]. Land fragmentation is a complex phenomenon that involves factors such as the number, size, shape, or distance between farms [9]. Generally, land fragmentation will result in agricultural inefficiencies since smaller and widely spread or unevenly shaped parcels of farmland can be less productive or difficult to cultivate without economies of scale [10]. These agricultural inefficiencies can subsequently reduce farm values since the price of farmland is based on its productivity [11]. Other evidence shows that land-fragmentation can reduce household incomes through decreasing crop incomes in rural areas [12]. Globally, land fragmentation is common, as mean parcel sizes are less than five hectares in some countries in Europe and two hectares in most of Asia [13].

Given the fact that the agricultural sector has been shrinking in many countries of the world, one of the policy tools of the agricultural authority is to restrict on land use to maintain farm scale. In particular, policymakers have considered an array of policies to combat land fragmentation. The most common policy includes land consolidation, which is the reallocation and reorganization of farmland and their ownership structures [14]. Many studies have examined the effects of land consolidation. For example, Hiironen and Riekkinen [15] found that land consolidation reduces farming costs through improving farm structures in Finland. Zeng et al. [16] showed that land consolidation increases technical efficiency through land tenure transfers and encouraging non-agricultural employment in Jiangsu, China. Finally, Asimeh et al. [17] suggested that land consolidation increases agricultural sustainability and the net present value of farmland in Fars, Iran.

Although there is extensive research on land consolidation, few studies have examined the connection between agricultural zoning and land fragmentation. While agricultural zoning is commonly used to protect farmland and reduce urban sprawl, this policy can also reduce land fragmentation in several ways. Agricultural zoning includes restrictions on farmland use, such as minimum farm sizes and limits on the number of non-farm dwellings or distance between properties [18]. In particular, agricultural zoning is a regulatory approach that is typically monitored by local authorities. These restrictions can deter land fragmentation through strictly enforced laws and punitive fines, discouraging the cultivation of smaller farms in large areas.

Due to the small-scale nature of agriculture in Taiwan, the government has also used agricultural zoning as part of its anti-land fragmentation policy. In 2000, the Council of Agriculture reformed the 'Agricultural Development Act' to increase the amount of farmland used for farm production and the scale of farms [19]. The major components of these reforms established a minimum lot size for farmhouses and strict rules on dividing or transferring farmland at a cut-off point of 0.25 hectares. Such reforms can also indirectly affect the environmental quality. Anti-land fragmentation policies will impact the environment if they change the allocation of farm production inputs used in agriculture. For example, policies resulting in larger parcels of farmland or more farm production will increase the use of production inputs (e.g., fertilizers, irrigation systems, and underground water) that harm the environment. Based on the farm production theory, the optimal allocation of the inputs used in farm production are highly determined by the relative prices among the farm production. Therefore, agricultural zoning can influence the allocation of farm production inputs if the policy affects farmland prices (e.g., through an optional amenity), subsequently impacting the amount of these farm production inputs.

This paper considers the effect of an anti-land fragmentation policy on farmland use and farm production inputs relevant to the environmental quality. Specifically, this paper aims to answer the following research questions: (1) Do anti-land fragmentation policies affect the allocation of farmland used in farm production, conservation, or other purposes? (2) How do anti-land fragmentation policies affect the use of production inputs that are relevant to environmental quality? (3) Which types of farms are disproportionately affected by these policies? To answer these questions, we apply the regression discontinuity method to carefully quantify the causal impacts of anti-land fragmentation policies on eligible and non-eligible farms in Taiwan.

This paper contributes to the research on agricultural zoning and land fragmentation on several fronts. First, we consider the effects of agricultural zoning on land fragmentation. Prior research has mostly focused on the effects of land consolidation. For example, Nilsson [20] found that land consolidation increased crop yields for farmers cultivating more than one hectare in Rwanda. Similarly, Wu et al. [21] observed that land consolidation improved land quality and production structures in Hunan Province, China. Janus and Markuszewska [22] presented evidence suggesting that land consolidation can slow land abandonment and that these effects can persist up to 40 years in Poland. However, there is little research quantifying the impact of agricultural zoning on land fragmentation. Many anti-land fragmentation policies, such as land consolidation, have the explicit goal of increasing the size of land in farm production [16]. Thus, our study provides an empirical analysis illustrating the relationship between agricultural zoning and land fragmentation through farmland use.

Second, we consider the effects of an anti-land fragmentation policy on urban and rural farms. Anti-land fragmentation policies will have various effects depending on whether the farm is located in urban or rural areas. For example, farm household income is not solely from the sales of farm products on the market of urban farms. It is expected that many urban farms can engage in off-farm labor market to receive non-farm income to support the family farm. Therefore, urban farms could be less responsive to the anti-fragmentation policy in that they are located closer to cities and subject to speculation for non-agricultural purposes [23]. However, most of the existing studies in land economics and development economics have only considered the effects of these policies on rural farms, and evidence has been provided in countries such as China and Lithuania [24,25]. This study aims to fill the knowledge gap by providing supportive evidence on how anti-land fragmentation policies affect farms that are located in an urban and rural area in a different way.

Third, we identify the causal impact of anti-land fragmentation policies using the regression discontinuity design method. Much of the previous literature relies on descriptive evidence or statistical matching methods to reduce selection bias since the implementation of these policies is not random [20,24,25]. One drawback of these approaches is to fail to correct for the selection bias that is due to unobserved factors. This study goes one step further from these studies to exploit the unique eligibility rule of the anti-land fragmentation policy to assess its causal impacts in Taiwan. It has been documented that a regression discontinuity design requires fewer identification assumptions compared to other program evaluation methods [26]. By applying this method, we can better identify the causal effect of the program on the allocation of farm production inputs by farm households.

Finally, we link anti-land fragmentation policies to recent work on agricultural and sustainable intensification. Research has recently identified practices such as land-sparing, where land is segregated for high-yielding agriculture with the remaining portions being conserved as a potential framework for reconciling agricultural and environmental needs [27]. Since many anti-land fragmentation policies are implemented with the explicit goal of increasing agricultural productivity, we link these measures to both agricultural and sustainable intensification based on our empirical analysis on agricultural use and farm production inputs.

2. Materials and Methods Data

2.1. Background on the Anti-Land Fragmentation Program in Taiwan

Taiwan is an island with 797,000 hectares under cultivation [28]. Furthermore, the agricultural industry is characterized by small farms producing low yields, as farm households cultivate about 1.1 hectares on average [28]. As a result, the government reformed the 'Agricultural Development Act' in 2000 to increase the amount of farmland used for farm production and the scale of farms on the island through regulating agricultural enterprises [29].

The reforms to the 'Agricultural Development Act' consisted of several measures to expand farm production. First, authorities removed the requirement that only eligible farmers could purchase farmland [29]. This change allowed legal entities and private enterprises to participate in agriculture, which increased the amount of capital and investment in the sector. Second, landowners who purchased their farmland after the reforms without a farmhouse could construct one if their farmland is larger than 0.25 hectares [29]. The rationale behind this requirement is that machinery and production inputs (e.g., pesticides, fertilizer, and underground water use) are more productive on larger parcels of land in Taiwan [30]. Finally, the government placed strict rules forbidding the division or transfer of farmland smaller than 0.25 hectares [29]. The exceptions to this provision are: (1) merging an adjacent piece of purchased arable land; (2) land that is changed to non-arable land where the unchanged part is co-owned with separate management; (3) arable land inherited by legal successors after the enactment of these reforms; (4) co-owned arable land before the enactment of these reforms; (5) non-agricultural land consolidation regions to serve as farm irrigation or drainage waterways, and (6) other lands deemed necessary for the implementation of land or agricultural policies or national development [29].

Figure 1 provides a map of the distribution of land use zone-type in non-urban planned districts [31]. The geography of Taiwan is characterized by diverse landscapes. eastern Taiwan is covered by forests and trees. In contrast, the land in central and western Taiwan is more intensively used for agriculture. Thus, the anti-land fragmentation program will predominantly affect farm sizes in central and western Taiwan.

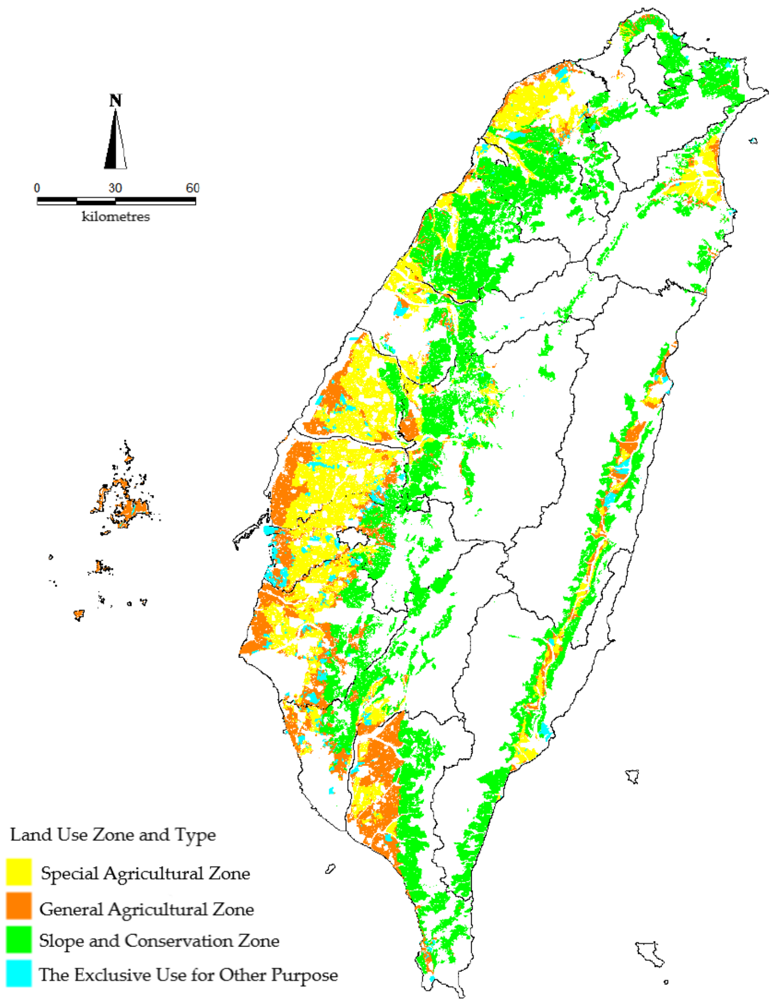

Figure 1. Land use zone-type in non-urban planned districts.

2.2. Data

This paper uses the 2015 Agricultural Census Survey, which was conducted by the Directorate-General of Budget, Accounting, and Statistics of the Executive Yuan. The census survey has detailed information on the population of farm households in Taiwan. During an in-person interview, one principal farm operator for each household reports their farm's production and family characteristics.

The 2015 Agricultural Census Survey also contains information on the proportion of farmland each farm uses for farm production, conservation, and other purposes. The principal farm operator also indicates the proportion of farmland that cultivated using fertilizers, irrigation systems, and underground water. Since fertilizer use is more intense for fruit and vegetable farms compared to other crop farms, we first limit our sample to fruit and vegetable farms.

The eligibility rule of the anti-land fragmentation policy is dependent on whether the farmland is above (eligible) or below (non-eligible) a cut-off point of 0.25 hectares in size. We restrict our sample to fruit and vegetable farms whose farmland is smaller than 0.5 hectares, because certain farms can qualify for additional government financial support and subsidies at this size. The number of farms that are eligible for the anti-land fragmentation policy (i.e., their farm is larger than 0.25 hectares) is 109,661 farms. The number of farms that are non-eligible (i.e., their farm is smaller than 0.25 hectares) is 73,939. Thus, our final sample consists of 183,600 fruit and vegetable farms.

We control for other variables that affect farmland use and production inputs. Two variables for the number of children and adults in the household are specified to control for family structures that affect farm labor [32]. We also define several variables that reflect the socio-demographic characteristics of the principal farm operator. Gender is specified as a dummy variable since men tend to have more access to resources in agriculture [33]. Age is measured as a continuous variable in years. Finally, educational attainment is specified by four dummy variables to indicate if the principal farm operator has completed primary school, junior high, senior high, or college, since human capital will affect farm production practices of the farm operation.

Table 1 presents the sample statistics of the selected variables. Although eligible and non-eligible farms have similar family structures and socio-demographic characteristics, there are differences in farmland use and production inputs relevant to the environment. Eligible farms use a small proportion of farmland in farm production (89%) compared to non-eligible farms (94.8%). These farms are also more likely to use fertilizers (77.8%) than their counterparts (64.7%). Thus, the summary statistics provide snapshot evidence that the anti-land fragmentation program may affect the allocation of farm production inputs.

Table 1. Sample Statistics of the Selected Variables.

		(A) Full Sample		**(B) Eligible**		**(C) Non-Eligible**	
Variable	**Definition**	**Mean**	**S.D.**	**Mean**	**S.D.**	**Mean**	**S.D.**
Dependent Variables							
R_production	Ratio of farmland in farm production.	0.925	0.218	0.890	0.252	0.948	0.188
R_conservation	Ratio of farmland in conservation.	0.006	0.065	0.004	0.054	0.007	0.071
R_others	Ratio of farmland in other purposes.	0.069	0.210	0.106	0.248	0.045	0.176
R_fertilizer	Ratio of farmland with fertilizer use.	0.725	0.453	0.778	0.424	0.647	0.483
R_water_irrigation	Ratio of farmland with irrigation water use.	0.237	0.705	0.233	0.797	0.243	0.539
R_water_underground	Ratio of farmland with underground water use.	0.350	0.531	0.365	0.559	0.328	0.487
R_water_other	Ratio of farmland with other water sources.	0.855	2.157	0.779	2.283	0.968	1.951
Independent Variables							
Eligibility	If eligible to farm zoning program (=1).	0.597	0.490	0	-	1	-
Children	Number of family member aged <15 years old (person).	0.285	0.737	0.287	0.740	0.282	0.732
Adult	Number of family member aged ≥15 years old (person).	3.102	1.632	3.122	1.633	3.073	1.629
OP_male	If farm operator is male (=1).	0.760	0.427	0.771	0.420	0.743	0.437
OP_age	Age of the farm operator (years).	63.074	11.962	62.860	11.944	63.391	11.982
OP_junior	If the operator finished junior high school (=1).	0.227	0.419	0.229	0.420	0.225	0.418
OP_senior	If the operator finished senior high school (=1).	0.250	0.433	0.257	0.437	0.240	0.427
OP_college	If operator has college degree or higher education (=1).	0.094	0.291	0.093	0.290	0.095	0.294
Fruit	If a fruit farm (=1).	0.502	0.500	0.560	0.496	0.414	0.493
N	Number of farm households	183,600		109,661		73,939	

Note: Data come from the 2015 Agricultural Census Survey in Taiwan. Eligible and non-eligible farms are those above/below 0.25 hectares in size.

2.3. Econometric Model

To identify the causal effect of the program on the proportion of farmland used in production and the input allocation, we employ the regression discontinuity (RD) design. It has been well documented that the RD design has many merits compared to other methods, such as propensity score matching, the instrumental variable method, and the fixed effects panel data model. The most attractive feature of the RD design is that it is an alternative to randomized experiments for evaluating social programs [26]. However, the RD design cannot be applied to every case, since it depends on the program design. The RD design is only suitable in a program where individuals participate in a program depending on whether their value for a numeric rating (often called the running variable) falls above or below a certain threshold. In other words, the RD design can only be used for a program that has a clear threshold point or a cutoff point in determining the eligibility of participation. By comparing the change of the outcome variable for individuals that are just below and above the cutoff point, we can then identify the causal effect of program participation on the outcome variable. The magnitude of the discontinuity in the outcome variable around the cut-off point can then provide an objective measure of the average treatment effect (ATE) of the program [34].

In our case, only farms with farmland larger than 0.25 hectares is eligible to participate in the anti-land fragmentation program. Therefore, 0.25 hectares of farmland size serves as a cutoff point to determine the participation status of the individuals. The *ATE* of the anti-land fragmentation program can then be identified by comparing the outcome variable for farms whose sizes are around the neighborhood of 0.25 hectares. Conceptually, the *ATE* can be expressed as [26]:

$$ATE = E[\mathrm{Y}_i(1) - \mathrm{Y}_i(0)|R_i = \bar{r}] = E\left[\mathrm{Y}_i(1)\,\middle|R_i = \bar{r}^+\right] - E\left[\mathrm{Y}_i(0)\middle|R_i = \bar{r}^-\right] \quad (1)$$

where $\mathrm{Y}_i(1)$ and $\mathrm{Y}_i(0)$ denote the potential outcome of the allocation of farm land and farm inputs among farms whose farmland size is larger and smaller than 0.25 hectares, respectively. R_i is the 0.25 hectares cutoff point. Empirically, Equation (1) can be specified as a parametric form and estimated using the regression method. Given a fixed sample of farmland surrounding the 0.25 hectares, the outcome equation can be specified as [26]:

$$\mathrm{Y}_i = \alpha_0 + f(p_i) + \alpha_1 \times D_i + D_i \times f(p_i)'\alpha_2 + \beta'\mathrm{X}_i + \varepsilon_i \quad (2)$$

where Y_i is the observed outcome variable, D_i is a dummy variable of which the value is equal to 1 if the parcel of farmland is larger than the 0.25 hectares, and 0 otherwise, $f(p_i)$ is a low-order polynomial function of the running variable, X_i is a vector of the other covariates associated with farmland use and farm production use, α_0, α_1, α_2, and β are the estimated coefficients and ε_i is the random error. In Equation (2), the ATE of the anti-land fragmentation program on the outcome variable can then be identified by the coefficient α_1. The consistent estimates of the parameters in Equation (2) can be identified by using the Ordinary Least Squares (OLS) method.

The dependent variables for the main results are the ratios of farmland used in farm production, conservation, and other purposes (three variables). Similarly, the dependent variables on the use of farm production inputs are the ratios of farmland using fertilizer, irrigated water, underground water, and other water sources (four variables). In total, we estimate these seven regression models to examine the impact of the anti-land fragmentation policy on farmland use and production inputs relevant to the environment. We use STATA 14 [35] to implement the empirical analysis.

3. Results

We begin by presenting the results on the association between the independent variables and farm production, conservation, and other purposes. The results reported in Column A of Table 2 present the results on farm production. Farm operators that are male or older used more farmland for farm production, although the magnitude of these associations is minimal. Compared to vegetable farms, fruit farmers increased their ratio of farmland used for farm production by 3.9 percentage points. Column B of Table 2 presents the results on conservation. Similarly, older farm operators are also more likely to use their farmland for conservation. One explanation for these results is that elderly farmers are less likely to engage in off-farm work, causing them to use their farmland for farm production or conservation. Education affects conservation use on farmland, although the size of these effects is also minimal. Finally, Column C presents the results on farmland used for other purposes. With respect to the independent variables, the number of adults, and whether the farm operator is male decreased the ratio of farmland used for other purposes. Finally, fruit farms decreased the ratio of farmland used for other purposes by 3.5 percentage points.

Table 2. Estimation of farmland use equations.

Variable	(A) Farm Production Coef.	S.E.	(B) Conservation Coef.	S.E.	(C) Other Purposes Coef.	S.E.
Eligibility	−0.022 ***	0.003	0.000	0.001	0.023 ***	0.003
Magnitude	−2.42%		−2.64%		33.19%	
land-0.25	0.527 ***	0.053	0.004	0.045	−0.551 ***	0.051
$(\text{land-0.25})^2$	1.291 ***	0.254	−0.310	0.492	−1.203 ***	0.244
(land-0.25) * Eligibility	−0.301 ***	0.060	0.029	0.050	0.287 ***	0.057
$(\text{land-0.25})^2$ * Eligibility	−2.292 ***	0.276	0.257	0.534	2.297 ***	0.265
Children	0.000	0.001	0.000	0.000	0.000	0.001
Adult	0.000	0.000	0.000 ***	0.000	−0.001 **	0.000
OP_male	0.002 **	0.001	0.000	0.000	−0.002 **	0.001
OP_age	0.000 ***	0.000	0.000 ***	0.000	0.000 ***	0.000
OP_junior	0.002	0.001	0.000	0.000	−0.002	0.001
OP_senior	0.001	0.001	0.001 *	0.000	−0.001	0.001
OP_college	−0.005 ***	0.002	0.002 ***	0.001	0.003	0.002
Fruit	0.039 ***	0.001	-0.004 ***	0.000	−0.035 ***	0.001
County FE	Yes		Yes		Yes	
Constant	0.929 ***	0.052	0.003 *	0.002	0.068 ***	0.005
Adjusted R^2	0.244		0.121		0.244	
N	183,600		183,600		183,600	

Note: *, **, and *** denotes significance at the 10, 5, and 1 percent levels, respectively.

An advantage of the regression discontinuity design is that the effect of the policy can be visually assessed. To do this, we plot the outcome variable against the ‘running variable’ to observe the impact of the anti-land fragmentation policy [30]. Since the eligibility rule of the policy is dependent on whether the farmland exceeds 0.25 hectares, any ‘discontinuity’ in the farm production across this threshold provides intuitive evidence of the policy’s effect.

Figure 2 plots the ratio of farmland used for farm production to farmland size, which is normalized to the policy’s cutoff point at 0.25 hectares. As farmland size approaches 0.25 hectares, farmland use for farm production steadily increases. However, as farmland size exceeds the cutoff point at 0.25 hectares, there is an immediate and significant decrease in farmland use for farm production. This ‘discontinuity’ shows that the anti-land fragmentation policy reduced the ratio of farmland used for farm production.

Table 2 presents the estimation results of the anti-land fragmentation policy on farmland use while controlling for other variables. Column A shows that the anti-land fragmentation policy reduced the ratio of farmland used for farm production by 2.2 percentage points, other things being equal. The magnitude of this effect is 2.42% of the sample mean of farm production for the overall sample (0.022/0.925 = 2.4%).

Column B of Table 2 presents the estimation results of the anti-land fragmentation policy on the proportion of farmland used for environmental conservation. The policy had no statistically significant impact on the ratio of farmland used for conservation. Finally, Column C presents the estimation results of the anti-land fragmentation policy for other purposes. This farmland is typically fallow (idle) or subject to speculation for non-agricultural purposes. Results indicate that the anti-land fragmentation policy increased the ratio of farmland used for other purposes by 2.3 percentage points. The magnitude of this effect is 33% of the sample mean for farmland used for other purposes.

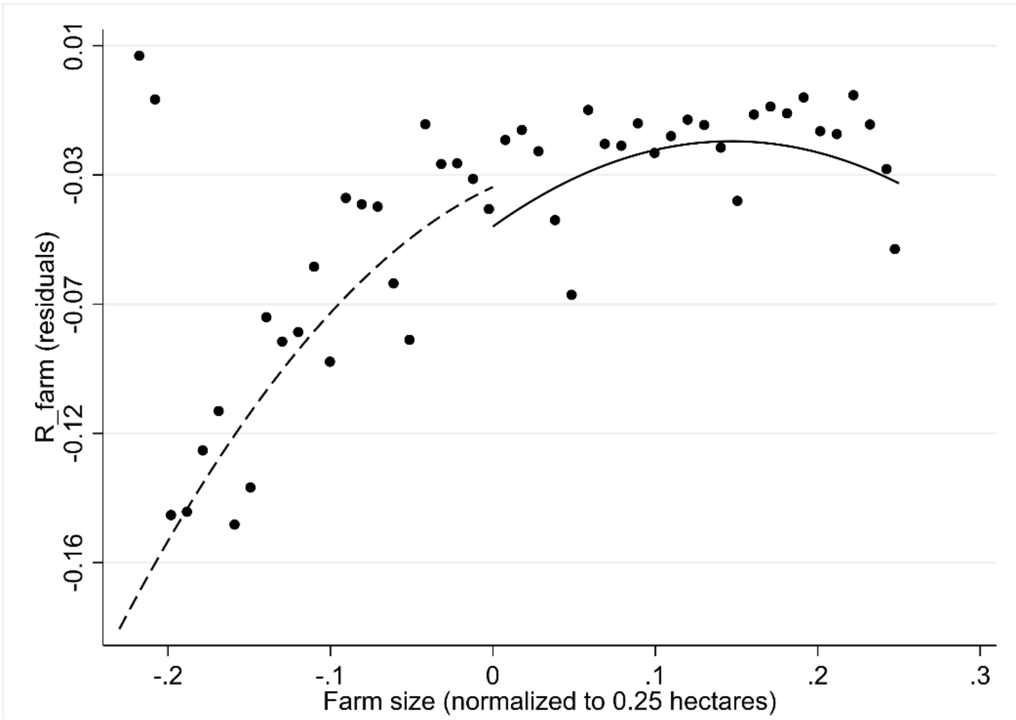

Figure 2. The effects of the anti-land fragmentation policy on the ratio of farmland production to total land. Note: the running variable is the size of farmland normalized to 0.25 hectare. The dashed and solid line are the non-parametric local-polynomial-based fits of the value of the ratio of the farmland used for farm production, after controlling for the explanatory variables.

Table 3 presents the results of the anti-land fragmentation policy on the use of farm production inputs relevant to environmental quality. The results reported in Column A show that the anti-land fragmentation policy increased the ratio of farmland using fertilizer by 1.9 percentage points. The magnitude of this effect is 2.64% of the sample mean for fertilizer use in the full sample. Results reported in Column B show that the program decreased the ratio of farmland using irrigated water by 1.7 percentage points, which is 7.33% of the sample mean for irrigated water use. Column C indicates that the policy increased the ratio of farmland using underground water by 5.1 percentage points. The magnitude of this effect is 14.58% of the sample mean for underground water use. Finally, results reported in Column D indicate that the program had no statistically significant impact on the ratio of farmland using water from other sources.

Table 3. Estimation results for production inputs relevant to the environment.

	(A) R_fertilizer		**(B) R_water_irrigation**		**(C) R_water_underground**		**(D) R_water_other**	
Variable	**Coef.**	**S.E.**	**Coef.**	**S.E.**	**Coef.**	**S.E.**	**Coef.**	**S.E.**
Eligibility	0.019 *	0.008	−0.017 *	0.010	0.051 ***	0.007	−0.105	0.028
Magnitude	2.64%		−7.33%		14.58%		−12.24%	
Other variables	Yes		Yes		Yes		Yes	
Adjusted R^2	0.125		0.183		0.190		0.147	
N	183,600		183,600		183,600		183,600	

Note: * and *** denotes significance at the 10 and 1 percent levels, respectively.

Table 4 presents the results of the anti-land fragmentation policy on farmland use on urban and rural farms. Results reported in Column A show that the anti-land fragmentation program decreased the ratio of farmland used for farm production by 2.6 and 1.9 percentage points among urban and rural farms, respectively. The magnitude of these effects is 2.83% and 2% of the sample means for their respective samples. Column B shows that the anti-land fragmentation policy had no statistically significant impact on conservation for urban and rural farms. Finally, Column C indicates that the anti-land fragmentation policy increased the ratio of farmland used for other purposes by 2.7 and 0.09 percentage points among urban and rural farms, respectively. The magnitude of this effect is 31.93% and 16.99% of the sample mean for farmland used for other purposes, respectively.

Table 4. Estimation results of the urban and rural sample.

	Urban Sample					
	Farm Production		**Conservation**		**Other Purposes**	
Variable	**Coef.**	**S.E.**	**Coef.**	**S.E.**	**Coef.**	**S.E.**
Eligibility	−0.026 ***	0.004	0.000	0.002	0.027 ***	0.004
Magnitude	−2.83%		5.33%		31.93%	
Other variables	Yes		Yes		Yes	
Adjusted R^2	0.249		0.141		0.247	
N	96,291		96,291		96,291	
	Rural Sample					
Variable	**Coef.**	**S.E.**	**Coef.**	**S.E.**	**Coef.**	**S.E.**
Eligibility	−0.019 ***	0.004	−0.001	0.002	0.009 ***	0.004
Magnitude	−2.00%		−18.37%		16.99%	
Other variables	Yes		Yes		Yes	
Adjusted R^2	0.178		0.091		0.230	
N	87,309		87,309		87,309	

Note: *** denotes significance at the 1 percent level.

4. Discussion

The results highlight the importance of the anti-land fragmentation program on the allocation of farmland used for production and other purposes. The '2000 Agricultural Development Act' was intended to increase farm production and the scale of farms in Taiwan [30]. However, the policy had the opposite effect since it decreased the amount of farmland used for farm production. Although the anti-land fragmentation policy had strict rules on dividing or transferring farmland, one explanation for these results is that it also allowed landowners to construct a farmhouse if their farmland is larger than 0.25 hectares.

Why does the proportion of farmland used for farm production decrease due to the anti-land fragmentation program? One likely reason can be attributable to the option value of the farmland resulting from the implementation of the program. That is, the policy created an optional amenity that applied to eligible farms. Chang and Lin [30,36] have shown that this component of the anti-land fragmentation program has decreased farm incomes and increased farm values since farmhouses are only permissible on farmland larger than 0.25 hectares in size. These farmhouses can be used for future urban development. Similarly, the anti-land fragmentation policy reduced farm production since farmhouses can generate higher returns from non-agricultural purposes than agriculture.

The results on farmland use in urban and rural areas are also consistent with this argument. We show that farmland where farmhouses can be constructed are more valuable on the residential housing market due to their proximity to nearby cities, where they are bought as recreational homes. In contrast, farmhouses in rural areas have less value. Thus, the anti-land fragmentation policy had more adverse effects on farm production in urban areas compared to rural areas.

Our findings are policy relevant. Governments should ensure that agricultural zoning and anti-land fragmentation programs are carefully designed to avoid creating economic incentives that hinder their effectiveness. Although the anti-land fragmentation has discouraged the cultivation of smaller parcels of farmland, it has also spurred the construction of farmhouses that are not used for farm production. We suggest two changes to the anti-land fragmentation program in Taiwan. First, authorities should tax farmhouses used for non-agricultural purposes since they are currently tax-exempt in Taiwan. These financial charges will reduce the economic distortions caused by the anti-land fragmentation program. Second, the anti-land fragmentation policy should be based on additional requirements other than farm size. Other variables that affect things such as agricultural productivity and soil quality should be considered when implementing anti-land fragmentation policies to ensure that farmland is being used for agriculture.

Consistent with the literature on agricultural production functions, we found that the anti-land fragmentation program encourages eligible farms to apply fertilizers. Since farmland is one of the necessary inputs in agriculture, increases in the scale of farming can also increase the amount of farm production inputs being used [37]. Fertilizers are an especially common production input in Taiwan, as the Council of Agriculture has subsidized their cost because farmers generously spray their fields to protect against exogenous shocks (e.g., weather and production-related concerns) [38]. Subsequently, 378,928 hectares (two-thirds) of the island's cultivated land is treated using fertilizers [39]. As farms increase in scale, they are also more likely to apply fertilizers.

At the same time, farms are increasingly relying less on irrigation systems while pumping more underground water. Taiwan entrusts irrigation associations to operate irrigation systems across the island's hydraulic regions, which service nearly 400,000 hectares [40,41]. Irrigation associations are highly autonomous and can charge and levy water fees on farmers [40]. However, larger farms are less likely to use irrigated water since farmers need to pay for these services. In contrast, underground water is unregulated and only involves the cost of extraction in Taiwan. For example, reports from the Council of Agriculture suggest that 15,000 out of 17,000 groundwater wells in the Pingtung Alluvial Plain in southwestern Taiwan are illegal [42]. Thus, the anti-land fragmentation policy has resulted in farmers substituting their water source from irrigation systems to groundwater wells.

Another policy implication from this study indicates that agricultural zoning and anti-land fragmentation programs must also consider how they impact farm production inputs relevant to environmental quality. Research has shown that fertilizers can degrade land quality and result in soil contamination [43]. Similarly, excessive pumping of underground water will cause land salinization and subsidence [42]. Although the anti-land fragmentation policy had the objective of increasing the size and amount of farmland used for farm production and the scale of farms, these governments should consider their undesired effects on environmental externalities and educate farmers on how to reduce these farm production inputs when possible.

Finally, our paper connects anti-land fragmentation programs with the complex discussion on agricultural intensification and sustainable intensification. There is ongoing research (particularly among environmentalists) on how to manage farmland use with respect to agricultural and environmental concerns. For example, the land-sparing theory suggests that small, but highly productive parcels of farmland would allow for a greater amount of farmland to be used for conservation [44,45]. Although the literature on this approach has not yet reached a consensus (and is dependent on area- and environment-specific variables), our results show that public policies such as anti-land fragmentation programs that are designed to increase farmland use may have the opposite effect. Our results highlight the importance of challenges that measures designed to increase agricultural intensification (i.e., anti-land fragmentation and land-sparing) have in reaching their desired outcome.

5. Conclusions and Research Limitations

This paper examines the impact of an anti-land fragmentation policy on farmland use and farm production inputs relevant to the environment using population-based census survey data in Taiwan. Although there is considerable research on the effects of land consolidation, this study is among the first that examines the relationship between agricultural zoning and land fragmentation. We applied the regression discontinuity method using eligible and non-eligible farms to carefully identify the policy's causal impacts.

We found that the anti-land fragmentation policy reduced farmland use of farm production. Furthermore, the policy also increased the intensity of fertilizer use while encouraging farmers to substitute their water source from irrigation systems to groundwater wells. The effects on farm production are more pronounced on urban farms. To explain these results, we postulate that the anti-land fragmentation policy spurred the construction of farmhouses that created economic incentives reducing farmland production. In contrast, the policy also contributed to larger farms that will use more fertilizers and feasibly pump underground water.

Although some interesting findings are revealed, some caveats remain. For example, in accordance with the information documented in the survey, we can only examine the effect of the anti-land fragmentation on farmland use and farm production inputs. Information on the labor use between on-farm and off-farm work of the farm household was not documented in our dataset. If this type of information becomes available, we can further examine whether the program changes the allocation for labor use between on-farm and off-farm work of the farm household. Farm production is also associated with soil quality and land productivity. With these data, we would be able to check the robustness of our findings for unobserved farmland characteristics. Finally, our study can benefit from collecting additional information on farmland prices for each parcel of farmland. With the precise information on farmland prices, we can identify the mechanism on the option value of land resulting from the anti-land fragmentation policy.

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