ABSTRACT OF THE DISSERTATION OF

Toru Hagimoto for the degree of Doctor of Philosophy in AppliedEconomics presented on June 10, 2015.

Title: Essays of Land Use Changes, Open Space, and Water Pollution

Abstract Approved:

Christian A. Langpap

Land use is one of the leading factors that cause environmental degradation, such as water pollution, open space contraction and habitat loss. This dissertation consists of three essays. First paper investigates the relationship between land use and water pollution. Combining land use choice model and water pollution data, I simulate the effects of the policies that changes returns to land uses such as afforestation payments in five watersheds in Japan. From this simulation, I derive abatement cost of chemical oxygen demand, total nitrogen, and total phosphorous and I reveal that afforestation payment is best policy for most of pollutants and regions but in some regions it increases chemical oxygen demand. The cost data is then compared with abatement cost from upgrading and construction of sewage treatment plants to compare relative

efficiency and show that combining both policy is sometimes more efficient that single policy. The second essay focuses on one watershed in Japan and I analyze the effect of the subsidy that promotes eco-friendly agriculture using fixed effect panel. Using budget as abatement cost, policy effect is estimated and compare it with land use subsidy and sewage treatment construction and upgrade cost. For my study area, afforestation payment is most cost effective while investing sewage treatment plants are least cost effective but the result depends on existing sewage treatment plants and regional characteristic. The third model focuses on land use and open space. Even though previous study (Bento et al. 2006) revealed that a tax and an urban growth boundary is equivalent in terms of efficiency. When I relax assumption by adding uncertainty and heterogeneity in soil quality, I show counterexamples of equivalence of two policies.

Essays of Land Use Changes, Open Space, and Water Pollution

by

Toru Hagimoto

A DISSERTATION

submitted to

Oregon State University

in partial fulfillment of

the requirements for

the degree of

Doctor of Philosophy

Presented June 10, 2015

Commencement June 2016

Doctor of Philosophy dissertation of Toru Hagimoto presented on June 10, 2015

.

APPROVED:

Major Professor, representing Applied Economics

Director of the Applied Economics Graduate Program

Dean of the Graduate School

I understand that my dissertation will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my dissertation to any reader upon request.

Toru Hagimoto, Author

ACKNOWLEDGEMENTS

I am very grateful for this opportunity to pursue a Doctor of Philosophy degree at Oregon State University. First, I would like to express my gratitude to my major professor, Dr. Christian Langpap. I appreciate your encouragement, guidance, understanding, and support throughout my program. Dr. Yong Chen also gave me great support throughout my coursework and as I developed my thesis.

I would also like to thank Dr. Junjie Wu, Dr. William Jaeger, and Dr. Jonathan Kaplan for serving on my committee and for their insightful comments and suggestions on this dissertation. Great thanks also to the faculty and staff and my fellow classmates from the Applied Economics Program for their help and support.

Finally, I would like to give thanks to my family and friends. Without their support, I could not have made it this far.

Toru Hagimoto

June 10, 2015

TABLE OF CONTENTS

Page

TABLE OF CONTENTS (Continued)

Page

TABLE OF CONTENTS (Continued)

Page

TABLE OF CONTENTS (Continued)

Page

Essays of Land Use Changes, Open Space, and Water Pollution

Chapter 1

General Introduction

Land use is one of the leading factors that causes water pollution. Once land is developed, its surface becomes impermeable, and water cannot pass through like it can with undeveloped land such as agricultural land and forests. Runoff water quickly flushes water pollution, especially during storms, and this causes water pollution (U.S. Department of the Interior, 2003). Cropland is also a major source of nutrient loading, overproducing elements such as phosphorous and nitrogen (U.S. Environmental Protection Agency, 2005). When these chemicals exceed plant needs, or nutrients are washed out by rain, they flow into aquatic ecosystems and cause algae blooms, remove oxygen from the water (which kills fish), create foul taste and odor, and even cause potentially fatal disease in infants. Since different forms of land use have different pollution loading, it is important to include several forms of land use in researching their effects. These include agriculture, forest, urban land, and others.

The effect of pollution is different among regions. If a watershed is mainly covered with forest, water does not flush at once when it rains as it does on urban surfaces. In addition, since soil acts as a water filter, water that runs through permeable surfaces has a tendency to become cleaner than water that runs through impermeable ones, and soil quality affects water quality. Slope also affects the direction of water flow. As a result, across regions, there are differences in how many nutrients reach water bodies even among the same land uses. Therefore, a policy that is sui*table* to one watershed may not fit well with other watersheds.

In Japan, sewage treatment water is also major source of water pollution, which accounts for 26.4% of chemical oxygen demand (COD), 28.8% of total nitrogen (T-N) and 36.2% of total phosphorous (T-P) (Ministry of Land, Infrastructure, Transport, and Tourism et al., 2006). Historically, the Japanese government has mitigated the water pollution problem by building efficient treatment plants (Ministry of the Environment 2012), so it is difficult to achieve further improvement through better treatment plants in some regions.

Agriculture is another major source of water pollution, soin addition to policies that attempt to affect land use decisions, water quality can be improved by policies that target agricultural practices, such as best management practices or set asides. In Japan, the local government of Shiga Prefecture adopted agri-environmental schemes that subsidize farmers who adopted environmentally friendly practices since 2004. Since policies that attempt to change returns to land use (such as development taxes, afforestation payment, or agricultural subsidies) have small impacts (Langpap et al., 2008), subsidizing farmers who voluntarily change their behavior to environmentally friendly practices might be a more cost effective option.

Land use also is a cause of open space contraction. Since individuals do not take land development externalities into account, private equilibrium does not result in social optimality. To control urban size, urban growth boundaries (UGB) have been adopted in some parts of the United States. For example, Portland's growth boundary was adopted in 1979 as part of Oregon's statewide growth management law (Oregon Department of Land Conservation and Development, 2000). Also, rather than controlling the quantity of development, economists advocate market-based instruments such as development impact fees (Bento et al., 2006). When there is no uncertainty, both mechanisms achieve same level of efficiency. However, when there is uncertainty, price mechanism and quantity mechanism are no longer equivalent (Weitzman 1974, Weitzman 2002, Malcomson 1978). Even though this comparison is discussed in

many fields (Wu and Babcock 1999 discussed this for NPS pollution, for example), in the field of urban development, this uncertainty is not yet fully discussed.

This dissertation consists of three essays that collectively address issues related to land use, agriculture, water quality, and open space. In particular, each paper compares the relative efficiency of policies and gives guidelines to help policymakers.

The first essay (Chapter 2), *Cost analysis of non-point source and point source water* *pollution*, examines the effects of land use on water pollution (COD, T-N, and T-P) loading. It estimates the cost of pollution abatement policies that alter land use returns in five watersheds in Japan. Sewage treatment plant data is used to derive abatement costs for four of the watersheds. These abatement costs from land use and sewage treatment plants are compared to decide which policy is cost-effective for each watershed and pollutant.

The second essay (Chapter 3), *Agri-environmental payments and water pollution in Japan*, evaluates best management practices in the Shiga region of Japan and estimates the cost of abating water pollution using an agri-environmental payments (AES) policy. This abatement cost is compared to the abatement costs of policies that change both land use returns and that rely on building improved sewage treatment plants.

The third essay (Chapter 4), *The efficiency of urban development policies for heterogeneous land*, conducts an exploratory investigation of the relationship between land use and open space. Specifically, this paper compares the relative efficiency of a development tax and a UGB. Bento et al. (2006) shows that a tax and a UGB are equivalent in terms of efficiency in a statistical setting. This essay modifies the assumption in realistic ways. First, I add heterogeneity of soil quality across the landscape. Second, I assume there is information asymmetry between the regulator and the landowners. Under these settings, I check the equivalence of a development tax and a UGB.

References

Bento, Antonio, Franco, Sofia, and Kaffine, Daniel. "The efficiency and distributional impacts of alternative anti-sprawl policies." *Journal of Urban Economics* 59 (2006): 121-141

Langpap, C, Hascic, I, and Wu, J. (2008), "Protecting Watershed Ecosystems through Targeted Local Land Use Policies." *Am. J. Agr. Econ.* 90: 684-700

Malcomson, J. M. (1978), "Price vs Quantities: A Critical Note on the Use of Approximations.", *Review of Economic Studies* 68: 203-207

Ministry of Land, Infrastructure, Transport, and Tourism, Ministry of Agriculture, Forestry and Fisheries, and Ministry of the Environment. "Kosyousuishitu no tameno ryuuikitaisaku no kihonteki kangaekata [Basic concepts of controlling water pollution by watershed management]" (2006)

Minstry of the Environment. "Heisei 23 nendo Koukyouyousuiiki suishitsu sokuteikekka [Water quality measurement of public water in Japan]" (2012)

Oregon Department of Land Conservation and Development (2000), "Oregon Land Use Laws Update – Urban Growth Boundaries and Future Growth." *Inside the Boundaries,* Oregon

U.S. Department of the Interior (2003), "Effects of Urban Development on Floods.", *U.S. Geological Survey Water Resources,* Tacoma, WA

U.S. Environmental Protection Agency (2005), "Agricultural Nonpoint Source Fact Sheet.", Washington, DC

Weitzman, Martin L. (1974), "Prices vs. Quantities.", *The Review of Economic Studies* 41: 477-491

Weitzman, Martin L. (2002), "Landing Fees vs Harvest Quotas with Uncertain Fish Stocks.", Journal of Environmental Economics and Management 43: 325-338

Wu, Junjie and Babcock, Bruce (1999), "The Relative Efficiency of Voluntary vs Mandatory Environmental Regulations." *Journal of Environmental Economics and Management* 38: 158-175

Chapter 2

Cost analysis of non-point source and point source water pollution abatement

Abstract

Land-use and sewage water are two major sources of water pollution. Applying a discrete land use model to hydrological data, I estimate the abatement cost of non-point source water pollution for five watersheds in Japan (Inba, Tega, Biwa, Kojima, and Kamafusa). The results suggest that afforestation payments are cost-effective for treating total nitrogen (T-N) and total phosphorous (T-P). However, afforestation payments increase chemical oxygen demand (COD) in two watersheds (Kojima and Kamafusa), which suggests it is preferable to adopt regionally specific policies rather than national policies. This paper also explores sewage plants, which are a major point source of water pollution in four watersheds (Inba, Tega, Biwa, and Kojima). Using engineering data, the abatement cost of pollution from sewage plants is also calculated. Even though Japanese governments have tried to address eutrophication by building sewage treatment plants, the estimation results suggest that afforestation payment has an advantage in terms of cost-effectiveness for some pollutants.

2.1 Introduction

According to the water quality measurement of public water in Japan for 2011 (Ministry of Environment 2012), only 53.7%, 12.8%, and 51.3% of lakes satisfied water standards for COD (Chemical Oxygen Demand), Total Nitrogen (T-N), and Total Phosphorous (T-P), respectively. To overcome this situation, the Japanese Ministry of Environment (MOE) has set strict water emission standards and encouraged constructing advanced sewage treatment plants (MOE, 2012) to reduce water pollution from point-sources (PS). However, as shown in *table* 2.1, non-point-source (NPS) pollution accounts for 41-63% of overall water pollution, and therefore it is important to analyze both PS and NPS for cost-effective pollution reduction.

Table 2.1 The sources of water pollution in Japanese lakes/ponds/seas

	Point Source Pollution				Non-point Source Pollution			
	Sewer	Industry	Livestock	PS Total	Ag.	Urban	Forest & Rain[1,2]	NPS Total
COD	26.4%	8.2%	2.6%	37.2%	10.9%	16.5%	35.4%	62.8%
T-N	28.8%	9.1%	4.9%	42.7%	15.2%	12.4%	29.7%	57.3%
T-P	36.2%	18.7%	4.5%	59.5%	9.3%	8.6%	22.6%	40.5%

[1] Mountains cover about two-thirds of Japanese land, and their primary land use is forests. Although per hectare pollution is lower relative to other land uses, the large area makes forests the primary source of pollution.

[2] In addition to tree debris and animal manure, atmospheric deposition of air pollution is piled up on the surface, and rain water flushes out this pollution.

NPS pollution is closely related to land use, and land use change is one of the main reasons behind degradation of watershed ecosystems (Langpap et al., 2008). Among NPSs, many studies focus on agriculture (Lankoski et al., 2008, Malik et al., 1993, Breetz et al., 2005, Isik 2004, Lintner and Weersink, 1999, Aftab et al., 2007, Kampas and White, 2004, Prabodanie et al. 2010, Fleming and Adams, 1997, and Wu et al. 2004). However, agriculture accounted for 32%, 60%, and 49% of NPS pollution of COD, T-N, and T-P in the study area discussed in the next section in the year 2000[3]. Therefore, in this case it is important to account for urban and forest land use in addition to agriculture.

There are several empirical articles that use land use models to simulate environmental outcomes (Lubowski et al., 2006, Langpap et al., 2008, Lewis et al., 2011, Li, 2010). Lubowski et al., (2006) use a land use model to simulate the cost of forest-based carbon sequestration. Langpagp et al.,(2008) combines a land use model and watershed indicators to simulate the effect of incentive based policies, property acquisition policies and policies that alter land use returns. Lewis et al. (2011) use a land use model to investigate the relative efficiency of biodiversity conservation objectives. Li (2010) applies a land-use change model to estimate soil carbon sequestration in

[3] The Industrial sector is also a major source of PS pollution (8.2% to 18.7%). However, the industrial sector is not included since only output level data are available.

China.

There are few papers that use a land use model to examine the effects of land use choices on water pollution. Langpap et al. (2008) combine a land use choice model and three measures of watershed health, namely conventional water pollution, toxic water pollution, and the number of aquatic species at risk, and show that policies that attempt to change land use returns have smaller effects than local incentive-based and property acquisition policies, such as preferential property taxes and purchase or transfer of development rights. Wu and Irwin (2008) theoretically analyze the dynamic interactions between land development and water quality. They show that interactions between the economic and ecological systems need to be considered. Following Wu and Irwin, Tanaka (2010) empirically tests the relationship of land development and water quality and shows that there is endogeneity between land development and water quality. However, Tanaka does not use a hydrological model.

In this essay, I combine a land use model with watershed level pollution indicators. This is done by estimating an econometric model of land use choice that investigates the determinants of land use choice, such as the returns to different land uses and geological characteristics. After that, I simulate the effect of land use policies that change land use returns. The simulation results of land use areas are then combined with pollution data and give watershed-specific NPS abatement costs for each policy scenario. The results suggest that for controlling T-N and T-P, a land use subsidy that increases forest returns is the most cost effective policy option for all watersheds. However, for abating COD, a forest subsidy is not preferable since it actually increases pollution in three watersheds—this shows the importance of using regional and pollution-specific policies rather than a uniform policy.

In addition to NPS, PS is also an important source of water pollution. As shown in *Table 2.1*, sewage treatment plants are the primary type of PS, accounting for two-thirds of PS pollution loading. Although several papers cover sewage plants in the context of water pollution trading between PS and NPS, most of them do not use actual data to conduct simulations. Only Hanson and McConnell (2008) use actual sewage plant data and show that water pollution trading is beneficial compared to the Maryland Scheme, which taxed residents in order to collect a subsidy to upgrade sewage treatment plants. This research uses actual cost data of sewage plants, and it is more detailed than data used in previous research. In addition, since the data covers multiple watersheds, I show a clear difference in cost efficiency of sewage plants across watersheds due to differences in technology of existing plants.

Using these cost estimates, I compare the abatement cost of PS and NPS pollution and discuss cost-effectiveness. I show that traditional Japanese policies that focus on investing in advanced sewage plants are not uniformly preferable according to a cost effectiveness criterion, since subsidizing forest returns is cheaper than building advanced sewage plants in some areas.

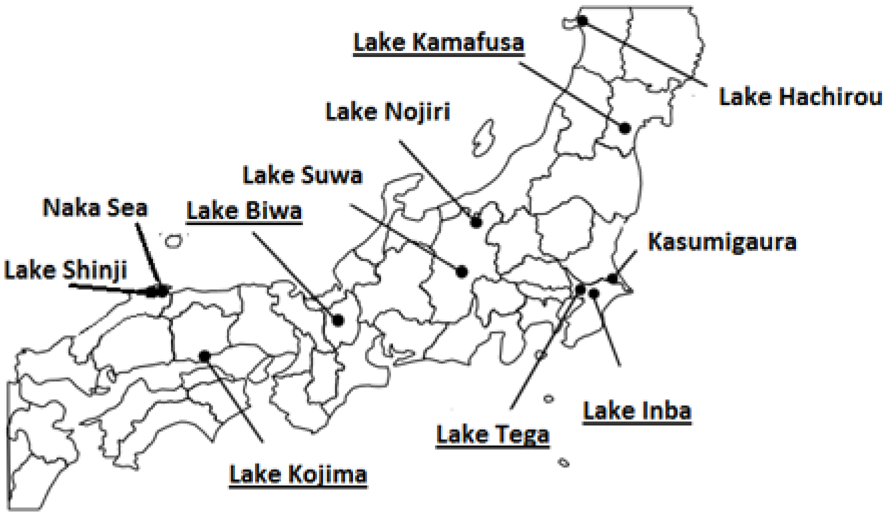
This paper consists of eight sections. In section 2.2, the study area is explained. In section 2.3, models of NPS and PS water pollution are explained. Data description and sources are explained in section 2.4. In section 2.5, results for the NPS model and PS estimation are presented, and NPS and PS abatement costs are compared. The conclusion and references follow.

2.2. Study area

The study area encompasses five eutrophicated watersheds across Japan. The Japanese government designated eleven major watersheds (*Figure 2.1*) as priority places to improve water quality and required local governments to set water pollution reduction plans every five years for these watersheds. Among these eleven watersheds, I choose five watersheds to analyze (underlined on *Figure 2.1*). I omitted Nojiri, Suwa, Naka, and Shinji watersheds because of limitations in measurement of important spatial characteristics, such as area and distance. In addition, watersheds Kasumigaura and

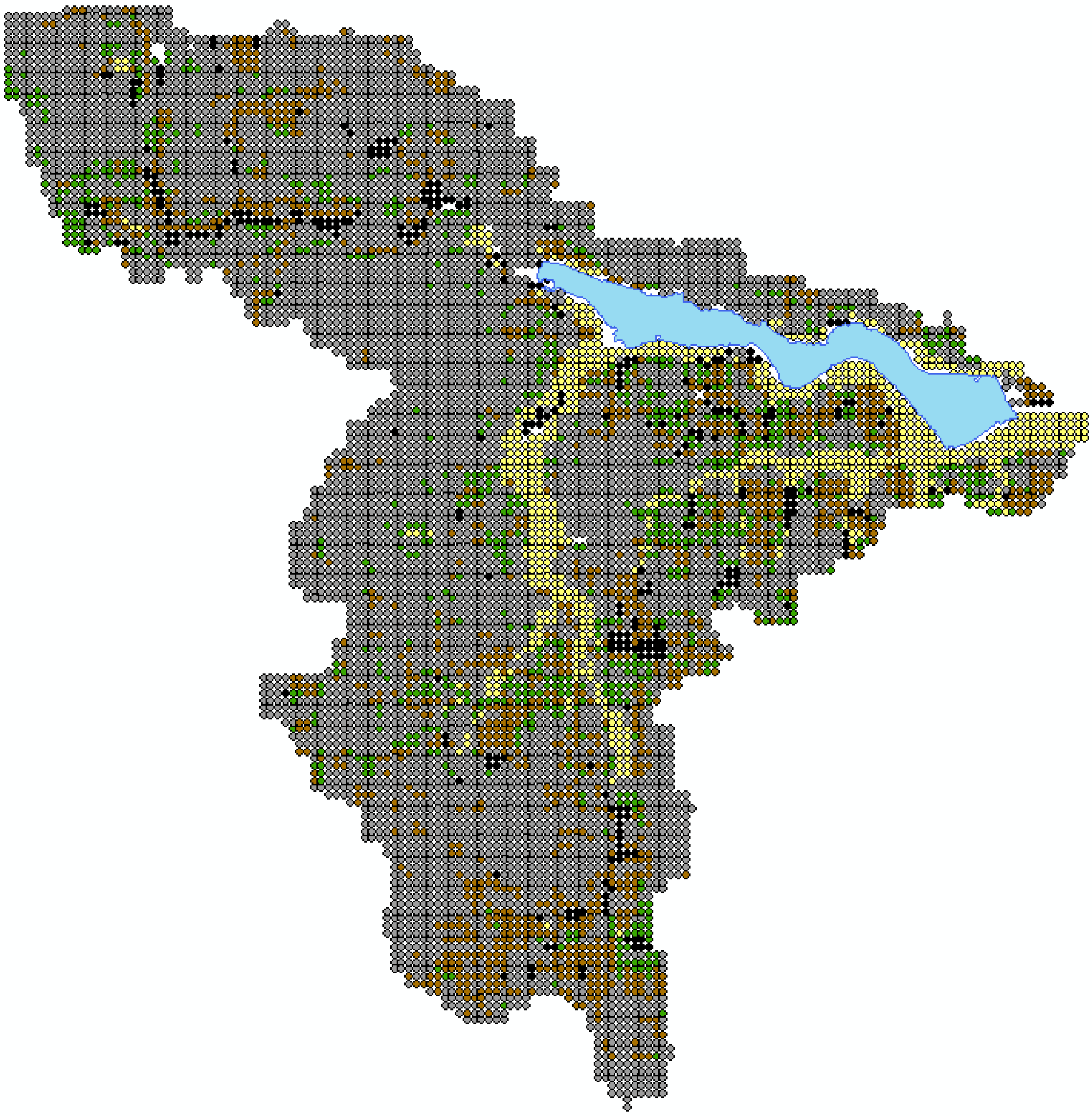
Hachirou are omitted due to sewage data availability.

Figure 2.1 – Location of Priority Lakes in Japan



The remaining five watersheds—Kamafusa, Inba, Tega, Biwa, and Kojima—are located in 4 prefectures: Miyagi, Chiba, Shiga, and Okazaki. Data from these 4 prefectures are used for analysis. For simplicity, watersheds Inba, Tega, Biwa, Kojimam and Kamafusa are named as watershed-1 to watershed-5, respectively. For the PS pollution analysis, only watersheds Inba, Tega, Biwa, and Kojima are used due to data availability. Figure 2.2 shows land use in watershed Tega. Blue area is Lake Tega, gray plots are urban land, brown plots are cropland, yellow plots are paddy fields, green plots are forests, and black plots are other land use.

Figure2.2 Land use in watershed Tega



2.3. Models of NPS and PS water pollution

2.3.1. Land use model

Assume that landowners maximize their net returns by choosing land uses among urban lands, croplands, and forests (Capozza and Helsey, 1990 and Capozza and Li, 1994). This is expressed as follows. Let V_{ijt} be the present value of expected net returns to land i which is used as *j* (*r* = rice paddy, *c* = cropland, *f* = forest, *u* = urban land, and *o*=other) at time t. Then a landowner chooses land use j if $V_{ijt} \geq V_{ikt}$ for all $k \neq j$, which means land use j's return is highest. V_{ijt} consists of two parts: $V_{ijt} = \beta_j' v_{ijt} + \varepsilon_{ijt}$, where $v_{ijt} = (\bar{\pi}_{ijt}, X_{ijt})$, $\bar{\pi}_{ijt}$ is an average net returns to land use j on parcel *i* at *t*[4], and X_{ijt} includes site specific characteristics such as urban development pressure, geography (slope and elevation), and soil quality. β_j' is a vector of parameters to be estimated, and ε_{ijt} is a random error.

Following Langpap et al. (2008), I assume the errors are independent and identically distributed (IID) with a Gumbel distribution, which implies that the probability of owners of land *i* choosing land use *j* at time t can be expressed using a multinomial logit model:

$$\text{Prob}_{ijt} = \frac{e^{\beta_j' v_{ijt}}}{\sum_{k=r,c,f,u,o} e^{\beta_k' v_{ikt}}} \qquad j = r, c, f, u, o$$

The multinomial logit model implies the assumption of independence from irrelevant alternatives (IIA). This assumption is tested by using a Hausman specification test (Hausman and McFadden, 1984). They suggest that if a subset of the choice set is irrelevant, then subtracting it from the model altogether will yield inefficient but still

[4] Due to data availability, municipal or prefecture average is used for estimation.

consistent parameter estimates, whereas if the IIA assumption is not true, then excluding that choice subset will yield inconsistent estimates. The results are listed in *Table 2.2*, which indicates that I cannot reject the assumption of IIA for any of the land use choices.

Table 2.2 Hausman test for IIA assumption

Omitted Variable	Chi_square	Prob>chi2
Rice	-2.40E+05	1.000
Crop	-2.30E+05	1.000
Forest	-1.20E+05	1.000
Urban	-2.50E+05	1.000
Other	-1.90E+05	1.000

2.3.2. Non-Point Source Pollution models

The Japanese government estimated per hectare water pollution caused by each land use for the five watersheds in the study area, as listed in *table*s 2.3-5. These data were derived by the MOE on the basis of a literature review and water quality measurements (MOE, 2005). There are two main reasons to use per hectare pollution data instead of using a physical water pollution model. First, due to its simplicity it is possible to cover many regions of Japan as opposed to a physical model such as SWAT, which sometimes can only cover 10% of one region. Second, hectare pollution data relies on parameters used by the Japanese government to estimate the impact of land use on water quality.

The data are therefore considered reliable for use in policy simulations. The limitation for using watershed level pollution data is that it cannot account the heterogeneity within the watershed. For example, land locates closer to a watershed have bigger impact than land locates further to watersheds with respect to pollution.

Table 2.3 COD pollution (kg/ha/year)

COD	Rice	Crop	Forest	Urban
Watershed1	41.2	16.5	14.6	65.7
Watershed2	40.9	16.5	14.6	65.7
Watershed3	43.1	22.6	17.3	52.6
Watershed4	50.7	8.2	14.1	35.9
Watershed5	53.8	38.3	57.2	57.7

Table 2.4 - T-N pollution (kg/ha/year)

T-N	Rice	Crop	Forest	Urban
Watershed1	10.3	36.2	3.7	13.5
Watershed2	10.4	36.1	3.7	13.5
Watershed3	14.3	95.3	6.8	14.1
Watershed4	11.4	2.4	1.4	7.5
Watershed5	22.9	42	5.1	5.4

Table 2.5 T-P pollution (kg/ha/year)

T-P	Rice	Crop	Forest	Urban
Watershed1	1.24	0.41	0.12	1.26
Watershed2	1.26	0.39	0.12	1.26
Watershed3	0.98	0.2	0.13	0.73
Watershed4	4.89	0.65	0.08	0.7
Watershed5	0.37	0.49	0.29	0.26

The coefficients in *table*s 2.3-2.5 are multiplied by the size of a catchment area[5] to derive water pollution loading for a watershed. Combing these values with econometric results allows me to simulate the effects of land use policies such as subsidies and taxes on pollution reduction. I do this in two stages. First, I simulate the effects of land use policies on land use choices by using the estimated model described in the previous section. The policy scenarios I consider are subsidies for rice, crops, and forests, and a tax on the returns to urban land. The reason for taxing urban land while subsidizing rice, crops and forests is because urban land use often causes water pollution, especially regarding COD relative to other land use. Urban land use also causes other effects such as air pollution, habitat loss, and open space degradation. I then use the estimated coefficient from the land use model to calculate the predicted area of each land use for each watershed under each of these policies and multiply the per hectare pollution listed on *table*s 2.3-2.5 to get total estimated pollution for each scenario.

To simulate the effects of policies that change the net returns of land use, I change the value of net returns for each land use, which range from 10,000 yen per ha to 100,000 yen per ha. For instance, a 10% subsidy for rice increases the returns to paddy fields by 41,234 yen while a 10% subsidy for crops increases the returns to crop land by

[5] ArcGIS is used to calculate catchment area.

145,827 yen. The simulation is computed by STATA, and I report the average results from one thousand simulations.

2.3.3. Point-source pollution estimation

This section describes how to estimate water pollution reduction from sewage plants. There are two options to reduce pollution from sewage plants.[6] The first option involves modifying existing plants. Rapid filtration (RF), Flocculation (F), and Activated carbon (AC), and Ozonation[7] are examples of technologies that could be adopted in existing plants but the required modifications might be infeasible due to constraints related to space or existing plant structure. I assume that there is enough space for modification in this model, but this might cause overestimation of pollution reduction potential.

The second option is to demolish an existing plant and build a new treatment plant. This option reduces pollution significantly if the existing plants are not effective at abating pollution, but building a new plant is costly. There are several kinds of sewage plants available, such as the conventional activated sludge process (CAS), the

[6] Another option is to increase connectivity to existing sewage treatment plants. However, it is difficult to calculate the cost of new connections because it depends on the distance from the existing sewer pipe but those data are unavailable and therefore I focus on the first and second option.
[7] Ozonation cost data is not available

modified Ludzack-Ettinger process (MLE), and the multistage nitrification-denitrification process (Multi). Among these, I choose Multi for the new construction scenario and assume that Multi has F, RF, and AC installed. This is because Multi reduces pollution the most and building other types of sewage plants does not reduce pollution compared to modification (*Table 2.6*). As for cost, converting CAS to MLE is more expensive compared to converting CAS to Multi for 4 plants out of 5.

Table 2.6 Removal ratio of pollution for each sewage treatment plants

Name of Sewage Plants	Modification			Removal ratio		
	F	RF	AC	COD	T-N	T-P
CAS	1	0	0	86.3%	28.3%	89.00%
	1	1	0	89.5%	28.30%	93.00%
	1	1	1	95.3%	41.70%	93.00%
MLE	0	0	0	86.3%	70.00%	55.00%
	1	0	0	87.4%	70.00%	89.00%
	1	1	0	89.9%	73.80%	90.70%
	1	1	1	95.3%	79.00%	93.00%
Multi	0	0	0	86.3%	76.70%	55.00%
	1	0	0	87.4%	76.70%	89.00%
	1	1	0	93.2%	81.30%	93.00%
	1	1	1	95.9%	83.70%	93.00%

Note: A 1 indicates corresponding modification is installed while 0 indicates not installed

Source: Japan Sewage Works Association (2008).

Among the five watersheds in the study area, three watersheds (watershed-1 (Inba), watershed-2 (Tega), and watershed-5 (Kamafusa)) drain treated water out of their watersheds because the treated water is not clean enough, and the watersheds are relatively small. In this case, building new plants or modifying existing equipment does not improve water quality of the watershed. Thus, controlling NPS pollution is preferable. However, for the purpose of the comparison exercise carried out here, I assume that treated water is drained into the waterbody for watershed-1 (Inba) and watershed-2 (Tega). This allows me to compare results with those of watershed-3 (Biwa) and watershed-4 (Kojima), where sewage water travels to the waterbodies within the watersheds[8].

I calculate the cost of abating PS pollution from sewage treatment plants by using engineering costs of sewage plants. These data are from Japan Sewage Works Association (JSWA) (JSWA, 2008). For estimation of the cost, I first evaluate existing sewage plants' operating cost and the amount of pollution reduced. Construction and operating costs are a function of capacity of water treated[9] and technology adopted. Examples of these costs are listed in *Table 2.7*.

---

[8] Watershed-5 Kamafusa is omitted since water pollution reduction data are not available.
[9] The capacity for each plant is not available, but the total capacity for each region and the total amount of water treated by each plant are available. Based on this information, I assume that each plant's capacity is proportional to the amount of water it treated.

Table 2.7 Cost of sewage plants

Sewage technology[10]	Construction cost (million yen)	Operation cost (million yen)
CAS	$1550C^{0.58}J$	18.8C^$^{0.69}$J
CAS with Flocculants	$1550{*}C^{0.58}J+54.1C^{0.67}K$	$18.8C^{0.69}{*}J+0.926C^{0.99}K$
MLE	$1550C^{0.58}J+86C^{0.8}K$	$18.8C^{0.69}J+1.2C{*}K$
MLE with Flocculants	$1550C^{0.58}J+93.1C^{0.83}K$	$18.8C^{0.69}J+1.59C^{1.01}K$
Multi with Flocculants	$1620C^{0.60}J$	$20.5C^{0.72}J$
Rapid Filtration	$353C^{0.46}K$	$0.739C^{0.92}J$
Activated Charcoal	$570C^{0.53}K$	$2.52C^{0.92}J$

C: capacity of water treatment (1000m^3/day)

J: (103.3/101.5) K: (103.3/101.1) are index that adjust price level from different year.

CAS (Conventional Activated Sludge Process) MLE (Modified Ludzack-Ettinger Process) Multi (Multistage Nitro and denitrification process)

Source: Japan Sewage Works Association (2008)

For existing facilities, operating costs are calculated using *Table 2.7* and the capacity of water treated. Building costs are annualized by multiplying $\frac{r(1+r)^T}{(1+r)^T-1}$ where r is the interest rate set to 0.05 and T is the expected lifetime, which is 32.5 years (Shiga, 2009). This annualized building cost is added to the operating cost to get annual total cost. This annual cost is subtracted from the original operating cost to get the annual cost of the scenario.

Pollution reduced by sewage treatment plants is calculated by multiplying sewage

[10] Since the exponent is less than 1 except for Operation cost of MLE with Focculants, there is an economy of scale.

water quality of water pollution that flows into the treatment plant (in mg/L), volume of water treated for each plant (in m^3/year), removal rate listed in *Table 2.6* (a percentage), and a multiplier of one million to adjust units. Original pollution reduced from existing sewage plants is subtracted from this new reduced pollution to determine additional reduced pollution for each scenario.

2.4. Data Description and sources

Land use data are from National Land Numerical Information, land utilization tertiary mesh data. The size of mesh is 100 meters. Data are available for years 1976, 1987, 1991, 1997, 2006, and 2009. I use four years of data—1987, 1991, 1997, and 2006—because for 1976, municipal-level agricultural returns and forest returns are unavailable. For 2009, municipal-level agricultural returns are not disclosed because of privacy concerns. There are 11 land use categories in 1987, and there are 12 land use categories after 1987. '*Rice*' includes rice paddies. '*Crop*' includes cropland, orchards, and other tree plantations. 'Forests' are places where a perennial plant grows more than 2m. 'Urban' includes buildings and parks. Roads, train tracks, and water are excluded. The remaining lands are categorized as '*Others*.'

'*Elevation*' and '*Slope*' data are from National Land Numerical Information, elevation, degree of slope tertiary mesh data. Average elevation (meter) is used for the variable ‘*Elevation*.’ ‘*Slope*’ is a dummy variable that takes a value of 1 if a site’s average value for slope angle (degrees) is less than 8 and a value of 0 otherwise.

Two variables are used as proxies for urban development pressure: ‘*Train*’ is the distance to the nearest train station (meters) since trains are a major mode of transportation in Japan, and land around stations tends to be developed since it is convenient for commuters and tourists. ‘Metropolitan’ is the distance to the nearest city (meters) with a population of over one million.

Land use capability classification from land survey gives soil productivity for rice, crops and forest. This productivity measures ranges from 1 (best) to 5 (worst), and I create dummy variables that take a value of 1 if a site is categorized as 1 or 2, and a value of 0 otherwise for rice, crop, and forest.

Farmland net returns data are obtained from agricultural production and income statistics generated by the Ministry of Agriculture, Forestry and Fisheries (MAFF), which provides municipal level net agricultural profits since 1971. Even though we have land use data at the parcel level, we lack parcel level net returns and use municipal level returns instead. Since there is a variation within a municipal, it is preferable to use parcel level data but due to data limitation, it is impossible. Parcel level data explained in this section, partially account for this spatial variation.

To assign net profits for rice and crop, the revenue ratio is used[11]. Dividing these ratios by area of cropland, I get net returns to rice and cropland per ha. Forestry net returns are from the Ministry of Agriculture, Forestry and Fisheries (MAFF). Forest area is used to calculate profit per ha. Municipal level data are not available, so I use prefecture level data.

Urban net returns are approximated using city average land prices multiplied by an annual 5% interest rate to convert to annual returns. The land price data are from land price announcements and prefectures' land price investigation. These land prices are not sales data but are prices assessed by The Ministry of Land, Infrastructure, Transport and Tourism (MLIT). Every year, each prefecture at predetermined points decide property values and real estate taxes. To account for expectation and smooth values, previous 5 years average are used for all net returns. Also, all returns are adjusted for inflation by utilizing the Consumer Price Index (CPI).

The number of cities in Japan have decreased due to merger. In April 1985, there were 3253 municipalities but the number was reduced to 1821 in March 2006. I use 2006 cities as references and sum up data if cities were merged. The sample summary

[11] For example, suppose city A's net profit from agriculture is 15 million yen, and rice and crop revenues are 20 million yen and 10 million yen, respectively. Rice net return is 10 million yen, and crop net return is 5 million yen.

statistics are in *Table 2.8*.

Table 2.8 Sample summary Statistics

Parameter	Level	Mean	Std. Dev.
Slope (dummy)	GIS point	0.439	0.496
Elevation (100m)	GIS point	0.230	0.207
Soil_rice (dummy)	GIS point	0.149	0.356
Soil_crop (dummy)	GIS point	0.104	0.305
Soil_forest (dummy)	GIS point	0.158	0.365
Train (1km)	GIS point	5.194	4.075
Metro (1km)	GIS point	88.386	57.89
Rice (1000yen/ha/year)	Municipal	412.30	154.20
Crop (1000yen/ha/year)	Municipal	1458.3	1140.1
Forest (1000yen/ha/year)	Municipal	28.7	14.1
Urban (1000yen/ha/year)	Prefecture	25269.2	25456.9

2.5. Results

2.5.1. Land use model

The results of the land use probability model are reported in *table* 2.9.[12] Since the estimated coefficients of the multinomial logit model cannot directly be interpreted as marginal effects, the estimated marginal effects are calculated as:

$$\frac{\partial \mathrm{Prob_{ijt}}}{\partial \mathrm{v}_{\mathrm{ijt}}^{l}} = \mathrm{Prob_{ijt}}\left[\beta_{\mathrm{j}}^{\mathrm{l}} - \sum\nolimits_{\mathrm{k=r,c,f,u,o}} \left(\mathrm{Prob_{ikt}} \cdot \beta_{\mathrm{k}}^{\mathrm{l}}\right)\right]$$

$$where\ \mathrm{v}_{\mathrm{ijt}}^{l} \text{ are the l th elements of vectors } \mathrm{v_{ikt}}$$

[12] Estimation result is reported in Appendix

Table 2.9 Estimated Marginal Effects for Multinomial Logit Model of Land Use Choice

Variable	Rice field	Cropland	Forest	Urban land	Other
Slope	0.25629***	0.095***	-0.48206***	0.06051***	0.07026***
Elevation	-0.17902***	-0.01516***	0.22343***	-0.03747***	0.00822***
Soil_rice	0.24343***	0.01823***	-0.31259***	0.02967***	0.02127***
Soil_crop	0.11897***	0.00134***	-0.12492***	0.01099***	-0.00637***
Soil_forest	-0.12009***	0.00436***	0.11877***	-0.00152***	-0.00152***
Train	0.00249***	0.00472***	0.00553***	-0.0086***	-0.00413***
Metro	0.00042***	0.00099***	0.00046***	-0.00064***	-0.00123***
Rice Returns	0.00012***	0.00004***	-0.00015***	0.00000892***	-0.00001***
Crop Returns	0.00003***	0.00001***	-0.00005***	0.00000657***	0.00001***
Forest Returns	-0.00138***	-0.00066***	0.00305***	-0.00075***	-0.00026***
Urban Returns	-1.36E-06***	-2.06E-08***	1.24E-06***	1.15E-07***	2.56E-08***

*, **, *** indicate significance level at α = 10%, 5%, and 1%

Observations: 1,755.165.   % Correct Prediction: 55.1%

All of the own-return marginal effects are positive and significant at the 1% level. The magnitudes of the effects are small. For example, to increase the area of rice paddies by 1%, about 26 million yen subsidy per ha is needed, which is quite high.[13] Only forest subsidies are economically meaningful because to increase the forest area by 1%, 32787 yen (114% of mean value) is needed. The cross-return marginal effects are not always negative and significant. For example, increasing *rice returns* results in increase in cropland and urban land. Also, increasing urban land returns results in an increase in forest land, in addition to urban land. If urban return is high, people have less motivation to do farming as a side job since the opportunity cost of leisure is high. These people will focus on their main job which results in forest and unused land use. Soil quality measures are positive and significant at the 1% level for all soils, but cross-soil effects are not always negative. For example, if one site is sui*table* for rice production, then it tends to be sui*table* for crop production, which is reasonable. The marginal effects of slope and elevation produce expected signs and are significant. If the average slope angle is above 8 degrees, (*slope* = 0), then that site is not sui*table* for rice, crop, and urban land use. In fact, high slope sites are not profi*table* for forest

[13] Langpap et al. (2008) shows that the policy that changes the returns to land use such as development impact fees, reforestation payments or agricultural subsidies have small impacts in control water pollution compared to local incentive based and property acquisition policies such as preferential property taxation and purchase or transfer of development rights using US data.

land use either, but compared to other land uses they are more sui*table* for forest usage, which explains the negative marginal effect of *slope* for *forest land use*. *Elevation* has similar effects as slope, although with opposite signs, as parcels in higher elevations are less sui*table* for rice, crop, and urban land.

Train and metro have the expected sign (negative/positive?) and the marginal effects are significant at the 1% level. If a site is far from a train station and metropolitan cities, then that site is not sui*table* for urban land because commuters use trains to commute to metropolitan areas Thus, it is preferable for them to live close to train stations and metropolitan areas.

2.5.2. Simulation: effects of land use policies on water pollution

The simulation results are shown in *tables* 2.10-2.12. Since land use patterns and pollution per ha are different for each watershed and land use (*tables* 2.3-2.5) because of different characteristics of soil, climate, distance, height, and slope, their effects are quite different for the same pollutants.

Table 2.10 Mean pollution change in COD relative to baseline

Land Use Policy	COD reduced (t)				
	Wat.1	Wat.2	Wat.3	Wat.4	Wat.5
↑ Rice Returns by 10000yen	-0.16%	-1.23%	0.13%	-0.07%	-0.23%
↑ Rice Returns by 25000yen	-0.39%	-2.44%	0.32%	-0.19%	-0.45%
↑ Rice Returns by 40000yen	-0.53%	-3.92%	0.51%	-0.31%	-0.71%
↑ Rice Returns by 50000yen	-0.60%	-4.79%	0.62%	-0.20%	-0.87%
↑ Crop Returns by 10000yen	0.03%	-0.33%	0.00%	0.00%	-0.08%
↑ Crop Returns by 25000yen	0.04%	-0.24%	0.02%	-0.01%	-0.12%
↑ Crop Returns by 40000yen	0.09%	-0.13%	0.04%	-0.02%	-0.15%
↑ Crop Returns by 50000yen	0.11%	-0.10%	0.05%	-0.03%	-0.18%
↑ Forest Returns by 10000yen	-0.58%	-2.29%	-0.47%	0.36%	1.16%
↑ Forest Returns by 25000yen	-1.19%	-4.64%	-1.82%	1.04%	2.93%
↑ Forest Returns by 40000yen	-1.77%	-6.27%	-3.24%	1.68%	3.99%
↑ Forest Returns by 50000yen	-2.21%	-8.15%	-3.84%	2.28%	4.07%
↓Urban Returns by 10000yen	0.01%	-0.38%	-0.01%	0.01%	-0.06%
↓Urban Returns by 25000yen	0.01%	-0.38%	-0.01%	0.01%	-0.06%
↓Urban Returns by 40000yen	0.01%	-0.38%	-0.01%	0.01%	-0.06%
↓Urban Returns by 50000yen	0.01%	-0.38%	-0.01%	0.01%	-0.06%

Table 2.11 Mean pollution change in T-N relative to baseline

Land Use Policy	T-N reduced (t)				
	Wat.1	Wat.2	Wat.3	Wat.4	Wat.5
↑ Rice Returns by 10000yen	1.32%	0.15%	1.03%	0.10%	1.72%
↑ Rice Returns by 25000yen	2.99%	0.18%	2.51%	0.29%	3.41%
↑ Rice Returns by 40000yen	5.14%	-0.35%	3.91%	0.46%	5.37%
↑ Rice Returns by 50000yen	6.38%	-0.69%	4.71%	1.09%	6.59%
↑ Crop Returns by 10000yen	0.33%	0.24%	0.06%	-0.01%	0.62%
↑ Crop Returns by 25000yen	0.46%	0.38%	0.18%	0.01%	0.91%
↑ Crop Returns by 40000yen	0.60%	0.52%	0.30%	0.04%	1.17%
↑ Crop Returns by 50000yen	0.71%	0.60%	0.38%	0.05%	1.37%
↑ Forest Returns by 10000yen	-4.12%	-1.07%	-3.54%	-0.54%	-8.76%
↑ Forest Returns by 25000yen	-10.69%	-4.23%	-14.91%	-1.55%	-22.22%
↑ Forest Returns by 40000yen	-17.36%	-8.01%	-27.12%	-2.49%	-30.25%
↑ Forest Returns by 50000yen	-22.06%	-10.51%	-32.31%	-3.39%	-30.84%
↓Urban Returns by 10000yen	0.21%	0.20%	-0.03%	-0.01%	0.45%
↓Urban Returns by 25000yen	0.21%	0.20%	-0.03%	-0.01%	0.45%
↓Urban Returns by 40000yen	0.21%	0.20%	-0.03%	-0.01%	0.45%
↓Urban Returns by 50000yen	0.21%	0.20%	-0.03%	-0.01%	0.45%

Table 2.12 Mean pollution change in T-P relative to baseline

Land Use Policy	T-P reduced (t)				
	Wat.1	Wat.2	Wat.3	Wat.4	Wat.5
↑ Rice Returns by 10000yen	0.17%	-1.79%	0.23%	0.61%	0.30%
↑ Rice Returns by 25000yen	0.40%	-3.76%	0.62%	1.65%	0.75%
↑ Rice Returns by 40000yen	0.91%	-6.09%	0.98%	2.67%	1.21%
↑ Rice Returns by 50000yen	1.20%	-7.35%	1.21%	4.76%	1.51%
↑ Crop Returns by 10000yen	0.17%	-0.54%	0.00%	-0.04%	0.15%
↑ Crop Returns by 25000yen	0.23%	-0.36%	0.03%	0.08%	0.15%
↑ Crop Returns by 40000yen	0.40%	-0.18%	0.07%	0.21%	0.30%
↑ Crop Returns by 50000yen	0.46%	0.00%	0.08%	0.30%	0.30%
↑ Forest Returns by 10000yen	-2.57%	-3.58%	-0.89%	-3.09%	-1.96%
↑ Forest Returns by 25000yen	-6.06%	-7.53%	-3.18%	-8.88%	-4.83%
↑ Forest Returns by 40000yen	-9.54%	-10.57%	-5.51%	-14.30%	-6.64%
↑ Forest Returns by 50000yen	-12.05%	-13.80%	-6.50%	-19.46%	-6.79%
↓Urban Returns by 10000yen	0.11%	-0.54%	-0.03%	-0.08%	0.15%
↓Urban Returns by 25000yen	0.11%	-0.54%	-0.03%	-0.08%	0.15%
↓Urban Returns by 40000yen	0.11%	-0.54%	-0.03%	-0.08%	0.15%
↓Urban Returns by 50000yen	0.11%	-0.54%	-0.03%	-0.08%	0.15%

For watershed-1 to watershed-3, subsidizing forest land use reduces pollution the most for every pollutant (T-N, T-P, and COD) as shown in *table*s 2.10-12. For instance, for watershed-1, subsidizing paddy fields by 10,000 yen/ha decreases T-N by 1.32% (1.2 tones) while subsidizing cropland by 10,000 yen/ha increases T-N by 0.33% (0.2 tones).

On the other hand, for watershed-4 and watershed-5, subsidizing forests is not always the best policy to control COD since subsidizing forests increase pollution as shown in *Table 2.10*. This is because per unit COD pollution for forest land use is bigger than rice paddy and cropland for watershed4 and watershed5 as shown in *table*s 2.3-2.5. For T-N and T-P, subsidizing forests is still the best policy. Therefore, instead of using national wide uniform policy, the results show that regionally specific policy is more effective in control water pollution.

2.5.3. Results of sewage plants model

Sewage treatment plants results are listed on *table*s 2.13-2.16 for watershed-1 to watershed-4. For example, there are four treatment plants in watershed-1, while in watershed-2 there is one treatment plant. Treatment plant 1 in watershed-1 is originally a CAS type plant that already installed F. Using its capacity, 165,000 m^3/day, and *Table 2.7*, the operating cost is 649 million yen. This treatment plant can be improved in three ways: constructing a new plant (Multi with F, RF, and AC), install RF, and install RF and AC. For example, new plants' annual total cost is 3749 million yen. Subtracting the original plant cost of 649 million yen from 3749 million yen yields 3397 million yen, which is the annual cost for the scenario. Pollution reduced by the scenario is derived by subtracting original plant pollution removed from new plant pollution removed and for COD, it is 513.3 tones.The improvement possibility depends on the installment of the original plant. For instance, since treatment plant 4 in watershed1 is originally MLE with F and RF installed, only AC can be installed. As expected, the cost of a new Multi plant is much higher than an improvement such as RF.

Table 2.13 Sewage plants cost and pollution reduced for watershed-1 (Inba)

Original plants	Process of improvement	Annual total cost (million yen)	COD removed	T-N removed	T-P removed
1.CAS	Multi with F, RF, AC	3397	15.6%	22.3%	9.3%
1.CAS	RF	324	5.2%	0.0%	9.3%
1.CAS	RF and AC	1162	14.6%	5.4%	9.3%
2.CAS	Multi with F, RF, AC	3868	19.4%	27.6%	11.5%
2.CAS	RF	367	6.4%	0.0%	11.5%
2.CAS	RF and AC	1333	18.1%	6.6%	11.5%
3.CAS	Multi with F, RF, AC	3102	10.7%	15.2%	6.4%
3.CAS	RF	297	3.5%	0.0%	6.4%
3.CAS	RF and AC	1056	10.0%	3.7%	6.4%
4.MLE	Multi with F, RF, AC	3119	0.8%	2.7%	3.7%
4.MLE	AC	757	0.8%	1.4%	3.7%

Table 2.14 Sewage plants cost and pollution reduced for watershed-2 (Tega)

Original plants	Process of improvement	Annual total cost (million yen)	COD removed	T-N removed	T-P removed
1.CAS	Multi with F, RF, AC	4660	51.8%	75.8%	0.0%
1.CAS	AC	1229	46.7%	18.3%	0.0%

Table 2.15 Sewage plants cost and pollution reduced for watershed-3 (Biwa)

Original plants	Process of improvement	Annual total cost (million yen)	COD removed	T-N removed	T-P removed
1. Multi	AC	438	1.2%	0.2%	0.0%
2. MLE	AC	467	2.5%	0.5%	3.0%
2. MLE	Multi with F, RF, AC	576	2.5%	0.5%	3.0%
3. MLE	AC	465	2.5%	0.5%	2.9%
3. MLE	Multi with F, RF, AC	574	2.5%	0.5%	2.9%
4. Multi	AC	384	0.9%	0.1%	0.0%
5. MLE	AC	262	0.6%	0.1%	0.7%
5. MLE	Multi with F, RF, AC	308	0.6%	0.1%	0.7%
6. MLE	AC	127	0.1%	0.0%	0.2%
6. MLE	Multi with F, RF, AC	506	0.1%	0.1%	0.2%
7. CAC	RF	139	0.3%	0.0%	1.0%
7. CAC	RF and AC	453	0.9%	0.3%	1.0%
7. CAC	Multi with F, RF, AC	1351	0.9%	1.1%	1.0%
8. MLE	RF	376	0.2%	0.0%	13.1%
8. MLE	RF and AC	665	1.3%	0.3%	14.7%
8. MLE	Multi with F, RF, AC	1766	1.4%	0.4%	14.7%

Table 2.16 Sewage plants cost and pollution reduced for watershed4 (Kojima)

Original plants	Process of improvement	Annual total cost (million yen)	COD removed	T-N removed	T-P removed
1. MLE	AC	289.5	1.5%	1.8%	1.6%
1. MLE	Multi with F, RF, AC	1261.5	1.7%	3.4%	1.6%
2. Multi	AC	664.1	2.9%	3.0%	0.0%
3. Multi	AC	608.8	2.6%	2.6%	0.0%
4. Multi	AC	270.1	0.7%	0.7%	0.0%

There are two major differences among watersheds. I define watershed-1 and watershed-2, which emit treated water outside of watersheds, as 'flow-out.' watershed-3 and watershed-4, where treated water is released within the watershed, are defined as 'flow-in.' CAS type plants are common in flow-out watersheds (75% of treatment planta in watershed1 and 100% treatment planta in watershed-2). CAS plants with a low removal ratio can be improved significantly, especially for T-N, by modification or through construction of a new building as listed on *Table 2.6*. For flow-out watersheds, the maximum T-N reduced are 1323 tones in watershed-1 (*Table 2.13*) and 2168 tones (*Table 2.14*) in watershed-2. For flow-in watersheds, maximum T-N reduced are 109 tones and 21 tones in watershed-3 and watershed-4, respectively. Finally, for watershed-2 and watershed4, reducing phosphorous by improving sewage plants is difficult. For watershed-2, reducing T-P is not possible (*Table 2.14*) and for watershed-4, only 0.65 tones reduction is possible compared to 9.8 tones and 11.7 tones in watershed-1 and watershed-3, respectively. This is because for those 2 watersheds, F and RF are already installed, and installing AC and building a Multi plant achieves small reduction in T-P, as shown in *Table 2.6*.

2.5.4. Results of comparison of land use policies and sewage plants

This section compares the abatement costs of land use policies and sewage plants. I compare the cost of reducing pollution from 1% to 10% for each watershed. These costs are listed on *table*s 2.17-2.19[14]. For PS abatement, the cost is calculated as the sum of the treatment plant costs that achieve goal at minimum abatement cost. For example, to reduce COD by 10% in watershed-1, RF should be installed for plant 1 and plant 3, which reduces pollution by 379 tones (for a COD reduction of 10%, 328 tones is needed). From *Table 2.13*, the cost of reducing this pollution is 324 million yen plus 367 million yen, with a total of about 690 million yen.

To reduce COD by 1% in watershed1, installing RF for plant 3 reduces pollution by 115t, which is even greater than 3% of total COD. Therefore, PS abatement goals are sometimes exceeded with a given technology. For NPS, afforestation payment per ha multiplied by forest area increases the yield's abatement cost. Due to the discrete nature

[14] This abatement cost is total cost which is equal to social cost plus producer surplus.

of abatement for PS pollution, some of the pollutant abatement goals cannot be achieved, which means it is not possible to compare PS with NPS pollution abatement. These cases are listed as Not Applicable (NA) in *table*s 2.17-2.19. On the other hand, the subsidy required to attain some of the NPS abatement goals is beyond the range considered as realistic for the simulation of afforestation payments. For instance, in watershed-1, reducing pollution by 3% cannot be achieved by an afforestation payment up to 100,000 yen per ha. These cases are listed as Not Applicable (NA) in *table*s 2.17-2.19 as well.

Table 2.17 Comparison of PS and NPS for COD abatement cost (million yen)

COD reduced	Watershed1		Watershed2		Watershed3		Watershed4	
	PS	NPS	PS	NPS	PS	NPS	PS	NPS
1%	297	543	1229	78	438	282	289	NA
3%	297	NA	1229	NA	729	1864	664	NA
5%	324	NA	1229	NA	932	4895	1224	NA
10%	690	NA	1229	NA	3259	NA	NA	NA

Table 2.18 Comparison of PS and NPS for T-N abatement cost (million yen)

T-N reduced	Watershed1		Watershed2		Watershed3		Watershed4	
	PS	NPS	PS	NPS	PS	NPS	PS	NPS
1%	757	44	1229	NA	1351	6	289	271
3%	1056	374	1229	NA	5638	45	879	NA
5%	1162	NA	1229	NA	NA	104	1168	NA
10%	2389	NA	1229	NA	NA	322	2805	NA

Table 2.19 Comparison of PS and NPS for T-P abatement cost (million yen)

T-P reduced	Watershed1		Watershed2		Watershed3		Watershed4	
	PS	NPS	PS	NPS	PS	NPS	PS	NPS
1%	297	0	NA	78	19	255	289	4
3%	297	1	NA	NA	376	1497	NA	39
5%	324	4	NA	NA	376	4129	NA	95
10%	690	17	NA	NA	376	NA	NA	354

Table 2.17 shows the results for COD abatement costs. With the exception of a 1% reduction goal in watershed-2 and watershed-3, PS abatement is cost effective or NPS reduction is not feasible. Specifically, in watershed-1, a 1% reduction of COD by NPS costs 543 million yen, which is higher than the abatement cost of a 5% COD reduction by PS. For watershed-2, due to the discrete nature of PS abatement, costs are constant for the entire range of abatement goals considered (1% to 10%).

Table 2.18 shows results for T-N. The data suggests that NPS is generally cost effective for reducing T-N. For example, a 3% pollution reduction in watershed-3 is achieved at 45 million yen by NPS abatement while 5638 million yen is needed for to achieve the same goal using PS abatement. In addition, since only 12.5% of plants are CAS in that watershed, there are limited opportunities for improving waste treatment plant technology to abate T-N. This is reflected in the “NA” cells for 5% and 10% T-N reduction for PS. For the other 3 watersheds, the capacity to remove T-N using NPS abatement is low.

Table 2.19 suggests that results for T-P are mixed. As seen in the previous section, for watershed-2 and watershed4, PS abatement cannot be used to significantly reduce T-P given the technologies considered here, because treatment plants in these watersheds have already installed F and RF. The limited opportunities for further abatement are reflected in the cells containing “NA” for watershed-2 and watershed-4. For watershed-1 and watershed-4, NPS abatement is cheaper. However, for watershed3, PS abatement is cheaper.

For each watershed, cost effective policy will depend on the pollutant (COD, T-N, T-P), the amount of pollution reduced, and any existing facilities. PS abatement is usually cost effective for relatively large amounts of reduction given the large capacity associated with the installation of new technology or the construction of new plants. This makes PS abatement a preferable option. On the other hand, NPS abatement is preferable for reducing relatively small amounts of pollution. Therefore, combining NPS and PS abatement options may lead to lower costs than choosing either option on its own.

2.6. Conclusions

This study combines economic land use models and physical data to estimate NPS abatement costs and compares them to PS abatement costs for T-N, T-P, and COD for four watersheds in Japan. Among land use policies that change returns of *rice, crop, forest*, and *urban land*, afforestation payment is the most cost effective policy for reducing NPS pollution in watersheds Inba, Tega, and Biwa. However, watersheds Kojima and Kamafusa, there are no NPS policies that reduce one or more pollutants without increasing another pollutant.

Comparison of abatement costs for given targets shows that PS abatement has more capacity to reduce pollution. For controlling T-N in watersheds Inba (watershed1) and Biwa (watershed3), a NPS abatement policy is cost effective, but for controlling COD, modifying and constructing new sewage plants is more cost effective. For T-P, NPS is cost effective in watershed Inba while PS is cost effective in watershed Biwa. As a result, the optimalpolicy will depend on the specific pollutant and watershed.

Combining both NPS and PS policies, such as reducing NPS pollution at first and then switching to PS pollution reduction later, is more cost effective than targeting a single source of pollution.[15]

In addition to the cost effectiveness, there are a few differences between NPS and PS

[15] For example, to reduce COD 10% in watershed3, achieving 10% reduction by PS costs 3259 mil yen, which results in 326 mil yen per 1% reduction (from *Table* 2.17). But for NPS, it costs 282 mil yen for a 1% reduction. Thus, reducing NPS pollution first and then switching to PS pollution reduction later is more cost effective than focusing on a single source of pollution.

water pollution control policy. First, NPS pollution is hard to predict due to its stochastic nature, as it can be affected by factors such as weather and soil type, and only ambient level pollution is measurable. Suppose a regulator is risk-neutral and discounts 3 tone of NPS reduction as 1 tone of PS reduction because of uncertainty and the difficulty in measuring individual contributions of NPS pollution. Even using this ratio, there is a watershed and pollutant that makes NPS abatement cheaper, such as watershed Biwa for T-N. Second, while remodeling and construction takes several years for a sewage plant, subsidies/taxes can be implemented more quickly and can be stopped relatively easily without building expensive facilities, even with inaccurate government forecasts. This is also important for Japan since its population is decreasing. Third, constructing sewage plants is politically easy compared to altering land use returns in Japan. Fourth, whereas increasing forest land use increases other environmental values such as open space conservation, habitat preservation, and reducing greenhouse gases, building plants does not achieve these benefits.

2.7. References

Aftab A, Hanley N, and Kampas A. "Co-ordinated environmental regulation: controlling non-point nitrate pollution while maintaining river flows." Environ Resource Econ

38(2007): 573-593

Bento, Antonio, Franco, Sofia, and Kaffine, Daniel. “The efficiency and distributional impacts of alternative anti-sprawl policies.” *Journal of Urban Economics* 59 (2006): 121-141

Breetz H L, Fisher-Vanden K, H Jacobs, and Schary C. “Trust and Communication: Mechanisms for Increasing Farmers’ Participation in Water Quality Trading.” *Land Economics* 81(2005): 170-190

Capozza D R and Helsey R W. “The Stochastic City.” *Journal of Urban Economics* 28 (1990): 187-203

Capozza D R and Li Y. “The intensitiy and Timing of Investment: The Case of Land.” *American Economic Review* 84(1994): 889-904

Chakir R and Parent O. “Determinants of land use changes: A spatial multinomial probit approach.” *Regional Science* 88(2009): 327-344

Doole, Graeme J. (2010), "Evaluating I nput Standards for Non-point Pollution Control under Firm Heterogeneity.", Journal of Agricultural Economics 61 (680-696)

Fleming R A and Adams R M. “The Importance of Site-Specific Information in the Design of Policies to Control Pollution.” Journal of Environmental Economics and Management 33 (1997): 347-358

Hanson, James C. and McConnell, E. K, "Simulated Trading for Maryland's Nitrogen Loadings in the Chesapeake Bay", Agricultural and Resource Economics Review 37 (2008): 211–226

Havnø K, Madsen MN, and Dørge J. "MIKE 11 – A generalized river modelling package, In: Singh VP (ed.) Computer models of watershed hydrology" *Water Resources Publication,* Colorado (1995): 733-782

Isik M. "Incentives for Technology Adoption Under Environmental Policy Uncertainty: Implications for Green Payment Programs." Environmental and Resource Economics 27 (2004): 247-263

Johansson, Robert C. (2004), "Metamodelling Phosphorus Best Management Practices for Policy Use: A Frontier Approach.", *Agricultural Economics* 30 (63-74)

Japan Sewage Works Association. "Ryuuikibetu gesuidouseibi sougoukeikaku tyousa sisinn to kaisetu [General investigation of operation of the sewage plants for each watershed]" (2008)

Kampas A and White B. "Administrative Costs and Instrument Choice for Stochastic Non-point Source Pollutants." *Environmental and Resource Economics* 27 (2004): 109-133

Hausman, J. and McFadden, D. "Specification Tests in Econometrics." *Econometrica* 52

(1984): 1219-40

Langpap, C, Hascic, I, and Wu, J. “Protecting Watershed Ecosystems through Targeted Local Land Use Policies.” *Am. J. Agr. Econ.* 90(2008): 684-700

Lankoski, J., Lichtenberg E., and Ollikainen, M. “POINT/NONPOINT EFFLUENT TRADING WITH SPATIAL HETEROGENEITY.” *Amer. J. Agr. Econ* 90 (2008): 1044-1058

Lewis D J, Plantinga A J, Nelson E, and Polasky S. “The efficiency of voluntary incentive policies for preventing biodiversity loss.” *Resource and Energy Economics* 33(2011):192-211

Li M. “Essays on Land-use change, carbon sequestration in China.” Dissertation (2010)

Lintner A M and A Weersink. “Endogenous Transport Coefficients.” *Environmental and Resource Economics* 14 (1999): 269-296

Lubowski R N, Plantinga A J, and Stavoms R N. “Land-use change and carbon sinks: Econometric estimation of the carbon sequestration supply function.” *Journal of Environmental Economics and Management* 51 (2006): 135-152

Lubowski R N, Plantinga A J, and Robert N Stavins. “What drives land-use change in the United States? A national analysis of landowner decisions.” *Land economics* 84(2008): 529-550

Malik A S, Letson D, and Stephen R C. “Point/Nonpoint Source Trading of Pollution Abatement: Choosing the Right Trading Ratio.” *Amer. J. Agr. Econ* 75(1993):959-967

Prabodanie R A R, Raffensperger J, and Mike M W. “A Pollution Offset System for Trading Non-Point Source Water Pollution Permits.” *Environ Resource Econ* 45 (2010): 499-515

Ministry of Land, Infrastructure, Transport, and Tourism, Ministry of Agriculture, Forestry and Fisheries, and Ministry of the Environment. “Kosyousuishitu no tameno ryuuikitaisaku no kihonteki kangaekata [Basic concepts of controlling water pollution by watershed management]” (2006)

Minstry of the Environment. “Heisei 23 nendo Koukyouyousuiiki suishitsu sokuteikekka [Water quality measurement of public water in Japan]” (2012)

Minstry of the Environment. “Heisei 17 nendo Koukyouyousuiiki suishitsu sokuteikekka [Water quality measurement of public water in Japan]” (2005)

Rabotyagov, Sergey S., Jha, Manoj., Campbell, Todd D.　(2010). "Nonpoint-Source Pollution Reduction for an Iowa Watershed: An Application of Evolutionary Algorithms.", *Canadian Journal of Agricultural Economics* 58 (411–431)

Refsgaard. J.C. “Parameterisation, calibration and validation of distributed hydrological models.” *J Hydrol* 198 (1997):69–97

Tanaka K. “Estimating the Process of Urbanization and its Influence of Lake Water Quality” *WEAI* 2010

J. R. Thompson. “Simulation of wetland water-level manipulation using coupled hydrological/hydraulic modeling.” *Physical Geography* 25(2004): 39-67

J. R. Thompson., H. Refstrup. Sørensonb., H. Gavina,1., and A. Refsgaardb. “Application of the coupled MIKE SHE/MIKE 11 modelling system to a lowland wet grassland in southeast England” *Journal of Hydrology* 293 (2004):151–179

Wu J, Adams R M, Kling C L, amd Tanaka K. “From Micro-Level Decisions to Landscape Changes: An Assessment of Agricultural Conservation Policies. “ *American Journal of Agricultural Economics* 86(2004): 26-41

Appendix : Estimation results

Table 2.20. Estimation results for multinomial logit models

Variable	Rice field	Cropland	Forest	Urban land
Slope	0.50318***	0.64115***	-1.86250***	0.46921***
Elevation	-1.27997***	-0.42548***	0.20685***	-1.12934***
Soil_Rice	0.76762***	0.04472***	-0.85335***	0.35252***
Soil_Crop	0.66086***	0.05130***	-0.13452***	0.32601***
Soil_Forest	-1.11403***	0.10788***	0.18054***	-0.01330**
Train	0.07577***	0.15059***	0.06811***	-0.16632***
Metro	0.02056***	0.03829***	0.01827***	0.00108***
Rice returns	0.00089***	0.00097***	-0.00013***	0.00050***
Crop returns	-0.00001***	-0.00007***	-0.00024***	-0.00002***
Forest returns	-0.00496***	-0.00946***	0.00868***	-0.01641***
Urban returns	-4.50.E-07***	-4.38.E-08***	7.69.E-08***	1.29.E-07***
Constant	2.17159***	-0.38276***	2.36098***	2.43635***

*, **, *** indicate significance level at α = 10%, 5%, and 1%

Observations: 1,755.165. Prob. > chi square =0.0000 Pseudo R2=0.2

Chapter 3

Agri-environmental payments and water pollution in Japan

Abstract

Agriculture is a major source of water pollution. In 2004, Japan introduced an agri-environmental scheme (AES) that subsidized farmers who adopted greener practices and reduced chemical pesticide and chemical nutrients in Shiga Prefecture. This paper estimates the effect of this policy in terms of a reduction ratio using a fixed effects[16] panel. After that, the research estimates the cost of abating water pollution using the AES in Lake Shiga and compares it with a subsidy that changes land use return and the construction cost of sewage treatment plants. The analysis shows that AES is less cost effective than the afforestation payment[17], but it is more cost effective than building sewage plants to reduce water pollution in Shiga.

[16] Fixed effect cannot capture time-varying factors other than explanatory variables.

[17] Afforestation payment is effective since pollution per ha is lowest in the study area. Other subsidies that changes land use return reduce forest and therefore they are not cost effective policies.

3.1. Introduction

Agriculture is one of the major sources of water pollution. However, since it is a non-point source (NPS)[18] and the agricultural sector has strong political influence, agricultural water pollution has not been regulated for a long time in Organization for Economic Cooperation and Development (OECD) countries, including Japan. Recently, agri-environmental schemes (AESs) have been implemented because farmers are less resistant to voluntary policies as compared to traditional standards since they receive payments in exchange for regulations, and they can choose whether they want to participate or not. In addition, green subsidies are exempt from the World Trade Organization (WTO) rules that limit agricultural subsidies in ways that distort trade (Colyer 2004).

AESs can be classified into two types: set-asides and best management practices (BMPs). In a set-aside, farmers receive payments and stop their agricultural production entirely. Examples include the Conservation Reserve Program (CRP), Wetland Reserve Program (WRP), and Wildlife Habitat Incentives Program (WHIP). Although the environmental benefit per area is large, set-aside policies are usually costly[19] because

[18] NPS pollution is hard to regulate since it is hard to measure the contribution of each polluter. See Segerson (1988)**,** Segerson and Wu(2006), Peterson and Boisvert (2001) for first or second best policy for NPS pollution.
[19] The budget for CRP for 2012 was $2 billion (Stubbs 2013)

the payments farmers receive for ceasing agricultural production are high compared to BMPs (Dupont 2010). In addition, as Wu (2000) reports, there is the potential problem of slippage effects, which is an unintended consequence when non-cropland is converted to cropland as a result of the set-aside.

There are several policies categorized as BMPs, including cover crops, conservation tillage, no till, and buffer. Typically, governments pay a cost share for these practices. Examples include the Environmental Quality Incentives Program (EQIP) in the US and Ontario's Rural Water Quality Program in Canada and many other programs in the European Union (EU). BMPs are cheaper than set-asides in the sense that the policy doesn't exclude agricultural production and there are no slippage effects. However, the environmental benefit per area is smaller compared to set-aside programs since they allow agricultural or forestry production.

Many articles have identified the factors affecting the decision of farmers to adopt AESs, including Bergtold et al. (2010), Brooks et al. (1992), Cattaneo (2003), Christensen et al.(1983), Dupont (2010), Featherstone et al.(1993), Gillespie et al. (2007), Kim et al. (2005), Lasley et al. (1990), Parks and Kramer (1995), Rehelizatovo et al. (2004), Rahm et al. (1984), Van Vuuren et al. (1995), and Ward et al. (2008). According to these studies, the factors influencing the adoption of AESs are age of farmers, education, farm income, off-farm employment opportunity, and ownership of land.

These studies generally suggest that age is expected to have a negative effect on adoption because older operators have shorter time horizons. Education is likely to increase the adoption ratio, but better education also indicates better off-farm employment opportunities, which may decrease the adoption rate. Hence, the expected effect of education is ambiguous. Higher farmer income enables farmers to invest more in conservation, but it is also possible that higher income farmers tend to value profits more, which may make them less willing to participate. Farmers who have off-farm opportunities or who rent land are less likely to participate in conservation programs because of a lack of information and commitment.

A variety of methods can be used to measure the effect of AESs. For example, there are case studies and evaluations of AESs by Bamiere, Laure et al. (2011), Baylis et al. (2008), Bazzani and Viaggi (2004), Dobbs and Pretty (2008), Helin et al. (2006), Tamini (2011), Watzold (2008), and Ziolkowska (2009). Helin et al. (2006) estimated the abatement cost of nitrogen loading from agriculture in Finland and found that it was between 25 - 28 million euro for a 50% nitrogen reduction. Bejranonda et al. (1999) uses a hedonic analysis to evaluate the effect of a policy that controls agricultural sedimentation on property values. Some studies, such as Nyaupane et al. (2012), Tamini (2011), Tamini et al. (2012), and Valentin et al. (2004), estimate the effect of AESs on farmers' profitability. Nyaupane et al. (2012) found that lakeside residents have a higher willingness to pay for sediment reduction from upstream soil conservation than for lake dredging. Valentin et al. (2004) found that adopting nutrient BMP has a positive impact on net farm income for wheat and corn.

The aim of this study is to evaluate the effectiveness of the Japanese AES, which subsidizes farmers in order to reduce the application of chemical fertilizers and pesticides. This policy was implemented by Shiga Prefecture. I follow Fleming (2004), Parker and Thurman (2011), Petrolia and Ibendahl (2008), Smith (1995), Wu (2000), and Wu and Lin (2010) in using aggregate municipal-level data to examine the impact of the program because farmer-level data are not available.

This Japanese policy is categorized as a BMP, since it requires farmers to adopt management practices instead of ruling out agricultural production. There are few economic papers analyzing Japanese AESs. Bai (2001) uses a survey to analyze the profitability of rice farmers who adopted greener practices as compared to the common practice in Kyusyu region. Sasaki (2005) and Fujiie (2008) analyze Shiga's AES. Sasaki uses CVM (contingent valuation method) to estimate consumer willingness to pay

(WTP) to encourage farmers to adopt greener practices. Fujiie (2008) attempts to estimate the impact of Shiga's AES, as does this research. Fujiie uses ordinary least squares (OLS) analysis to estimate the factors affecting the adoption ratio of greener practices using prefecture data. Fujiie then compares the difference between the predicted value of the adoption ratio and the actual adoption ratio and points out that since the difference is large, there is evidence that Shiga's AES affects the adoption of the greener practices. However, this difference can be simply due to the error term, missing variables, or outliers. Furthermore, Fujiie (2008) did not quantify the effect of the AES.

In this paper, I compare three major abatement options: reducing NPS pollution from agriculture through an AES, reducing NPS pollution from land use by utilizing incentives for land to remain in desired uses, and reducing PS pollution from sewage treatment plants by upgrading existing plants or constructing new plants. While other papers focus on one policy option or two at most, I can identify more cost effective policies by considering three major abatement alternatives. Additionally, the municipal level data used in this paper provides more detailed information than the prefecture-level data used in Fujiie (2008). This paper is also the first to analyze the environmental effect of Japanese AES by combining scientific data and econometric results to estimate the water pollution loading reduction resulting from the program.

For agricultural pollution, I directly evaluate the policy's effects using a fixed effects framework and an indicator variable for the policy that directly measures the impact of the AESs. After that, I estimate the abatement cost for COD (chemical oxygen demand), T-N (total nitrogen), and T-P (total phosphorous) using the AES in Shiga. I then calculate the cost of abating NPS pollution through policies that impact land use by combining a land use change model and water pollution data. Finally, I calculate the cost of reducing pollution (via upgrading or constructing new sewage treatment plants).

The reason for analyzing Japanese AESs instead of other countries' is that they have interesting attributes that other programs don't have. These include a fixed payment per hectare for each crop instead of cost share, the fact that the payment does not require organic production, farmer's ability to use half the amount of chemical nitrogen fertilizer, and these programs encourage farmers to use traditional fertilizer such as leaves and manure.

This paper is organized as follows: AESs in Japan are described in Section 2, the theoretical model and data to be used for the Shiga's AES are discussed in Section3, results of econometric model of AES are in Section 4, and estimation result of pollution reduction by AES is in Section 5. In section 6, abatement cost from AES, land use, and sewage treatment plants are derived and compared. Conclusions, references, and the appendix follows.

3.2. AES Program description

In Japan, AESs had not been implemented before 2004. Even though the government adopted a set aside program as did other countries, its intention was to reduce the production of rice rather than to reduce environmental externalities such as soil erosion and water pollution. Agriculture is instead promoted through subsidies as in the EU (Baylis 2008). This is because agriculture is valued for reasons other than agricultural output, such as scenery, preservation of rural communities, and mitigating flooding by retaining rain water.[20] In addition, payments to promote or preserve these aspects of agriculture are exempted from the limit of the WTO agreement.

The first policy intended to support greener agricultural production was introduced in Shiga Prefecture. Lake Biwa, located in Shiga Prefecture, has long time problems with excessive eutrophication. To control the nutrient loading of the lake, the local government searched for ways to control agricultural runoff and implemented the AES in 2004. This policy awards subsidies to farmers who reduce chemical pesticides

[20] Unpriced agricultural benefits other than production of food and fiber are called multifunctionality. See Kym (2000) and Dale (2004) for more discussion.

and fertilizers to less than half of their common practice.[21] Farmers are also required to adopt best practices such as planting cover crops, pasteurizing seeds, and optimizing the timing of fertilizer application. In addition, Shiga's government gives certificates to farmers so that they can earn a price premium for implementing greener practices.[22] The payment depends on the crop and acreage as shown in *Table 3.1*. For example, a rice farmer who reduces usage of an agricultural chemical by more than 50% for five ha receives 200,000 yen.[23] The payment is calculated by the cost difference as compared to the customary practice. In 2003, the agricultural department of Shiga Prefecture conducted a conjoint analysis of a sample of citizens in Shiga in order to derive WTP to improve water quality. This data was used to decide the total budget of the program[24]. (Yoshida 2004).

[21] For example, a rice farmer is commonly expected to use fourteen kinds of chemicals and chemical fertilizers, worth 8 kg of nitrogen per 0.1 ha. If a farmer adopts AESs, he can only use seven kinds of chemicals and chemical fertilizers, worth 4 kg of nitrogen per 0.1 ha. To compensate for the reduced amount of chemical and nitrogen, best management practices and traditional manure is recommended.

[22] According to Bai (2001), the price of rice grown by reduced agri-chemical practices is 7% higher than those grown using common practices.

[23] 3ha times 50,000 yen plus 2 ha times 25,000 yen.

[24] The survey was a choice experiment and consumers chose the best policy among four policies which are different with respect to cost and benefit. According to the survey the benefit for reducing chemical and fertilizer was 378,790,000 yen.

Table 3.1
Shiga's AES payment for each crop

Crop		Payment (yen/0.1ha)
Rice	For the first 3ha	5,000
	For the first 3ha or more	2,500
Vege*table*	Grown in greenhouse	30,000
	Not grown in greenhouse	5,000
Fruit	Grape, peach, pear, fig	30,000
	Plum, persimmon, chestnut, blue berry	10,000
Tea		10,000
Rapeseed		2,000

Another unique point compared to other countries' AES is that the policy gives a fixed payment per ha per crop. Other policies such as the Environmental Quality Incentives Program (EQIP) and the Grand River's Rural Water Quality Program (RWQP) provide payment as a cost share or fixed payment for all crops. For a flat payment, farmers may receive payments above their willingness to accept (WTA) because of asymmetric information. Furthermore, some farmers may adopt those practices without any payments—this is called the wind-fall profit problem. A flat payment greatly reduces administrative costs and transaction costs, which can be high but are sometimes neglected because the government does not need specific cost information and does not need to hold an auction. Although this point is important, I don't investigate this characteristic in this paper.

3.3. Model and data for AES

To analyze the effects of the policies, a fixed effects panel model with time trends is used in this paper. There are two groups of municipalities: 20 in Shiga, which received the treatment in 2005, and a group of 1,795 other municipalities. The estimation is based on the following equation:

(3.1) $$y_{it} = \beta_1 \mathrm{S_i} T_1 + \beta_2 T_1 + \beta_3 \boldsymbol{X_{it}} + \alpha_\mathrm{i} + \epsilon_{it}$$

The dependent variable (y_{it}) is the percentage of farmers who reduced the agri-chemical and chemical fertilizer by more than half as compared to the customary practice for each municipality i at time t (t=2000 and 2005). Each municipality is either in Shiga Prefecture ($\mathrm{S_i} = 1$) or in other prefectures ($\mathrm{S_i} = 0$). T_1 is a dummy variable valued at 1 for 2005 and 0 otherwise.

β_1 is the coefficient that captures Shiga's AES effect. β_2 is the coefficient of the year dummy for 2005. $\boldsymbol{X_{it}}$ is a vector of independent variables that includes the percentage of farmers who have no non-farm jobs, are older than 65 years old, own average cropland sizes (ha), earn a municipal agricultural income per farm household (10,000 yen), and earn a municipal average income per capita (10,000 yen)[25]. These variables consist of municipal-level data, from the Nouringyou census (Census of

[25] The percentage of agricultural area used for each crop is also considered as a independent variable, however due to protect privacy of farmers, many data is truncated and therefore it is not included in the model.

Agriculture and Forestry) (Ministry of Agriculture, Forestry and Fisheries 2000 and Ministry of Agriculture, Forestry and Fisheries 2005). α_i is the fixed effect for each municipality. To avoid multicolinearity, one municipality is left out as the reference category. Summary statistics are listed in *Table 3.2* and *Table 3.3*.

Table 3.2 Summary statistics for all municipals

Variables	Mean	Std. Dev.	Unit
Reduced nitrogen	22.7[26]	12.0	%
Shiga AES	0.006	0.074	Dummy
Year 2005	0.500	0.500	Dummy
No subjob	24%	15%	%
Over 65	31%	5%	%
Cropland size	3.04	7.62	Ha
Ag. Income	389.00	586.01	10,000yen
City Income	313.47	44.87	10,000yen

Table 3.3 Summary statistics for Shiga

Variables	Mean	Std. Dev.	Unit
Reduced Nitrogen	33.4	17.7	%
No subjob	10%	3%	%
Over 65	28%	3%	%
Cropland size	1.35	0.38	Ha
Ag. Income	165	122	10,000yen
City Income	323	35	10,000yen

[26] This ratio is higher than expected. Part of the reason for this is that organic products sell higher than non-organic foods.

3.4. Result of econometric model of AES

The estimation result using equation (3.1) is listed in *Table 3.4*. The first F-statistic is for testing the significance of the time effect and the null hypothesis that the time effect = 0 is rejected. The second F-statistic is for testing the significance of the group effect, and the null hypothesis that the group effect is constant is also rejected.

Table 3.4 Coefficient estimates for a fixed effects panel of farmers who reduced nitrogen more than half

Variables	Coefficient	Std. Err.
Shiga AES	0.055240*	0.02001
Year 2005	0.127761***	0.00599
No subjob	-0.091929**	0.04328
Over 65	0.253872**	0.08665
Cropland size	0.000357	0.00119
Ag. Income	0.000067***	0.00007
City Income	-0.000167	-0.00017

*, **, *** indicate significance level at α = 10%, 5%, and 1%

$R^2_{within} = 0.7433$ $R^2_{between} = 0.0003$ $R^2_{overall} = 0.3283$

F(7,1625) = 672.21 Prob>F = 0.0000

F(1653,1625) = 2.94 Prob>F = 0.0000

Number of Observations: 3286

The main result is the effect of Shiga AES with a coefficient of 0.055 and significance at the 10% level. This means Shiga AES only increases the proportion of farmers who reduced pollution by 5.5%. This suggests that it is not a very effective policy to mitigate water pollution. One possible explanation for this is that the policy was not well known because the adoption ratio was only 8.1% in 2005. The Japanese government adopted a similar policy in 2009, and its adoption rate in Shiga was 30% (Shiga 2011).[27]

The time effect is positive and significant. If the ratio of farmers who have no side jobs increase 1%, then it reduces the adoption of AES by 9.1%. If the ratio of farmers over 65 years old increases 1%, then the adoption ratio of AES increases 0.25%. The result is counterintuitive, as young farmers are more likely to adopt a new practice than old farmers because they have longer time horizons. The average cropland size is not significant. Agricultural income is positive, but the result is not economically meaningful because increasing agricultural income by one million yen only increases adoption of AES by 0.67%.

To check the appropriateness of using a fixed effect model, Hausman's specification test is used (Hausman 1978). Under the null hypothesis of no correlation, both a fixed effect and a random effect model are consistent, but the fixed effect model is inefficient. Under the alternative hypothesis, the fixed effect model is consistent but the random effect model is not. The value of the test statistic is 92.54, and the null

[27] This policy is not analyzed in this paper because it does not require best management practice as does Shiga's regional policy.

hypothesis that both the fixed effect and the random effect model are consistent but the random effect is efficient is rejected at 1% level, which justifies the use of a fixed effect model.

3.5. Comparison of abatement costs using an AES, land use subsidies, and sewage treatment plants

Since agriculture is only one major source of pollution, abatement for other sources of water pollution should be considered to compare cost efficiency. In this section, I derive and compare three kinds of abatement costs: the abatement cost of the AES, program subsidies for land use change, and upgrading or construction of sewage treatment plants. To carry out this comparison, I use the abatement achieved with the AES program (for example, 35.62*t* for COD) and calculate the cost of achieving the same level of abatement using a land use subsidy and a sewage treatment plant upgrade.

3.5.1. Estimate of abatement cost by AES

According to Shiga Prefecture, the total annual payment was 212 million yen in 2005 (Shiga 2007), which is the cost of abatement. The contract was for five years and each year, 212 million yen was provided to farmers. Since cropland size is not a factor that significantly affects the ratio of farmers who reduced agricultural pollution (*Table 3.4*), I assume that the average size of cropland for farmers who adopted AES is the same. To calculate COD, T-N, and T-P reduction for *rice* and *crop*, the Shiga AES effect from *Table 3.5* (5.5%) is multiplied by average water pollution reduction rate from the program (%), per ha water pollution for each land use. This is listed in *Table 3.5* (kg/ha) with area size for each land use (ha). Average pollution reduction rates are 30-40% for COD, 46-48% for T-N, and 14-28% for T-P. Using the average rate of reduction, the amount of pollution reduced by AES are, 35.62 tones for COD, 200.31 tones for T-N, and 0.19 tones for T-P. Abatement cost is the government budget[28] of 212 million yen for 2005 and is the same for all pollutants.

Table 3.5 Land use water pollution in Shiga (kg/ha/year)

	Rice	Crop	Forest	Urban
COD	43.1	22.6	17.3	52.6
T-N	14.3	95.3	6.8	14.1
T-P	0.98	0.2	0.13	0.73

3.5.2. Estimate of abatement cost by land use subsidy

Consider that net returns maximizing landowners chose land use among *r* (rice paddy),

[28] Again, this cost is not a social cost but a total cost which is social cost plus producer surplus but since supply curve is not available, social cost cannot be estimated

c (cropland), *f* (forest), *u* (urban) and *o* (other), and let *t* = 1987, 1991, 1997, and 2006 index the years when parcel-level data on land use and other municipal data are available. Then land owner choose land use *j* on parcel *i* in year *t* if and only if it satisfies $V_{ijt} \geq V_{ikt}$ for all $k \neq j$ where V_{ijt} is the present value of expected net returns to land i which is used as j. V_{ijt} is decomposed to two parts: $V_{ijt} = \beta_j' v_{ijt} + \varepsilon_{ijt}$, where $v_{ijt} = (\bar{\pi}_{ijt}, X_{ijt})$, $\bar{\pi}_{ijt}$ is an average net returns to land use j on parcel *i* at *t*[29], and X_{ijt} includes site specific characteristics such as urban development pressure, geography (slope and elevation), and soil quality. β_j' is a vector of parameters to be estimated, and ε_{ijt} is a random error term.

Following Langpap et al. (2008) and Langpap and Wu (2008), I assume the random error terms are IID with a Gumbel distribution. This implies that the probability of land *i* choosing land use *j* at time *t* can be described using a multinomial logit model:

$$\text{Prob}_{ijt} = \frac{e^{\beta_j' v_{ijt}}}{\sum_{k=r,c,f,u,o} e^{\beta_k' v_{ikt}}} \qquad j = r, c, f, u, o$$

The Multinomial logit model assumes independence from irrelevant alternatives (IIA). This assumption is tested by using a Hausman specification test (Hausman and McFadden, 1984). They suggest that if a subset of the choice set is irrelevant, then subtracting it from the model altogether will yield inefficient but still consistent

[29] Due to data availability, municipal or prefecture average is used for estimation.

parameter estimates, whereas if the IIA assumption is not true, then excluding that choice subset will yield inconsistent estimates. The test result listed in *table* 3.6 indicated that I cannot reject the assumption of IIA for any of the land use choices.

Table 3.6 Hausman test for IIA assumption

Omitted Variable	Chi_square	Prob>chi2
Rice	-2.40E+05	1.000
Crop	-2.30E+05	1.000
Forest	-1.20E+05	1.000
Urban	-2.50E+05	1.000
Other	-1.90E+05	1.000

Detailed data used for estimation is described in appendix 1. Estimation result is reported in Appendix 2 since estimated coefficients cannot be directly interpreted as marginal effects. Estimated marginal effects are reported in *table* 3.7. They are calculated using

$$\frac{\partial \mathrm{Prob}_{ijt}}{\partial \mathrm{v}_{ijt}^{l}} = \mathrm{Prob}_{ijt}\left[\beta_j^{\mathrm{l}} - \sum\nolimits_{k=r,c,f,u,o} \left(\mathrm{Prob}_{ikt} \cdot \beta_k^{\mathrm{l}}\right)\right]$$

where v_{ijt}^{l} are the l th elements of vectors v_{ikt}

Table 3.7 Estimated Marginal Effects for Multinomial Logit Model of Land Use Choice

Variable	Rice field	Cropland	Forest	Urban land	Other
Slope	0.25629***	0.095***	-0.48206***	0.06051***	0.07026***
Elevation	-0.17902***	-0.01516***	0.22343***	-0.03747***	0.00822***
Soil_rice	0.24343***	0.01823***	-0.31259***	0.02967***	0.02127***
Soil_crop	0.11897***	0.00134***	-0.12492***	0.01099***	-0.00637***
Soil_forest	-0.12009***	0.00436***	0.11877***	-0.00152***	-0.00152***
Train	0.00249***	0.00472***	0.00553***	-0.0086***	-0.00413***
Metro	0.00042***	0.00099***	0.00046***	-0.00064***	-0.00123***
Rice Returns	0.00012***	0.00004***	-0.00015***	0.00000892***	-0.00001***
Crop Returns	0.00003***	0.00001***	-0.00005***	0.00000657***	0.00001***
Forest Returns	-0.00138***	-0.00066***	0.00305***	-0.00075***	-0.00026***
Urban Returns	-1.36E-06***	-2.06E-08***	1.24E-06***	1.15E-07***	2.56E-08***

*, **, *** indicate significance level at α = 10%, 5%, and 1%

Observations: 1,755.165.   % Correct Prediction: 55.1%

All of the own-return marginal effects are positive and significant at 1% level. The magnitudes of the effects are small. For example, to increase the area of rice paddy for 1% about 26 million yen subsidy per ha is needed which is quite high. Only Forest subsidy is economically meaningful because to increase the forest area 1%, 32787 yen (114% of mean value) is needed. Therefore, I use afforestation payments as an alternative pollution abatement option for comparison with the AES program.

The cross-return marginal effects are not always negative and significant. For example increasing rice returns results in increase in cropland and urban land. Also, increasing urban land returns results in increase in forest land in addition to urban land. If urban return is high, people have less motivation to do farming as a side job since opportunity cost of leisure is high and focus on their main job which results in forest and unused land use.

Soil quality measures are positive and significant at 1% level for all soils, but cross-soil effects are not always negative. For example, if one site is sui*table* for rice production then it tends to be sui*table* for crop production, which is reasonable.

The marginal effects of slope and elevation have expected signs and are significant. If average slope angle is above 8 degrees, (slope = 0), then that site is not sui*table* for rice, crop, and urban land use. In fact, high slope sites are not profi*table* for forest land use either, but compared to other land uses they are more sui*table* for forest, which explains the negative marginal effect of slope for forest land use. Elevation has similar effects as slope, although with opposite signs, as parcels in higher elevations are less sui*table* for rice, crop, and urban land.

Train and metro have the expected sign and the marginal effects are significant at 1% level. If a site is far from a train station and metropolitan cities then that site is not sui*table* for urban land because commuters use trains and commute to metropolitan area so it is preferable for them to live close to train stations and metropolitan area which explains urban pressure well.

The Japanese government estimated per hectare water pollution caused by each land use for Shiga watersheds, as listed in *table* 3.4. These data were derived by the Japanese Ministry of Environment (MOE) on the basis of a literature review and water quality measurements (MOE, 2005).

The coefficients in *table* 3.4 are multiplied by the size of a catchment area[30] to derive water pollution loading for a watershed. Combing these values with econometric results allows me to simulate the effects of land use policies such as subsidies and taxes on pollution reduction. I do this in two stages. First, I simulate the effects of land use

[30] ArcGIS is used to calculate catchment area.

policies on land use choices by using the estimated model described in this section. The policy scenario I consider here is an afforestation payment since subsidizing forest has biggest effect from *table* 3.4. Then, I use the estimated coefficient from the land use model to calculate the predicted area of each land use for each watershed under each of these policies, and multiply the per hectare pollution listed on *table*s 3.4 to get total estimated pollution for each scenario. For abatement cost, the difference between base and the predicted area is multiplied by per ha afforestation payment. Results are jointly discussed in Section 3.5.4 with AES result and Sewage treatment plants result.

3.5.3. Estimate of abatement cost by sewage treatment plants

This section describes how to estimate reductions in water pollution generated by sewage plants. There are two options to reduce pollution from sewage plants[31], modifying existing plants and building a new treatment plant. Here I assume that a plant can be improved by installing Rapid filtration (RF), Flocculation (F), and Activated carbon (AC).

Building new treatment plants reduces pollution significantly if the existing plants are not so effective at abating pollution, but building a new plant is costly. For new

---

[31] Another option is to increase connectivity to existing sewage treatment plants. However, it is difficult to calculate the cost of new connections because it depends on the distance to the existing sewer pipe but those data are unavailable and therefore I focus on the first and second option.

construction, I choose Multi (Multistage nitrification denitrification process) for the new construction scenario and assume that Multi plants have F, RF, and AC installed. This is because Multi reduces pollution most and building other types of sewage plants does not reduce pollution compared to modification (*table* 3.8). As for cost, converting CAS (Conventional activated sludge process) to MLE (modified Ludzack Ettinger process) is more expensive compared to converting CAS to Multi.

Table 3.8 Removal ratio of pollution for each sewage treatment plants

Name of Sewage Plants	Modification			Removal ratio		
	F	RF	AC	COD	T-N	T-P
CAS	1	0	0	86.3%	28.3%	89.00%
	1	1	0	89.5%	28.30%	93.00%
	1	1	1	95.3%	41.70%	93.00%
MLE	0	0	0	86.3%	70.00%	55.00%
	1	0	0	87.4%	70.00%	89.00%
	1	1	0	89.9%	73.80%	90.70%
	1	1	1	95.3%	79.00%	93.00%
Multi	0	0	0	86.3%	76.70%	55.00%
	1	0	0	87.4%	76.70%	89.00%
	1	1	0	93.2%	81.30%	93.00%
	1	1	1	95.9%	83.70%	93.00%

Note: A 1 indicates corresponding modification is installed while 0 indicates not installed

I calculate the cost of abating PS pollution from sewage treatment plants by using engineering cost of sewage plants. These data are from Japan Sewage Works

Association (JSWA) (JSWA 2008). For estimation, I first evaluate existing sewage plants' operating cost and the amount of pollution reduced. Construction and operating costs are a function of capacity of water treated[32] and technology adopted. Examples of those costs are listed in *table* 3.9.

Table 3.9 Cost of sewage plants

Sewage technology	Construction cost (million yen)	Operation cost (million yen)
CAS	$1550C^{0.58}J$	$18.8C$^$^{0.69}J$
CAS with Flocculants	$1550*C^{0.58}J+54.1C^{0.67}K$	$18.8C^{0.69}*J+0.926C^{0.99}K$
MLE	$1550C^{0.58}J+86C^{0.8}K$	$18.8C^{0.69}J+1.2C*K$
MLE with Flocculants	$1550C^{0.58}J+93.1C^{0.83}K$	$18.8C^{0.69}J+1.59C^{1.01}K$
Multi with Flocculants	$1620C^{0.60}J$	$20.5C^{0.72}J$
Rapid Filtration	$353C^{0.46}K$	$0.739C^{0.92}J$
Activated Charcoal	$570C^{0.53}K$	$2.52C^{0.92}J$

C: capacity of water treatment ($1000m^3$/day)

J: (103.3/101.5) K: (103.3/101.1) are index that adjust price level from different year.

CAS (Conventional Activated Sludge Process) MLE (Modified Ludzack-Ettinger Process) Multi (Multistage Nitro and denitrification process)

For existing facilities, operating costs are calculated using *table* 3.9 and capacity of water treated. Building cost is annualized by multiplying $\frac{r(1+r)^T}{(1+r)^T-1}$ where r is interest rate set to 0.05 and T is expected lifetime which is 32.5 (Shiga, 2009) and add to

[32] The capacity for each plant is not available, but the total capacity for each region and the total amount of water treated by each plant are available. Based on this information, I assume that each plant's capacity is proportional to the amount of water it treated.

operating cost to get annual total cost. This annual cost is subtracted from the original operating cost to get the annual cost of the scenario.

Pollution reduced by sewage treatment plants is calculated by multiplying sewage water quality of water pollution that flow into the treatment plant (mg/L), volume of water treated for each plant (m^3/year), removal ratio listed in *table* 3.7 (%), and multiplier that adjust units (one million). Original pollution reduced from existing sewage plants is subtracted from this new pollution reduced to give additional pollution reduced for each scenario. Once again results are jointly discussed in next subsection with AES result and Sewage treatment plants result.

3.5.4. Comparison of abatement cost

Estimates of abatement costs for the same levels of pollution abated through each of the three policies considered are listed in *Table 3.10*. For example, to reduce same amount of COD at 35.62 t, the AES costs 212 million yen while afforestation payments cost only 107 million yen, and upgrades and building sewage treatment plants cost 262 million yen. This ordering, in which the afforestation payment is the most cost-effective abatement policy, followed by the AES, and finally by the sewage plant modification or construction, holds as well for T-N, and T-P. Therefore, these results suggest that, for this region and this set of pollutants, an afforestation payment is the most cost effective abatement policy. The reason for the high abatement cost of sewage treatment plants are because in this watershed, treatment plants are already efficient and to reduce pollution further, large investment are necessary. AES payments are not cost effective relative to afforestation payment due to the low adoption rate of AES.

Table 3.10 Abatement cost for reducing same amount of pollution (million yen)

	AES	Afforestation	Sewage
COD	212	107	262
T-N	212	22	2283
T-P	212	14	262

These results are based on the average pollution abatement achieved with the AES policy. However, there are ranges of pollution reduced from the AES because pollution from agriculture is a NPS, and therefore hard to predict due to its stochastic nature. This is also the case for land use pollution. As a robustness check, I repeated these calculations for the upper and lower bounds of these ranges of pollution abatement. The results hold for both the upper and lower boundaries of AES.

3.6. Conclusions

In addition to land use change and sewage treatment plants, agriculture is one of the main sources of NPS water pollution. Using data on the Shiga AES, which subsidized farmers who adopted best management practices, I estimate the policy effect in terms of an adoption ratio, defined as the proportion of farmers who reduced water pollution by more than half. I use a fixed effects econometric model and show that Shiga AES only increases the number of farmers who reduced use of nitrogen by 5.5%. This result is used to estimate the abatement cost of reducing water pollution using the AES in Shiga. I then calculate the abatement cost of reducing pollution from land use by combining land use change model and water pollution data. I also calculate abatement cost by using sewage treatments plant data. The results show that afforestation payments are most cost effective in Shiga, AES is in the middle, and sewage treatment plants are the most expensive for COD, T-N, and T-P. However, this does not necessarily imply that an afforestation payment is generally a superior policy to AESs and investing in sewage treatment plants. For instance, as shown in the previous chapter, in Kojima, watershed afforestation payments actually increase COD pollution loads.

When a policymaker chooses policies, factors other than cost are important to consider. Since afforestation payments and Shiga AES are both NPS policies, they have similar characteristics, such as the difficulty of measuring reduction from individual landowners. NPS policies can be implemented more quickly and stop relatively easily by not adopting best management practice as compared to building and demolishing sewage treatment plants. By decreasing pesticide application, AES affect positively to biodiversity. Afforestation payment increases open space, preserves habitat for wildlife, and reduces greenhouse gas. Building sewage plants cannot achieve any of them.

3.7. References

Arriagada, A. Rodrigo., Ferraro, J. Paul ., Sills, O. Erin., Pattanayak, K. Subhrendu., and Cordero-Sancho, Silvia. (2012), "Do Payments for Environmental Services Affect Forest Cover? A Farm-Level Evaluation from Costa Rica", *Land Economics* 88 (382-99)

Bai, Hu (2001), "Profitability and Determination of Low Input Sustainable Rice Farming", Sci. Bull. Fac. Agr., Kyusyu Univ. 55 (245-258)

Bamiere, Laure., Havlik, Petr., Jacquet, Florence., Lherm, Michel., Millet, Guy., and Bretagnolle, Vincent. (2011), "Farming System Modelling for Agri-environmental Policy Design: The Case of a Spatially Non-aggregated Allocation of Conservation Measures.", *Ecological Economics* 70 (891-99)

Baylis, Kathy., Peplow, Stephen., Rausser, Gordon., and Simon, Leo. (2008), "Agri-environmental Policies in the EU and United States: A Comparison.", *Ecological Economics* 65 (753-64)

Bazzani, M. Guido and Viaggi, Davide. (2004), "Improving the Design of Agri-environmental Policies: A Case Study in Italy.", *Agricultural Economics Review* 5, (21-35)

Bejranonda, Somskaow., Hitzhusen, J. Fred J., and Hite, Diane. (1999), "Agricultural Sedimentation Impacts on Lakeside Property Values.", *Agricultural and Resource Economics Review*, 28(208-18)

Bergtold, S Jason. and Molnar, J Joseph. (2010), "Limited Access to Conservation: Limited-Resource Farmer Participation in the Conservation Security Program in the Southeast.", *Journal of Agricultural and Applied Economics*, 42(211-27)

Bravo-Ureta, E. Boris., Nunes Almeida, Alexandre., Solis, Daniel., Inestroza, Aaron. (2011), "The Economic Impact of Marena's Investments on Sustainable Agricultural Systems in Honduras.", *Journal of Agricultural Economic*s 62 (429-48)

Brooks, H. G., Aradhyula, V. Satheeh., and Johnson, S. R. (1992), "Land Quality and Producer Participation in U.S. Commodity Programs.", *Review of Agricultural Economics* 14(105-115)

Cattaneo, Andrea (2003), "The Pursuit of Efficiency and Its Unintended Consequences: Contract Withdrawals in the Environmental Quality Incentives Program.", *Review of Agricultural Economics* 25(449-469)

Chabe-Ferret, Sylvain and Subervie, Julie. (2013), “How much green for the buck? Estimating additional and windfall effects on French agro-environmental schemes by DID-matching.”, *Journal of Environmental Economics and Managemen*t 65 (12-27)

Christensen, A. Lee, and Patricia E. Norris. (1983), "Soil Conservation and Water Quality Improvement: What Farmers Think.", *Journal of Soil and Water Conservation* 38 (1): 15-20.

Colyer, Dale (2004), "Environmental Regulations and Agricultural Competitiveness.", *The Estey Center Journal of International Law and Trade Policy* 5(70-90)

DeVuyst A. Eric., and Ipe C. Viju. (1999), “A Group Incentive Contract to Promote Adoption of Best Management Practices.”, *Journal of Agricultural and Resource Economics* 24(2):367-382

Dobbs, L. Thomas and Pretty, Jules. (2008), “Case Study of Agri-environmental Payments: The United Kingdom.”, *Ecological Economics* 65 (765-75)

Dupont, Diane (2010), “Cost-Sharing Incentive Programs for Source Water Protection: The Grand River’s Rural Water Quality Program.”, *Canadian Journal of Agricultural Economics* 58 (481-496)

Featherstone, M. Allen, and Barry K. Goodwin. (1993), "Factors Influencing a Farmer's Decision to Invest in Long-term Conservation Improvements.", *Land Economics* 69

(Feb.):67-81.

Fleming, Ronald A. (2004), "An Econometric Analysis of the Environmental Benefits Provided by the Conservation Reserve Program.", *Journal of Agricultural and Applied Economics* 36 (399-413)

Fujiie, Takeshi (2008), "Nougyou kankyou seisaku no keizai bunseki[Economic Analysis of Agri-environmental policy : Case study of Shiga's Agri-environmental support].", *Hikone rongi* 370(65-85)

Gillespie, J., S. Kim, and K. Paudel.(2007), ''Why Don't Producers Adopt Best Management Practices? An Analysis of the Beef Cattle Industry.'', *Agricultural Economics* 36:89–102

Hasukawa, Hiroyuki., Shibahara, Fujiyoshi., Komai Sachiko., Mizutani, Satoshi., Oobayashi, Hiroyuki., Fujii Yoshitaka., and Sudo, Miki. (2009), "Reduction in Outflow Loads during Paddy Rice Cropping Period by Environment – Conscious Agricultural Practice.", *Bull. Shiga Pref. Agric. Tech. Promo. Cent* 48 (1-21)

Helin, Janne., Laukkanen, Marita., and Koikkalainen, Kauko. (2006), "Abatement Costs for Agricultural Nitrogen and Phosphorus Loads: A Case Study of Crop Farming in South-Western Finland.", *Agricultural and Food Science*15 (351-74)

Jaud, Melise and Cadot, Olivier (2012), "A Second Look at the Pesticides Initiative

Program: Evidence from Senegal.”, *World Trade Review* 11 (490-506)

Kim, S., J.M. Gillespie, and K.P. Paudel.(2005), ‘‘The Effect of Socioeconomic Factors on the Adoption of Best Management Practices in Beef Cattle Production.’’, *Journal of Soil and Water Conservation* 60(111–20)

Kym, Anderson (2000), "Agriculture's 'multifunctionality' and the WTO.", *The Australian Journal of Agricultural and Resource Economics* 44(475-494)

Lasley, Paul, Michael Duffy, Kevin Kettner, and Craig Chase. (1990), "Factors Affecting Farmers' Use of Practices to Reduce Commercial Fertilizers and Pesticides." *Journal of Soil and Water Conservation* 45 (132-6).

Martinez, Jose (2011), “Liberalisation and Its Impact on Migration in Agricultural Communities in Mexico.”, *Canadian Journal of Development Studies*, 32(162-79)

Meng, Lei (2012), “Can Grain Subsidies Impede Rural-Urban Migration in Hinterland China? Evidence from Field Surveys.”, *China Economic Review*, 23(729-41)

Nyaupane, P. Narayan., Gillespie, M. Jeffrey., and Paudel, P. Krishna. (2012), “Economic Impacts of Adoption of Best Management Practices by Crawfish Producers: The Role of the Environmental Quality Incentives Program.”, *Agricultural and Resource Economics Review* 41 (247-59)

Parker, P. Dominic and Thurman, N. Walter (2011), "Crowding Out Open Space: The

Effects of Federal Land Programs on Private Land Trust Conservation.", *Land Economics* 87 (202-22)

Parks, J, Peter., and Kramer, A. Randall (1995) “A Policy Simulation of the Wetlands Reserve Program.”, *Journal of Environmental Economics and Management* 28 (223-240)

Peterson, Jeffrey and Boisvert, Richard (2001), “Control of Nonpoint Source Pollution Through Voluntary Incentive-Based Policies: An Application to Nitrate Contamination in New York.”, *Agricultural and Resource Economics Review* 30 (127-138)

Petrick, Martin and Zier, Patrick (2011), “Regional Employment Impacts of Common Agricultural Policy Measures in Eastern Germany: A Difference-in-Differences Approach.”, *Agricultural Economic*s 42 (183-93)

Petrolia, R. Daniel and Ibendahl, A. Gregory (2008), "Conservation Programs: Will Grain Production Reclaim Acres in the South?", *Journal of Agricultural and Applied Economics* 40 (559-72)

Plantinga, Andrew and Ahn, SoEun (2002),"Efficient Policies forEnvironmental Protection: An Econometric Analysis of Incentives for Land Conversion and Retention.", *Journal of Agricultural and Resource Economics* 27(128-145)

Postali, Fernando Antonio Slaibe and Nishijima, Marislei. (2013), “Oil Windfalls in

Brazil and Their Long-Run Social Impacts.”, *Resources Policy* 38(94-101)

Rahelizatovo, N.C., and J.M. Gillespie. (2004), ‘‘The Adoption of Best-Management Practices by Louisiana Dairy Producers.’’, *Journal of Agricultural and Applied Economics* 36(229–40)

Stubbs, Megan. “Agricultural Conservation: A Guide to Programs.” Congressional Research Service (2013)

APPENDIX 1: Land use data description

Land use data are from National Land Numerical Information, Land utilization tertiary mesh Data. The size of mesh is 100m. Data are available for the years 1976, 1987, 1991, 1997, 2006, and 2009. I use four years of data, 1987, 1991, 1997, and 2006 because for 1976 municipal-level agricultural returns and forest returns are unavailable, and for 2009 municipal-level agricultural returns are not disclosed because of privacy concerns. There are 11 land use categories in 1987 and there are 12 land use categories after 1987. ‘*Rice*’ includes rice paddies. ‘*Crop*’ includes cropland, orchards, and other tree plantations. ‘*Forests*’ are places where a perennial plant grows more than 2m. ‘*Urban*’ includes buildings and parks. Roads, train tracks, and water are excluded. The remaining lands are categorized as ‘*Others*’.

‘*Elevation*’ and ‘*Slope*’ data are from National Land Numerical Information, Elevation, degree of slope tertiary mesh data. Average elevation (meters) is used for the variable ‘*Elevation*’. ‘*Slope*’ is a dummy variable which takes a value of 1 if a site’s average value for slope angle (degrees) is less than 8 and a value of 0 otherwise.

Two variables are used as proxies for urban development pressure. ‘*Train*’ is distance to the nearest train station (meters) since train is a major mode of transportation in Japan and land around stations tends to be developed since it is convenient for commuters and tourists. ‘*Metropolitan*’ is distance to the nearest city (meters) with population over one million.

Land use capability classification from Land survey gives soil productivity for rice, crops and forest. This productivity measure ranges from 1 (best) to 5 (worst) and I create dummy variables which take a value of 1 if a site is categorized as 1 or 2 and a value of 0 otherwise for rice, crop, and forest.

Farmland net returns data are obtained from agricultural production and income statistics generated by the Ministry of Agriculture, Forestry and Fisheries (MAFF), which provides municipal level net agricultural profits since 1971. To assign net profits for rice and crop, the revenue ratio is used[33]. Dividing these ratios by area of cropland, I get net returns to rice and cropland per ha. Forestry net returns are from the Ministry of Agriculture, Forestry and Fisheries (MAFF). Forest area is used to calculate profit per ha. Municipal level data are not available, so I use prefecture level data.

Urban net returns are approximated using city average land prices multiplied by an annual 5% interest rate to convert to annual returns. The land price data are from land price announcement and prefectures' land price investigation. These land prices are not sales data but the price that are assessed by The Ministry of Land, Infrastructure, Transport and Tourism (MLIT) and each prefecture at pre-determined points for every year to decide property value and real estate tax. To account for expectation and smooth values, previous 5 years average are used for all net returns. Also, all returns are adjusted by Consumer Price Index (CPI).

The number of cities in Japan has decreased due to merger. In April 1985, there were 3253 municipalities but the number was reduced to 1821 in March 2006. To conduct this analysis, I use 2006 cities as references and sum up data if cities were merged. The summary statistics are in *table* 3.11.

[33] For example, suppose city A's net profit is 15 million yen and rice and crop revenue are 20 million yen and 10 million yen respectively. Rice net return is 10 million yen and crop net return is 5 million yen.

Table 3.11 Summary Statistics

Parameter	Level	Mean	Std. Dev.
Slope (dummy)	GIS point	0.439	0.496
Elevation (100m)	GIS point	0.230	0.207
Soil_rice (dummy)	GIS point	0.149	0.356
Soil_crop (dummy)	GIS point	0.104	0.305
Soil_forest (dummy)	GIS point	0.158	0.365
Train (1km)	GIS point	5.194	4.075
Metro (1km)	GIS point	88.386	57.89
Rice (1000yen/ha/year)	Municipal	412.30	154.20
Crop (1000yen/ha/year)	Municipal	1458.3	1140.1
Forest (1000yen/ha/year)	Municipal	28.7	14.1
Urban (1000yen/ha/year)	Prefecture	25269.2	25456.9

APPENDIX 2: Land use model result

Table 3.12 Estimation results for multinomial logit models

Variable	Rice field	Cropland	Forest	Urban land
Slope	0.50318***	0.64115***	-1.86250***	0.46921***
Elevation	-1.27997***	-0.42548***	0.20685***	-1.12934***
Soil_Rice	0.76762***	0.04472***	-0.85335***	0.35252***
Soil_Crop	0.66086***	0.05130***	-0.13452***	0.32601***
Soil_Forest	-1.11403***	0.10788***	0.18054***	-0.01330**
Train	0.07577***	0.15059***	0.06811***	-0.16632***
Metro	0.02056***	0.03829***	0.01827***	0.00108***
Rice returns	0.00089***	0.00097***	-0.00013***	0.00050***
Crop returns	-0.00001***	-0.00007***	-0.00024***	-0.00002***
Forest returns	-0.00496***	-0.00946***	0.00868***	-0.01641***
Urban returns	-4.50.E-07***	-4.38.E-08***	7.69.E-08***	1.29.E-07***
Constant	2.17159***	-0.38276***	2.36098***	2.43635***

*, **, *** indicate significance level at $\alpha = 10\%$, 5%, and 1%

Observations: 1,755.165. Prob. > chi square =0.0000 Pseudo R2=0.2

Chapter 4

The Efficiency of Urban Development Policies for Heterogeneous Land

Abstract

This paper aims to compare the efficiency of development taxes and urban growth boundaries to protect open space. Bento et al. (2006) show that these are equivalent instruments in terms of efficiency. However, this result only holds under the strong assumption that the government has perfect information. In this paper, I make two realistic assumptions. First, I add heterogeneity of soil quality across the landscape. Second, I assume the regulator does not have perfect information. In this setting, I show that development taxes and urban growth boundaries are no longer equivalent. The result of taxes and UGBs are hard to compare analytically, prompting the research to implement numerical simulation. Simulation results in addition to sensitivity analysis show that taxes and UGBs are not equivalent under parameter values I choose.

4.1. Introduction

Open space provides multiple benefits, such as the provision of wildlife habitat and recreation and the improvement of water and air quality. Several research articles using hedonic regression show that people value open space. Anderson and West (2006), for example, use hedonic analysis for the Minneapolis-St. Paul metropolitan area and find that urban residents near the CBD (central business district) in populated areas value open space more than suburban residents. Irwin (2002), on the other hand. uses a hedonic model for central Maryland and finds that open space greatly increases surrounding home sales values and that different kinds of open space have different effects.

However, when individuals make decisions about land use, they do not consider the social benefits of open space. As a result, urbanization occurs more than is socially optimal. According to the US Forest Service, the amount of open space decreased by roughly 6000 acres per day around the year 2007 (US Forest Service, 2007).

To preserve open space, governments have spent significant amounts of money. For example, in 2014, the Land and Water Conservation Fund spent 301 million dollars. Although the budget for open space conservation is large, the literature comparing the efficiency of different policies is relatively small. For instance, Brueckner (2000) describes the source of urban sprawl and recommends development taxes and congestion tolls to create open space and to mitigate excessive commuting cost, but the author provides no economic analysis. Thomas (2001) compares the purchase of development rights and land value taxation and recommends combining the two policies, but the analysis is mostly descriptive and not based on an economic model. Wu and Irwin (2008) analyze dynamic interactions between land development and water quality degradation as a result of open space loss. In their analysis, they compare impact fees of development and zoning regulations and find that while impact fees control both the pace and pattern of land development and result in the optimal levels of land development and water quality, zoning cannot control the pattern of development.

Bento et al. (2006) analyzes four anti-sprawl policies, namely development taxes, UGB (urban growth boundary), property taxes, and gasoline taxes by comparing the total rents of the city, which are the sum of urban rent and agricultural rent. They showed that among these four policies, development taxes and urban growth boundaries are equivalent and development taxes and urban growth boundaries are the most effective anti-sprawl policies. In addition to using analytical models, the authors also use numerical models to compare total rent under different schemes and distributional impacts for residents.

This paper examines the effect of uncertainty of agricultural rents on total efficiency under development taxes and UGB. The equivalence of development taxes and UGB with respect to efficiency showed by Bento et al. (2006) only holds under the strong assumption that the government has perfect information about soil quality. In this paper, I modify this assumption in a realistic way. First, I add heterogeneity of soil quality across the landscape and assume agricultural rent is a function of soil quality because soil productivity is closely related to agricultural production. Bento et al. (2006) does not take into account this perspective and uses fixed agricultural rent. Second, I assume there is an information asymmetry between the regulator and the landlords. Even though there are some productivity measures such as Soil Rating for Plant Growth (Sinclair and Terpstra, 2000) and Land Capability Class (Natural Resources Conservation Service, 1973), there are limitations to what governments know about agricultural productivity of all sites (Lubowski et al. 2008). Therefore, I relax the assumption that regulators have perfect information about soil quality and assume that they only know mean soil quality. These are more realistic assumptions as compared to the ones in Bento et al. (2006). These two assumptions alter the equivalency of development taxes and UGB in terms of total rent. Under development taxes, landowners have the flexibility to develop their land even if the regulator's prediction is not accurate as long as they pay development taxes. However, development is not possible if a parcel is in a UGB even if urban rent is much higher than agricultural rent. These results might cause differences between taxes and UGBs.

Under these assumptions, I show that the two policy instruments could be different with respect to efficiency in two angles :(i) numerically comparing the marginal effect of increasing open space, and (ii) numerically comparing expected total rent and conducting a sensitivity analysis to check if the result holds for different parameter values.

The paper is organized as follows. In Section 4.2, I develop the analytical model for the homogeneous soil case. In Section 4.3, I add heterogeneity in soil quality. In Section 4.4, I assume specific functional forms and compare the result of taxation and UGB in the two perspectives mentioned above. Finally Section 4.5 concludes this chapter.

4.2. The analytical model under homogeneous soil quality

In this section, I develop analytical models to compare the efficiency of a development tax and a UGB. I first explain the fixed homogenous agricultural revenue case following Bento et al. (2006).

Following Capozza and Helsley (1990), the model consists of a static open city with identical households. The households gain utility from one unit of fixed size land, numeraire non-housing goods (Z), and open space (A). The budget constraint is given as:

(4.1) $$\mathrm{Y} = \mathrm{sx} + \mathrm{r}^{\mathrm{u}}(\mathrm{x}, A) + Z$$

where Y is exogenous gross household income, s is round trip unit travel cost, x is distance to the central business district (CBD) and r^{u} is urban rent. In an open city with perfect mobility, indirect utility of residents V will be equalized within the city and across cities due to migration. This is expressed as follows:

(4.2) $$\mathrm{V}(\mathrm{Y}, \mathrm{s}, \mathrm{r}^{\mathrm{u}}, A, \mathrm{x}) = \overline{\mathrm{V}}$$

where $\overline{\mathrm{V}}$ is the national utility level. From this indirect utility, the bid rent function at each location is derived as:

(4.3) $$\mathrm{r}^{\mathrm{u}}(\mathrm{Y}, \mathrm{s}, \overline{\mathrm{V}}, A, \mathrm{x})$$

When the land is undeveloped, it yields agricultural rent r^{a}, which in this sub section I assume is fixed. Since $\mathrm{r}^{\mathrm{u}}(\mathrm{Y}, \mathrm{s}, A, \overline{\mathrm{V}}, \mathrm{x})$ is a decreasing function of the distance to CBD, and developers utilize land as long as urban rent exceeds agricultural rent, at the urban boundary ($\overline{\mathrm{x}}$), the following condition holds:

(4.4) $$\mathrm{r}^{\mathrm{u}}(\mathrm{Y}, \mathrm{s}, \overline{\mathrm{V}}, A, \overline{\mathrm{x}}) = \mathrm{r}^{\mathrm{a}}$$

Therefore, total rent of the city is expressed as:

(4.5) $$R = \int_0^{\bar{x}} r^u(Y, s, \bar{V}, A, x)\, dx + r^a(\bar{m} - \bar{x})$$

where $\bar{m}$ is the physical boundary of the city. Following several papers in the literature (Crampton, 1996; Crampton, 1997; Liu, 2009; Solow and Vickrey, 1971; Sasaki, 2004; Shibusawa, 2000; Taylor and Wagman, 2014) I assume the city is linear for tractability.

Following Bento et al. (2006), I assume that open space is only a function of total non-developed area and configuration or location does not change residents' utility.[34] Thus, open space is defined as:

(4.6) $$A = \bar{m} - \bar{x}$$

Since residents and developers don't take into account negative externalities in development, the regulator intervenes and tries to maximize total rent. Policymakers levy a development tax t per unit of developed land to control the area of open space in order to maximize total rent. The effect of changes in open space on total rent under a development tax can be expressed as:

(4.7) $$\frac{dR_t}{dA} = \int_0^{\bar{x}_t} \left[\frac{\partial r^u(Y, s, \bar{V}, A, x)}{\partial A}\right] dx + (r^u(Y, s, \bar{V}, A, \bar{x}_t) - r^a)\frac{d\bar{x}_t}{dA} = 0$$

where R_t is total rent under development tax and $\bar{x}_t$ is the boundary of the city under

[34] This is strong assumption. See Parkhurst (2007), Wu et al. (2000), and Wu and Boggess (1999).

the tax. Equation (4.7) is a first order condition with respect to open space.[35] The effects of changes in open space under UGB can be expressed as:

(4.8) $$\frac{dR_g}{dA} = \int_0^{\bar{x}_g} \left[\frac{\partial r^u(Y, s, \bar{V}, A, x)}{\partial A}\right] dx + \left(r^u(Y, s, \bar{V}, A, \bar{x}_g) - r^a\right)\frac{d\bar{x}_g}{dA} = 0$$

where R_g is total rent under UGB and $\bar{x}_g$ is the boundary of the city under UGB. Since (4.7) and (4.8) are identical given the same amount of open space preserved, Bento et al. (2006) have shown that urban development taxes and UGB are equivalent in the sense that providing more open space has the same effect on total rent regardless of whether it is achieved with a tax or a UGB.

4.3. Adding heterogeneity

In the previous sub section, I assumed a fixed agricultural rent and perfect information. In this section, I relax these assumptions as follows. First, I allow heterogeneity of agricultural rent, which is a function of soil quality (q) because agricultural production depends on soil quality, which is random. To simplify, I assume agricultural rent is a function of a random parameter ε: $r^a(\varepsilon)$.

Second, I assume the regulator only knows the distribution of soil quality but not actual soil quality at each location. Total rent under heterogeneous soil quality is defined

[35] The choice of a development tax implicitly defines open space and allows a comparison with the result under UGB, a first order condition with respect to open space instead of with respect to the tax.

as:

(4.9) $$R = \int_{r^u > r^a} r^u(Y, s, \bar{V}, A, x)\, dx + \int_{r^u < r^a} r^a(\varepsilon)\, dx$$

This equation implies that if urban rent exceeds agricultural rent, then a parcel is used as urban land and otherwise it is used as agricultural land. Both residents' and developers' decisions are the same as in the preceding section since they have perfect information about soil quality and therefore information about agricultural rent at each location. Developers decide whether to develop by comparing urban rent and agricultural rent. Thus, there is no continuous boundary $\bar{x}$ as before, since agricultural rent is not fixed anymore. Open space is now defined as follows:

(4.10) $$A = \bar{m} - \int_{r^u < r^a} 1dx$$

The regulator's behavior now changes due to asymmetric information. He only knows the distribution of soil quality and does not know the site-specific agricultural rent. Therefore, the regulator maximizes expected total rent by using a tax or UGB.

4.3.1. Development taxes under heterogeneity

Consider the effect of a development tax t per unit of developed land and a revenue-neutral lump sum transfer L per unit of land, which mitigates the burden for the development tax and opposition of the tax. With this policy, urban rent and agricultural rent become

(4.11) $$r_t^u(Y, s, \bar{V}, A_t, x) = r^u(Y, s, \bar{V}, A_t, x) - t + L$$

(4.12) $$r_t^a = r^a(\varepsilon) + L$$

As described in the preceding section, the regulator uses expected development taxes t and expected transfer L due to imperfect information. The maximization problem becomes

(4.13) $$\max_t ER_t$$

$$= \int_0^{\bar{m}} \int r^u(Y, s, \bar{V}, A_t, x) \Pr(r^u - t > r^a) d\varepsilon\, dx + \int_0^{\bar{m}} \int r^a(\varepsilon) \Pr(r^u - t < r^a)\, d\varepsilon dx$$

$$= \int_0^{\underline{x}_t} \int r^u(Y, s, \bar{V}, A_t, x)\, d\varepsilon dx + \int_{\underline{x}_t}^{\bar{x}_t} \int r^u(Y, s, \bar{V}, A_t, x) \Pr(r^u - t > r^a)\, d\varepsilon dx$$

$$+ \int_{\underline{x}_t}^{\bar{x}_t} \int r^a(\varepsilon) \Pr(r^u - t < r^a) d\varepsilon\, dx + \int_{\underline{x}_t}^{\bar{m}} \int r^a(\varepsilon)\, d\varepsilon\, dx$$

(4.14) $$A_t = \int_{\underline{x}_t}^{\bar{x}_t} \Pr(r^u - t < r^a) dx + (m - \bar{x}_t)$$

where $\underline{x}_t$ is the lower boundary of development under tax. All land located between 0 and $\underline{x}_t$ from CBD is developed. $\bar{x}_t$ is the upper boundary of development under a tax. Between $\underline{x}_t$ and $\bar{x}_t$, whether land is developed or undeveloped depends on urban rent and random agricultural rent. If land is located farther than $\bar{x}_t$, urban rent is lower than minimum agricultural rent, and therefore the land is undeveloped. The regulator chooses the tax t to maximize expected total rent (4.13) where open space under the tax is expressed as in (4.14)

4.3.2. Urban growth boundary under heterogeneity

In this subsection, I analyze the effect of an urban growth boundary. Assuming asymmetric information, the regulator tries to maximize expected total rents by choosing an optimal expected city boundary g. Since the regulator only has information about distance to city x and soil distribution, the regulator maximizes expected total rent rather than actual total rent. The regulator's maximization problem is:

$$(4.15)\qquad \max_{g} \mathrm{E}R_{g}$$

$$= \int_0^{\bar{m}} \int r^u(Y, s, \bar{V}, A_t, x) \Pr(r^u - t > r^a) d\varepsilon\, dx + \int_0^{\bar{m}} \int r^a(\varepsilon)\ \Pr(r^u - t < r^a)\, d\varepsilon dx$$

$$= \int_0^{\bar{m}} \int r^u\left(Y, s, \bar{V}, A_g, x\right) \Pr(r^u - t > r^a) d\varepsilon\, dx + \int_0^{\bar{m}} \int r^a(\varepsilon)\ \Pr(r^u - t < r^a)\, d\varepsilon dx$$

$$= \int_0^{\underline{x}_g} \int r^u\left(Y, s, \bar{V}, A_g, x\right) d\varepsilon dx + \int_{\underline{x}_g}^{g} \int r^u\left(Y, s, \bar{V}, A_g, x\right) \Pr(r^u - t > r^a)\, d\varepsilon dx$$

$$+ \int_{\underline{x}_g}^{g} \int r^a(\varepsilon)\ \Pr(r^u - t < r^a) d\varepsilon\, dx + \int_{g}^{\bar{m}} \int r^a(\varepsilon)\ d\varepsilon\, dx$$

$$(4.16)\qquad A_g = \int_{\underline{x}_g}^{g} \Pr(r^u < r^a)\, dx + (\bar{m} - g)$$

where $\underline{x}_g$ is the lower boundary of development under UGB. If land is located between 0 and $\underline{x}_g$ from CBD, every parcel of land is developed since urban rent is higher than maximum agricultural rent. g is an urban growth boundary and no development is allowed if land is located outside of boundary. Between $\underline{x}_g$ and g, whether land is developed or undeveloped depends on urban rent and random agricultural rent. The regulator chooses the UGB g to maximize expected total rent (4.15) where open space under UGB is given by (4.16)

4.4. Comparison of Tax and UGB

In this section, I compare expected total rent under development taxes and UGB. It is hard to compare expected total rent under the tax (4.13) and the UGB (4.15) analytically. Therefore, I use specific functional forms to solve the maximization problems. I use two counter-examples to illustrate the possibility that the policies are no longer equivalent once randomness is introduced. First, I show that the tax and the UGB are not equivalent in using numerical simulations by comparing the marginal effect of open space for the same amount of open space. Using graphs, I also show the equivalence of the tax and the UGB when there is no randomness. Second, I show that expected total rents are different under the two policies, and I verify that this difference still holds for different parameter values by conducting a sensitivity analysis.

4.4.1. Functional forms

Since it is not possible to compare the two instruments using the general analytical model, I assume specific functional forms. Specifically, for tractability I assume an additive-linear utility function:

(4.17) $$\mathrm{u} = Z + A$$

Using the budget constraint, the numeraire is:

(4.18) $$Z = \mathrm{Y} - \mathrm{sx} - \mathrm{r}^{\mathrm{u}}$$

Equilibrium of indirect utility can be derived by using (4.17) and (4.18):

(4.19) $$\overline{\mathrm{V}} = Z + A = \mathrm{Y} - \mathrm{x} - \mathrm{r}^{\mathrm{u}} + \mathrm{A}$$

From this indirect utility, urban rent is derived:

(4.20) $$\mathrm{r}^{\mathrm{u}}(\mathrm{Y}, \mathrm{s}, \overline{\mathrm{V}}, A, \mathrm{x}) = \mathrm{Y} - \mathrm{sx} - \overline{\mathrm{V}} + A$$

Urban rent is not a function of agricultural rent and no option value is existed due to use static model, urban rent is certain.

Agricultural rent is assumed to follow a uniform distribution:

(4.21) $$\mathrm{r}^{\mathrm{a}}(r_0^a, \varepsilon) = r_0^a + \varepsilon$$

where r_0^a is base agricultural rent and error term ε follows the uniform distribution with lower bound 0 and upper bound b:

(4.2) $$\varepsilon \sim \mathrm{u}(0, b)$$

Expected total rent under the tax is derived by following steps (detailed calculations are in Appendix). Under the additive-linear utility function and the uniform agricultural rent, expected open space under a tax ($\mathrm{A_t}$) is defined as:

$$(4.23) \qquad \mathrm{A_t} = \int_{\underline{\mathrm{x}}_\mathrm{t}}^{\overline{\mathrm{x}}_\mathrm{t}} \int_{\mathrm{r^u - t < r^a}} f(\varepsilon)\, \mathrm{d\varepsilon\, dx} + (\mathrm{m} - \overline{\mathrm{x}}_\mathrm{t})$$

where $f(\varepsilon)$ is a probability density function (pdf). Since ε follows the uniform distribution, its pdf is:

$$(4.24) \qquad f(\varepsilon) = \begin{cases} \dfrac{1}{b}, & 0 \le \varepsilon \le b \\ 0, & elsewhere \end{cases}$$

Expected total rent is expressed as

$$(4.25) \qquad \mathrm{ER}_t = \int_0^{\underline{\mathrm{x}}_\mathrm{t}} \mathrm{r^u}(\mathrm{Y, s, \overline{V}, A_t, x})\, \mathrm{dx} + \int_{\underline{\mathrm{x}}_\mathrm{t}}^{\overline{\mathrm{x}}_\mathrm{t}} \int_0^{\varepsilon_t} \mathrm{r^u}(\mathrm{Y, s, \overline{V}, A_t, x}) f(\varepsilon)\, \mathrm{d\varepsilon\, dx}$$

$$+ \int_{\underline{\mathrm{x}}_\mathrm{t}}^{\overline{\mathrm{x}}_\mathrm{t}} \int_{\varepsilon_t}^{b} \mathrm{r^a}(r_0^a, \varepsilon) f(\varepsilon)\, \mathrm{d\varepsilon\, dx} + \int_{\overline{\mathrm{x}}_\mathrm{t}}^{\overline{\mathrm{m}}} \int_0^b \mathrm{r^a}(r_0^a, \varepsilon)\, f(\varepsilon)\, \mathrm{d}\varepsilon \mathrm{dx}$$

To maximize expected total rent, the tax t is set to satisfy the first order condition. Solving this condition gives the optimal tax. Substituting the optimal tax and open space into expected total rent yields optimal expected total rent:

$$(4.26) \qquad \mathrm{ER}_t^* =$$

$$\frac{\begin{bmatrix} b^2(1+2s) + 6bs(\overline{m} + r_0^a + ms + V - Y) \\ +6s(\overline{m}^2 + (r_0^a + V - Y)^2 + 2m(r_0^a + r_0^a s - V + Y)) \end{bmatrix}}{12s(2+s)}$$

Expected total rent under UGBs is derived using following three steps (detailed calculations are in Appendix). For UGBs, there are two possible locations. The first one is closer to the CBD than the lower boundary of development, and the second one is between the lower boundary of development and the upper boundary of development. I define these as a strict UGB and a moderate UGB respectively. Expected total rent under optimal UGB is the maximum of the two UGBs.

Open space under a strict UGB is

$$(4.27) \qquad \mathrm{A_{gs}} = \bar{m} - \mathrm{g}$$

Where the subscript s represents strict UGB. Expected total rent under a strict UGB is defined as

$$(4.28) \qquad \mathrm{ER}_{gs} = \int_0^{\mathrm{g}} \int_0^{b} \mathrm{r^u}\left(\mathrm{Y, s}, \bar{\mathrm{V}}, \mathrm{A_{gs}}, \mathrm{x}\right) f(\varepsilon) \mathrm{d}\varepsilon \mathrm{dx} + \int_{\mathrm{g}}^{\bar{\mathrm{m}}} \int_0^{b} \mathrm{r^a}(r_0^a, \varepsilon) f(\varepsilon) \mathrm{d}\varepsilon \mathrm{dx}$$

$$= \int_0^{\mathrm{g}} \left(Y - sx - V + \mathrm{A_{gs}}\right) \mathrm{dx} + \int_{\mathrm{g}}^{\bar{\mathrm{m}}} \left(r_0^a + \frac{b}{2}\right) \mathrm{dx}$$

Solving the first order condition with respect to g yields the strict UGB that maximizes expected total rent. Substitutes this optimal UGB yields optimal expected total rent under the strict UGB:

$$(4.29) \qquad \mathrm{ER}_{gs}^{*} = \frac{b^2 + 4b(\bar{m} + r_0^a + \bar{m}s + V - Y) + 4[\bar{m}^2 + (r_0^a + V - Y)^2 + 2\bar{m}(r_0^a + r_0^a s - V + Y)]}{8(2+s)}$$

For moderate UGB, open space under a moderate UGB is defined as

$$(4.30) \qquad \mathrm{A_{gm}} = \int_{\underline{\mathrm{x}}_{\mathrm{g}}}^{\mathrm{g}} \int_{\mathrm{r^u} < \mathrm{r^a}} f(\varepsilon)\, \mathrm{d}\varepsilon\, \mathrm{dx} + (\bar{m} - \mathrm{g})$$

where the subscript m in open space $\mathrm{A_{gm}}$ represents moderate UGB.

Expected total rent under UGB is defined as

(4.31) $$\mathrm{ER}_{gm} = \int_0^{\underline{\mathrm{x}}_{\mathrm{g}}} \int_0^{b} \mathrm{r}^{\mathrm{u}}\left(\mathrm{Y}, \mathrm{s}, \overline{\mathrm{V}}, \mathrm{A}_{\mathrm{gm}}, \mathrm{x}\right) f(\varepsilon) \mathrm{d}\varepsilon \mathrm{dx}$$

$$+ \int_{\underline{\mathrm{x}}_{\mathrm{g}}}^{\mathrm{g}} \int_{\mathrm{r^u > r^a}} \mathrm{r}^{\mathrm{u}}\left(\mathrm{Y}, \mathrm{s}, \overline{\mathrm{V}}, \mathrm{A}_{\mathrm{gm}}, \mathrm{x}\right) f(\varepsilon)\, \mathrm{d\varepsilon}\, \mathrm{dx} + \int_{\underline{\mathrm{x}}_{\mathrm{g}}}^{\mathrm{g}} \int_{\mathrm{r^u < r^a}} \mathrm{r}^{\mathrm{a}}(r_0^a, \varepsilon) f(\varepsilon)\, \mathrm{d\varepsilon}\, \mathrm{dx}$$
$$+ \int_{\mathrm{g}}^{\overline{\mathrm{m}}} \int_0^{b} \mathrm{r}^{\mathrm{a}}(r_0^a, \varepsilon)\, f(\varepsilon) \mathrm{d}\varepsilon \mathrm{dx}$$

As in the case of the tax, substituting boundaries, soil quality, and open space and solving the first order condition yields six possible expected total rents[36] (described in the appendix). The maximum of these rents yields expected total rent under optimal UGB:

(4.32) $$\mathrm{ER}_g = \max\{\mathrm{ER}^*_{gs}, \mathrm{ER}^*_{gm}\}$$

4.4.2. Comparison of total rent under a tax and UGB

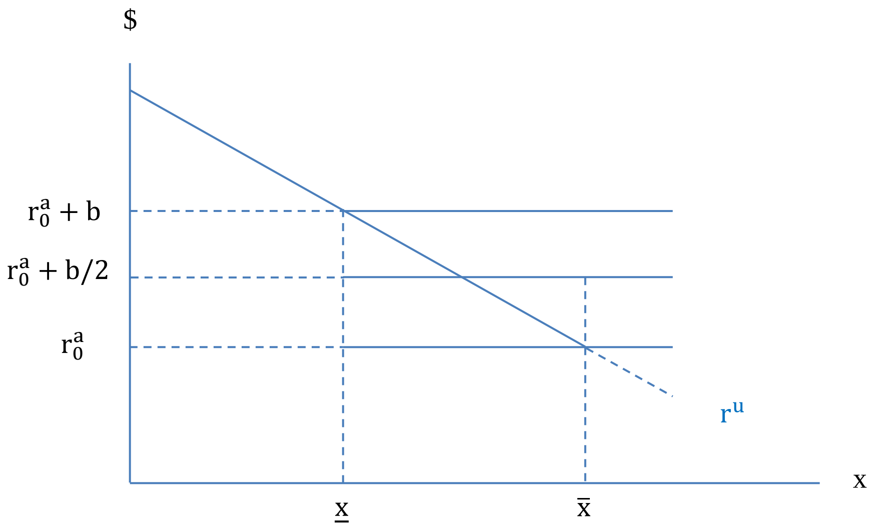
It is hard to compare outcomes under the two policies for two reasons. First, there are six possible outcomes for moderate UGB. Second, it is hard to compare resulting expected rents between moderate UGB and strict UGB and between tax and UGB using general functional forms. Therefore, I use specific parameter values to calculate expected rents and compare outcomes across the policies. Specifically, in this section I

[36] Without assuming numerical parameter values, it is hard to tell which one gives largest expected total rent. When I do numerical simulation and a robustness check explained later, four among six solutions are always out of the boundary. For the remaining two, one gives largest expected total rent when a UGB is an interior solution, further than the lower boundary of development. The other one gives largest result when a UGB is a corner solution where the UGB located at the lower boundary of development.

compare the marginal effect of increasing open space under the tax and UGB. For moderate UGB, I use numerical parameters explained in the next section to see which of the six possible outcomes produces the largest expected total rent.

First, suppose there is uncertainty but no government intervention. Without policy, land is developed until urban rent is equal to agricultural rent. Since agriculture rent at each site is uncertain, the government knows only the probability of development but does not know the exact location of development. In *Figure 4.1*, I illustrate the boundary of development. Urban rent and maximum agricultural rent ($r_0^a + b$) are equal at the lower boundary of development $\underline{x}$. From CBD to the lower boundary of development, no land is undeveloped because urban rent is always higher than agricultural rent. Urban rent and minimum agricultural rent (r_0^a) are equal at the upper boundary of development $\bar{x}$. No land is developed beyond this upper boundary since agricultural rent is always higher than urban rent. Between lower and upper boundaries of development, both development and agricultural land are possible.

Figure.4.1 Expected rent without policy intervention



To calculate expected total rent, it is convenient to define expected rent at distance x from CBD, $E\mathrm{r}(\mathrm{x})$. By taking the integral of expected rent from 0 (CBD) to $\bar{\mathrm{m}}$, expected total rent is derived. Under the no policy scenario, expected rent is expressed as the following:

$$E\mathrm{r}(\mathrm{x}) = \mathrm{r^u}(\mathrm{Y}, \mathrm{s}, \bar{\mathrm{V}}, \mathrm{A}\ \mathrm{x}) \qquad if\ \mathrm{x} < \underline{\mathrm{x}}$$

$$(4.33) \quad E\mathrm{r}(\mathrm{x}) = \mathrm{r^u}(\mathrm{Y}, \mathrm{s}, \bar{\mathrm{V}}, \mathrm{A}, \mathrm{x}) * \mathrm{Pr}(\mathrm{r^u} > \mathrm{r^a}) + \mathrm{r^a} * \mathrm{Pr}(\mathrm{r^u} < \mathrm{r^a}) \quad \text{if } \underline{\mathrm{x}} < \mathrm{x} < \bar{\mathrm{x}}$$

$$E\mathrm{r}(\mathrm{x}) = E\mathrm{r^a} \qquad if\ \mathrm{x} > \bar{\mathrm{x}}$$

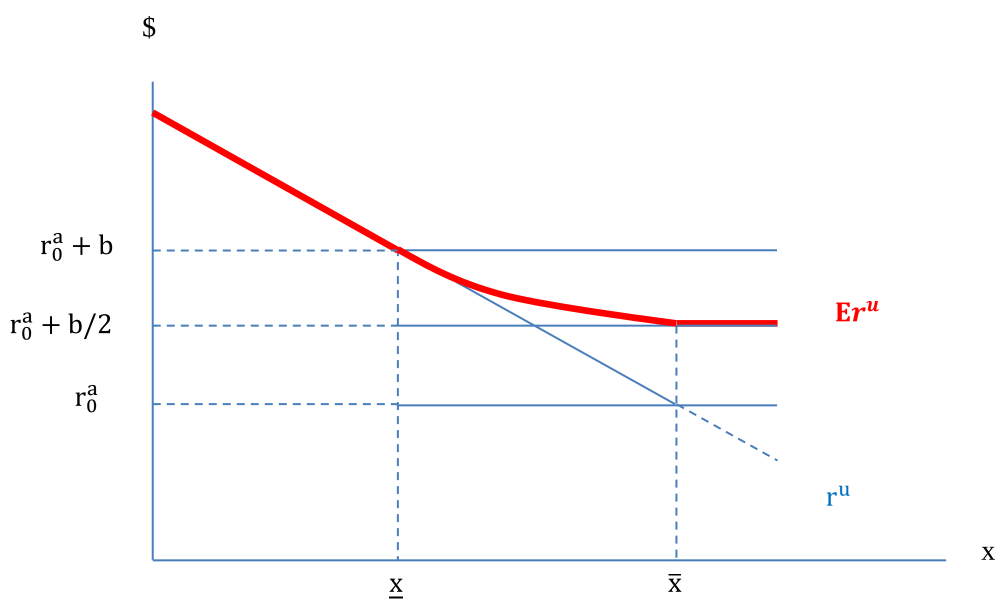
This is illustrated in *Figure 4.2*. If land is located closer to CBD than to the lower boundary of development ($\underline{\mathrm{x}}$), expected rent is urban rent. At the lower boundary of development, urban rent and expected rent are equal to maximum agricultural rent ($\mathrm{r}_0^a + b$). Between the lower and upper boundaries of development ($\bar{\mathrm{x}}$), expected rent is a weighted average of urban and agricultural rent. Between the lower and upper boundaries, a decreasing and quadratic convex function of distance is observed:

(4.34) $$\frac{\partial Er(x)}{\partial x} = \frac{s(-A + r_0^a + V + sx - Y)}{b} < 0$$

(4.35) $$\frac{\partial^2 Er(x)}{\partial x^2} = \frac{s^2}{b} > 0$$

At the upper boundary of development, expected rent equals expected agricultural rent ($r_0^a + b/2$). If land is located farther than the upper boundary, expected rent is expected agricultural rent. Therefore, expected rent under the tax is illustrated as a thick red line in the following *figure 4.2.*

*Fig. 4.2***.** Expected rent without policy



Next, suppose a tax is imposed to preserve open space more than market equilibrium. Expected rent at distance x from CBD, $E\mathrm{r}(\mathrm{x})$, under a tax is defined as

$$E\mathrm{r}(\mathrm{x}) = \mathrm{r}^{\mathrm{u}}(\mathrm{Y}, \mathrm{s}, \overline{\mathrm{V}}, \mathrm{A}_{\mathrm{t}}\, \mathrm{x}) \qquad if\ \mathrm{x} < \underline{\mathrm{x}}_{\mathrm{t}}$$

$$(4.36)\quad E\mathrm{r}(\mathrm{x}) = \mathrm{r}^{\mathrm{u}}(\mathrm{Y}, \mathrm{s}, \overline{\mathrm{V}}, \mathrm{A}_{\mathrm{t}}, \mathrm{x}) * \Pr(\mathrm{r}^{\mathrm{u}} - t > \mathrm{r}^{\mathrm{a}}) + \mathrm{r}^{\mathrm{a}} * \Pr(\mathrm{r}^{\mathrm{u}} - t < \mathrm{r}^{\mathrm{a}}) \quad \text{if } \underline{\mathrm{x}}_{\mathrm{t}} < \mathrm{x} < \overline{\mathrm{x}}_{\mathrm{t}}$$

$$E\mathrm{r}(\mathrm{x}) = E\mathrm{r}^{\mathrm{a}} \qquad if\ \mathrm{x} > \overline{\mathrm{x}}_{\mathrm{t}}$$

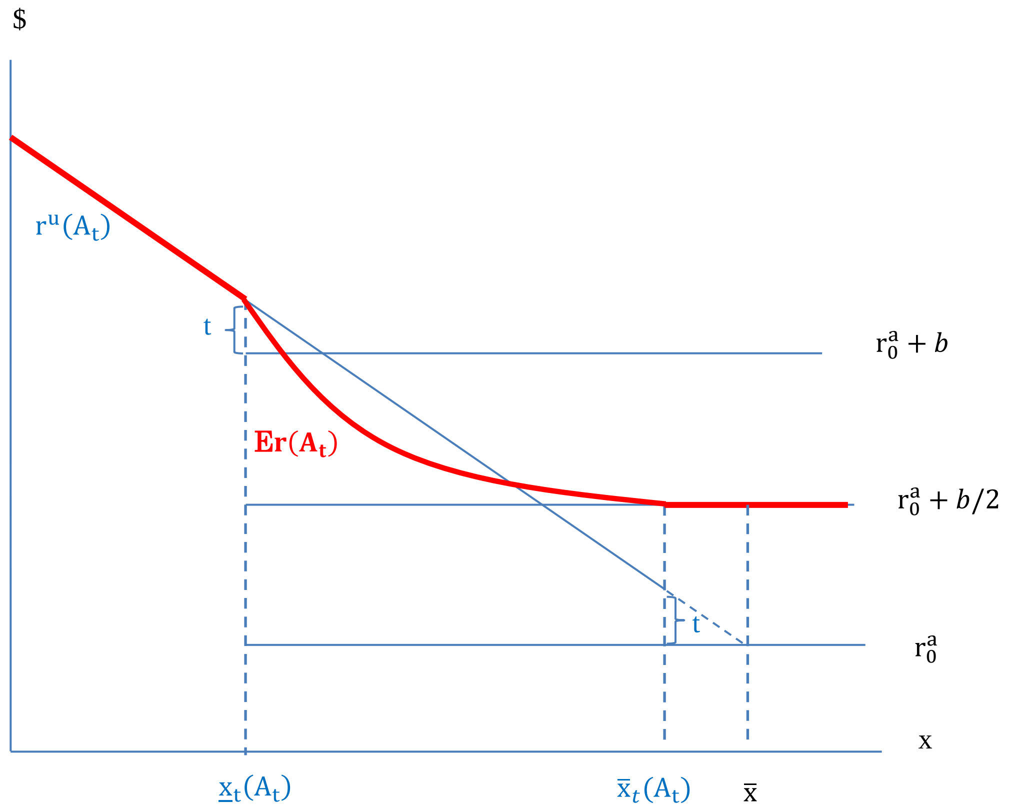
If land is located closer to CBD than the lower boundary of development under the tax ($\underline{\mathrm{x}}_{\mathrm{t}}$), expected rent equals urban rent since it is higher than maximum agricultural rent ($\mathrm{r}_0^{\mathrm{a}} + b$) plus a tax. At the lower boundary of development, urban rent and expected rent are equal to maximum agricultural rent. Between the lower and upper boundary of development under a tax ($\overline{\mathrm{x}}_{\mathrm{t}}$), expected rent is a weighted average of urban and agricultural rent where a tax t lowers the probability of urban development. Between the lower and upper boundary, a decreasing and quadratic convex function of distance is observed

$$(4.37)\qquad \frac{\partial Er(x)}{\partial x} = \frac{s(-\mathrm{A}_{\mathrm{t}} + r_0^a + V + sx - Y)}{b} < 0$$

$$(4.38)\qquad \frac{\partial^2 E\mathrm{r}(\mathrm{x})}{\partial \mathrm{x}^2} = \frac{s^2}{b} > 0$$

If land is located at or further than the upper boundary, expected rent is same as expected agricultural rent ($\mathrm{r}_0^{\mathrm{a}} + b/2$). Therefore, expected rent under a tax is illustrated as a thick red line in *Figure 4.3*.

Figure.4.3. Expected rent under tax



When tax increases, open space increases. As a result, urban rent also increases while the lower and upper boundaries of development decrease as expressed in the following equations and in *Figure 4.4*:

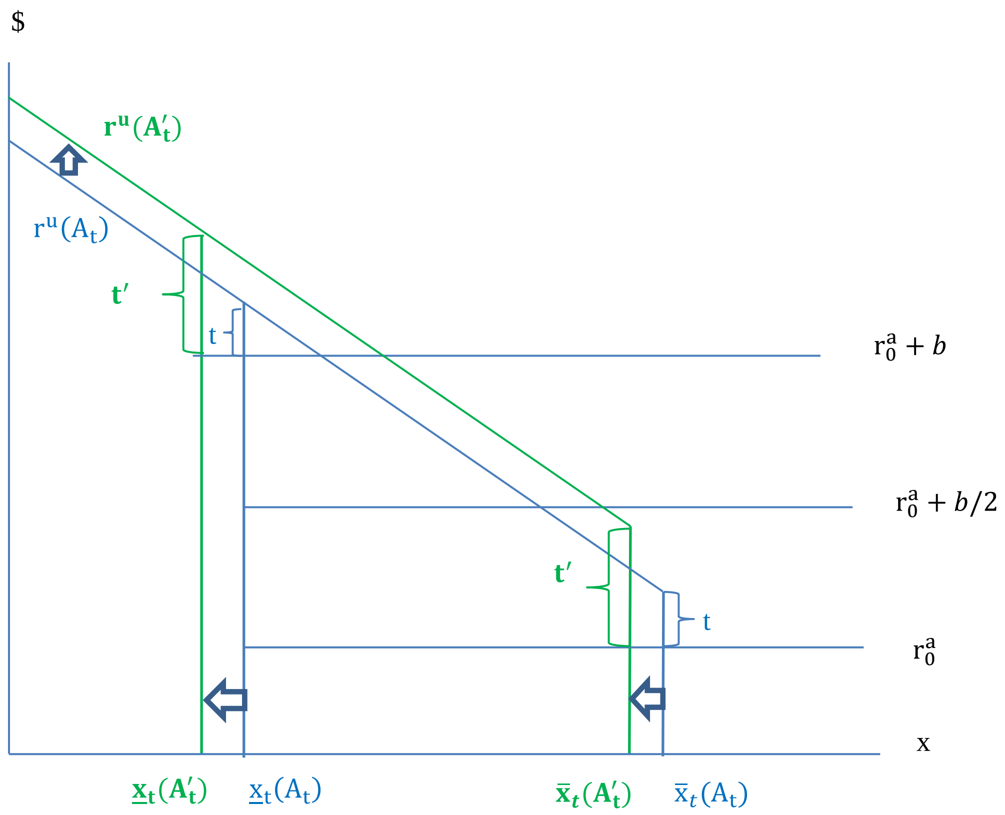
(4.39) $$\frac{\partial r^u(Y, s, \bar{V}, A_t\ x)}{\partial A_t} = 1$$

(4.40) $$\frac{\partial t}{\partial A_t} = 1 + s$$

(4.41) $$\frac{\partial \underline{x}_t}{\partial A_t} = -1$$

(4.42) $$\frac{\partial \bar{x}_t}{\partial A_t} = -1$$

Figure 4.4 Effect of open space increment under a tax



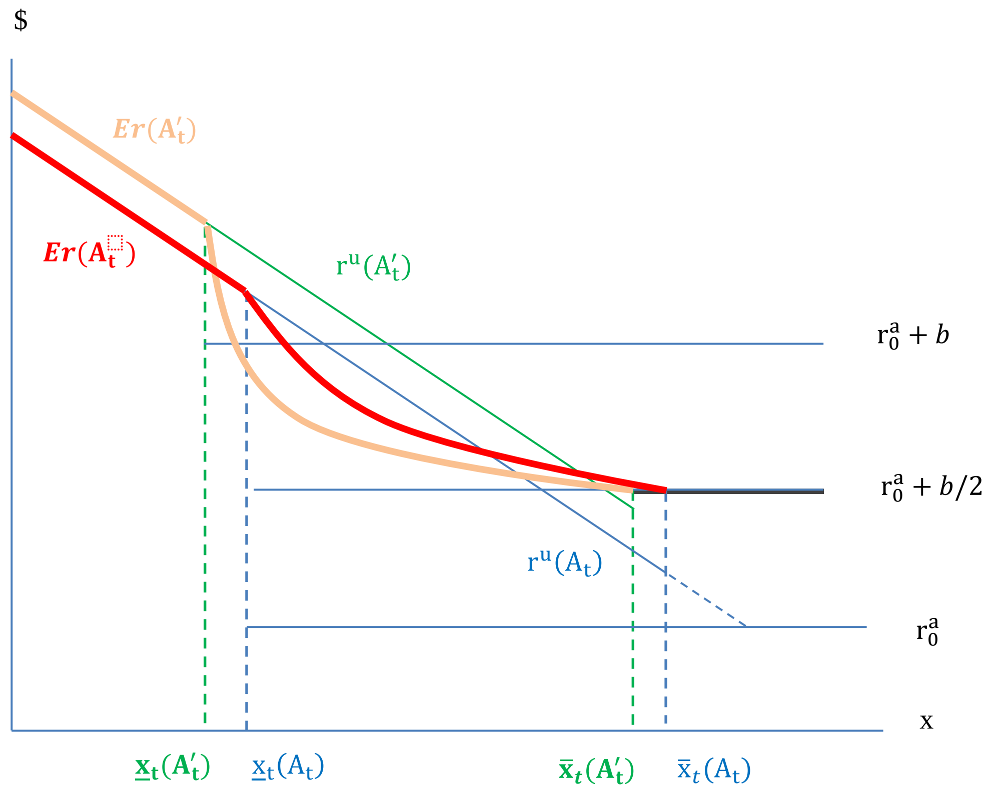
On the other hand, the marginal effect of open space on expected rent between the lower and upper boundary of development depends on parameter values:

(4.43) $$\frac{\partial E\mathrm{r}(\mathrm{x})}{\partial \mathrm{A_t}} = \frac{b - 2sx}{2b}$$

This is because a change in open space has two opposite effects. From (4.36), urban rent is a component of expected rent. This increases as a result of open space increments and therefore expected rent also increases. However, a tax needs to increase to preserve open space and this increase in tax reduces the probability of development.

The marginal effect of open space can be illustrated in *Figure 4.5*.

Figure. 4.5 Marginal effect of increasing open space under tax



The red line indicates expected rent at an initial open space (A_t) while the orange line indicates expected rent at a new open space (A'_t). The marginal effect of increasing open space is the gap between these lines. From CBD to the new lower boundary of development, $\underline{x}_t(A'_t)$, expected rent is greater due to the increase in open space and the resulting urban rent. However, the tax rate increases to preserve larger expanses of open space and therefore lowers the probability of development. The result of lower probability of development reduces expected rent since it is a weighted average of development and agriculture. Between the new lower and upper boundary of development, there is a reversal point where the relationship between the initial and new expected rent changes. From CBD to that point, expected rent under new open space is larger and the gap between new and old expected rent is the marginal benefit of increasing open space. Since expected rent under old open space is greater than that of new open space, the gap between old and new expected rent from the reverse point to the physical boundary is the marginal cost of open space. At the optimal open space value that maximizes total expected rents, the marginal cost and marginal benefit are equivalent. Otherwise, there would be improvement in expected total rent when increasing or decreasing open space.

Suppose moderate UGB yields higher expected total rent than strict UGB. For moderate UGB, the marginal effect of increasing open space is derived by a similar step as was done for the tax. To compare the marginal effect of increasing open space, expected rent at distance x from CBD under moderate UGB is defined as follows:

$$E\mathrm{r}(\mathrm{x}) = \mathrm{r}^{\mathrm{u}}\left(\mathrm{Y}, \mathrm{s}, \overline{\mathrm{V}}, \mathrm{A}_{\mathrm{gm}}\ \mathrm{x}\right) \qquad if\ \mathrm{x} < \underline{\mathrm{x}}_{\mathrm{gm}}$$

(4.44) $$E\mathrm{r}(\mathrm{x}) = \mathrm{r}^{\mathrm{u}}\left(\mathrm{Y}, \mathrm{s}, \overline{\mathrm{V}}, \mathrm{A}_{\mathrm{gm}}, \mathrm{x}\right) * \Pr(\mathrm{r}^{\mathrm{u}} > \mathrm{r}^{\mathrm{a}}) + \mathrm{r}^{\mathrm{a}} * \Pr(\mathrm{r}^{\mathrm{u}} < \mathrm{r}^{\mathrm{a}}) \quad if\ \underline{\mathrm{x}}_{\mathrm{gm}} < \mathrm{x} < \mathrm{g}$$

$$E\mathrm{r}(\mathrm{x}) = E\mathrm{r}^{\mathrm{a}} \qquad if\ \mathrm{x} > \mathrm{g}$$

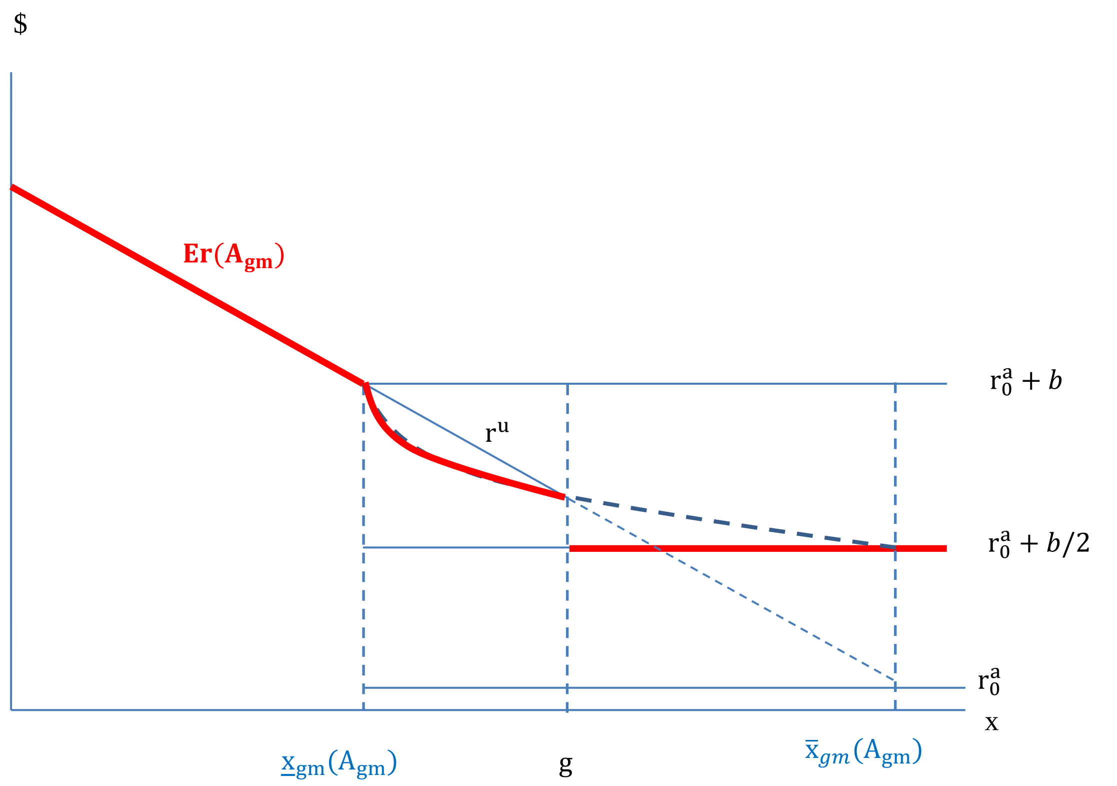
If land is located closer than lower boundary of development, expected rent is urban rent and if land is located further than upper boundary of development, expected rent is agricultural rent. Between the lower and upper boundaries of development, expected rent is weighted average of urban and agricultural rent and a decreasing and quadratic convex function of distance is observed

$$(4.45) \qquad \frac{\partial Er(x)}{\partial x} = \frac{s(-\mathrm{A}_{\mathrm{gm}} + r_0^a + V + sx - Y)}{b} < 0$$

$$(4.46) \qquad \frac{\partial^2 E\mathrm{r}(\mathrm{x})}{\partial \mathrm{x}^2} = \frac{s^2}{b} > 0$$

Unlike the no policy or tax cases, there is a gap of expected rent at the UGB (g). This is because expected rent is equal to expected urban rent at the upper boundary of development, but UGB located between the lower and upper boundaries of development. Therefore, if UGB is an interior solution, expected rent has a gap illustrated as follows:

Figure. 4.6 Expected rent under moderate UGB



When UGB gets stricter (lower g) to preserve more open space, urban rent, expected rent, and lower boundary of development increase.

(4.47) $$\frac{\partial r^{u}\left(Y, s, \bar{V}, A_{gm}\ x\right)}{\partial A_{gm}} = 1$$

(4.48) $$\frac{\partial Er(x)}{\partial A_{gm}} = \frac{A_{gm} - r_0^a - V - sx + Y}{b} > 0$$

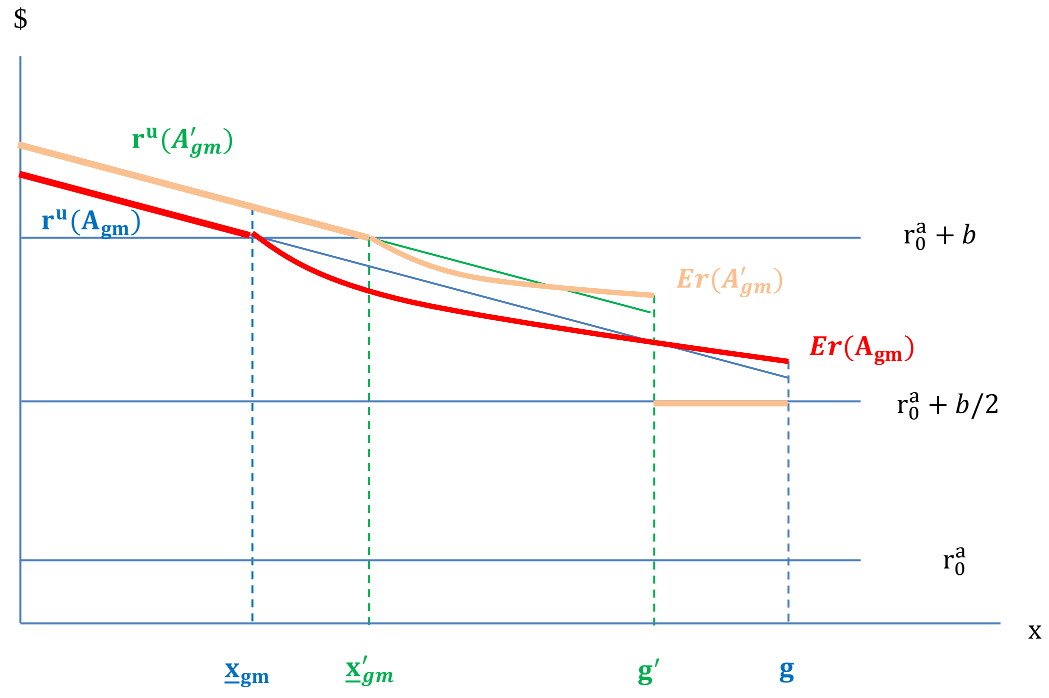
(4.49) $$\frac{\partial \underline{x}_{gm}}{\partial A_{gm}} = 1/s > 0$$

(4.50) $$\frac{\partial g}{\partial A_{gm}} = \frac{-b(1+s) + \sqrt{-b(b - 2A_{gm}(1+s) + 2(r_0^a + \bar{m}s + V - Y))}}{\sqrt{-bs^2(b - 2A_{gm}(1+s) + 2(r_0^a + \bar{m}s + V - Y))}}$$

An illustration of when open space under moderate UGB increases from A_{gm} to A'_{gm}

(the marginal effect), is found below:

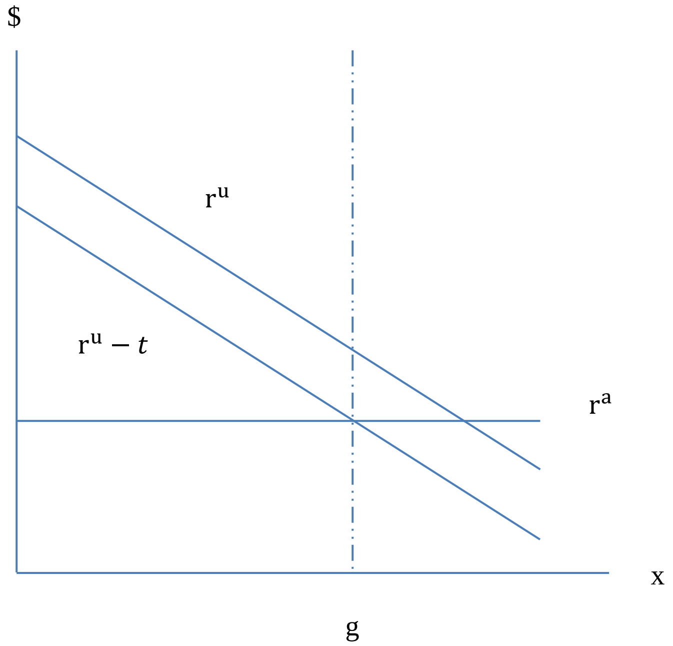
Figure. 4.7 Marginal effect of increasing open space under tax



The red line indicates expected rent at initial open space (A_{gm}), while the orange line indicates expected rent at a new open space(A'_{gm}). The marginal effect of increasing open space is the gap between these lines. From CBD to the new UGB (g′), expected rent is larger under new open space due to expansions in open space and the resulting urban rent. Unlike in the tax case, increasing open space does not reduce the probability of development, and therefore there is no reversal in the magnitudes of the new and initial expected rents until the new UGB (g') is reached. The area defined by the difference in expected rents from the CBD to the new UGB (g') represents the marginal benefit of open space. Since expected rent beyond the new UGB is expected agricultural rent, the area between the expected rent under the initial open space and the expected agricultural rent from the new UGB to the initial UGB is marginal cost of increasing open space. At the optimal amount of open space that maximizes expected total rent, these marginal costs and marginal benefits are equivalent. Otherwise, there should be improvement in expected total rent by increasing or decreasing open space.

Suppose there is no uncertainty, i.e. b=0. From (4.27) and (4.28), the lower and the upper boundary of development under a tax are the same: $\underline{x}_t = \overline{x}_t$. In the same way, $\underline{x}_g = \overline{x}_g$. In this case, urban rent minus a tax is equal to agricultural rent at x=g, $r^u(x = g) - t$. In addition, open space is equal under a tax and with the UGB. This no uncertainty case is illustrated in *Figure 4.8* below, and the result is equivalent to that in Bento et al. (2006). It also replicates their conclusion that a tax and UGB yield same value of total rent.

Figure 4.8 Tax and UGB under no uncertainty



If the marginal effect (differentiated expected total rent with respect to open space) is different under the tax and UGB for same amount of open space, the tax and UGB yield different expected total rents.

This can be expressed in following equation:

$$\left.\frac{dER_t}{d\mathrm{A}_t}\right|_{\mathrm{A}_t=\mathrm{A}''} \neq \left.\frac{dER_g}{d\mathrm{A}_g}\right|_{\mathrm{A}_g=\mathrm{A}''} \tag{4.51}$$

Here, ER_t and ER_g are expected total rent under the tax and UGB, respectively. A'' is an arbitrary area of open space. To compare marginal effects (4.51), parameter values listed in *Table 4.1* are used[37].

[37] The parameter values are chosen so that an interior solution exists for moderate UGB. For agricultural randomness b, it is normalized to 1. A robustness check is used in the next section.

*Table 4.1*Parameter values at base scenario

Variable	Description	Values
M	physical boundary	2.5
Y	income	4.5
V	reservation utility	2.5
S	travel cost	5.0
B	ag. randomness	1.0
ra0	base agri. Income	2.0

By substituting parameter values, the marginal effect of increasing open space are compared at $A = A_g^*$ which results in

$$(4.52) \qquad \left.\frac{dER_t}{dA_t}\right|_{A_t = A_g^*} = 0.149 \quad \neq \quad \left.\frac{dER_g}{dA_g}\right|_{A_g = A_g^*} = 0$$

Since the marginal effect is different at same level of open space, this is a second counterexample of the equivalence of a tax and UGB.

4.4.3. Robustness check

To show that tax and UGB are not identical, a numerical model is used in this section.

At base parameters listed in previous subsection, expected total rent under tax is 6.5441 while expected total rent under UGB is 6.5390 which implies that tax is preferable in the base parameter values. As for open space, tax gives larger open space than UGB. The expected total rent difference is 0.005. This difference might seem small. However, total rent in one city is large. Suppose a city's expected total rent is around 6.544 billion dollars under tax and 6.539 billion dollars under UGB. Then adopting a tax instead of a UGB yields 5 million dollars for one city. Moreover the difference is larger than numerical error from using computer program which is 16 decimal digits.

It is possible that this result, tax and UGB are not identical, only happens in base scenario. To verify that this is not the case, I conduct a robustness check by changing parameter values. Parameters are increased or decreased until lower boundary of development is close to zero and results are listed on *table*s *4.2-4.7. From table 2,* when agricultural randomness is zero, expected total rent under tax and UGB are identical. For other cases, tax gives higher expected total rent which supports the idea of difference between tax and UGB. For open space, sometimes it is identical under tax and UGB while other times tax gives higher open space. For first case, UGB is strict UGB.

Table 4.2. Robustness check for agricultural randomness

b	Expected total rent (ER)		Open space (A)		t	g	x_t		x_g
	tax	UGB	tax	UGB			low.bd.	up.bd.	low. bd.
0.00	5.4464	5.4464	2.1429	2.1429	0.3571	0.3571	0.3571	0.3571	0.4286
0.25	5.7159	5.7154	2.1607	2.1607	0.3393	0.3393	0.3143	0.3643	0.3821
0.50	5.9887	5.9866	2.1786	2.1786	0.3214	0.3214	0.2714	0.3714	0.3357
0.75	6.2647	6.2605	2.1964	2.1863	0.3036	0.3165	0.2286	0.3786	0.2873
1(=base)	6.5441	6.5390	2.2143	2.1932	0.2857	0.3258	0.1857	0.3857	0.2386
1.25	6.8266	6.8216	2.2321	2.2060	0.2679	0.3358	0.1429	0.3929	0.1912
1.50	7.1125	7.1077	2.2500	2.2217	0.2500	0.3462	0.1000	0.4000	0.1443
1.75	7.4016	7.3973	2.2679	2.2390	0.2321	0.3569	0.0571	0.4071	0.0978
2.00	7.6941	7.6902	2.2857	2.2573	0.2143	0.3676	0.0143	0.4143	0.0515

Table 4.3. Robustness check for physical boundary

M	Expected total rent (ER)		Open space (A)		t	g	x_t		x_g
	tax	UGB	tax	UGB			low.bd.	up.bd.	low. bd.
1.25	3.1735	3.1726	1.1429	1.1287	0.1071	0.1838	0.0071	0.2071	0.0257
1.50	3.8298	3.8281	1.3571	1.3399	0.1429	0.2120	0.0429	0.2429	0.0680
2.00	5.1691	5.1658	1.7857	1.7648	0.2143	0.2686	0.1143	0.3143	0.1530
2.5(base)	6.5441	6.5390	2.2143	2.1932	0.2857	0.3258	0.1857	0.3857	0.2386
3.00	7.9548	7.9481	2.6429	2.6252	0.3571	0.3834	0.2571	0.4571	0.3250
20	77.169	77.161	17.214	17.214	2.786	2.786	2.686	2.886	3.243

Table 4.4 Robustness check for income

Y	Expected total rent (ER)		Open space (A)		t	g	x_t		x_g
	tax	UGB	tax	UGB			low.bd.	up.bd.	low. bd.
3.25	6.2985	6.2976	2.3929	2.3487	2.3929	2.3487	0.0071	0.2071	0.0197
3.50	6.3298	6.3281	2.3571	2.3399	2.3571	2.3399	0.0429	0.2429	0.0680
4.00	6.4191	6.4158	2.2857	2.2648	2.2857	2.2648	0.1143	0.3143	0.1530
4.5(base)	6.5441	6.5390	2.2143	2.1932	2.2143	2.1932	0.1857	0.3857	0.2386
5.00	6.7048	6.6981	2.1429	2.1252	2.1429	2.1252	0.2571	0.4571	0.3250
7.50	8.0441	8.0357	1.7857	1.7857	1.7857	1.7857	0.6143	0.8143	0.7571
10.0	10.2762	10.2679	1.4286	1.4286	1.4286	1.4286	0.9714	1.1714	1.1857

Table 4.5 Robustness check for income

V	Expected total rent (ER)		Open space (A)		t	g	x_t		x_g
	tax	UGB	tax	UGB			low.bd.	up.bd.	low. bd.
0.25	7.5485	7.5402	1.8929	1.8929	1.8929	1.8929	0.5071	0.7071	0.6286
1.50	6.9012	6.8933	2.0714	2.0607	2.0714	2.0607	0.3286	0.5286	0.4121
2.5(base)	6.5441	6.5390	2.2143	2.1932	2.2143	2.1932	0.1857	0.3857	0.2386
3.00	6.4191	6.4158	2.2857	2.2648	2.2857	2.2648	0.1143	0.3143	0.1530
3.50	6.3298	6.3281	2.3571	2.3399	2.3571	2.3399	0.0429	0.2429	0.0680

Table 4.6 Robustness check for base income

ra0	Expected total rent (ER)		Open space (A)		t	g	x_t		x_g
	tax	UGB	tax	UGB			low.bd.	up.bd.	low. bd.
0.25	2.8878	2.8795	1.9643	1.9643	1.9643	1.9583	0.4357	0.6357	0.5429
1.00	4.4012	4.3933	2.0714	2.0607	2.0714	2.0607	0.3286	0.5286	0.4121
2(base)	6.5441	6.5390	2.2143	2.1932	2.2143	2.1932	0.1857	0.3857	0.2386
2.50	7.6691	7.6658	2.2857	2.2648	2.2857	2.2648	0.1143	0.3143	0.1530
3.00	8.8298	8.8281	2.3571	2.3399	2.3571	2.3399	0.0429	0.2429	0.0680

Table 4.7 Robustness check for base income

S	Expected total rent (ER)		Open space (A)		t	g	x_t		x_g
	tax	UGB	tax	UGB			low.bd.	up.bd.	low. bd.
1.00	6.9583	6.9167	1.1667	1.1667	1.1667	1.1667	0.1667	1.1667	0.8333
2.00	6.7708	6.7500	2.0000	1.9994	2.0000	1.9994	0.2500	0.7500	0.5000
4.00	6.5938	6.5861	2.1667	2.1432	2.1667	2.1432	0.2083	0.4583	0.2858
5(=base)	6.5441	6.5390	2.2143	2.1932	2.2143	2.1932	0.1857	0.3857	0.2386
6.00	6.5069	6.5035	2.2500	2.2318	2.2500	2.2318	0.1667	0.3333	0.2053
1000	6.2520	6.2520	2.4980	2.4980	2.4980	2.4980	0.0015	0.0025	0.0015

4.5. Conclusion

Despite the facts that there is considerable interest in preserving open space and government expenditures to do so are large, the relative efficiency of development taxes and UGB are not fully understood. This paper analyzes the effect of heterogeneity in agricultural rent and imperfect information in terms of total rents under development taxes and UGB. In contrast to Bento et al. (2006), I show using counter examples that development tax and UGB are not necessarily equivalent with respect to efficiency (total rent maximization). When there is heterogeneity in agricultural rent and a regulator does not know site specific information about agricultural rent, then the regulator does not have perfect information to efficiently regulate open space. Under those circumstances, the regulator cannot maximize total rent and maximize expected total rent instead.

Since it is not possible to derive clear implications about the equivalence of the two instruments from the analytical model, I use two approaches to show that tax and UGB could be different. First I compare marginal effect of open space at same points which is optimal amount of open space under moderate UGB. Then I conduct a robustness check that verifies that the policies are equivalent when agricultural randomness is zero, but are otherwise not equivalent for my chosen parameter values.

There are several limitations of this research. First, this chapter uses static models but regulator might learn soil and site specific true agricultural rent as time passes. In a dynamic model, if development is assumed to be irreversible, an option value also needs to be taken into account. Under that case, it might be better to save more open space by adopting UGB rather than tax. Second, these models assume open space is sum of undeveloped land, but other studies have shown that spatial configuration also matters (Wu and Plantinga, 2003). Third, I use simple functional form such as additive utility and uniform soil distribution. Relaxing this assumption is my future study.

The results of this study are not limited to development taxes and UGB. Rather this study can be viewed as an analysis of a price mechanism and a quantity mechanism for an urban development model under uncertainty in agriculture rent and imperfect information. One potential extension is subsidy for non-development rather than development taxes. Compared to development tax, it is politically more feasible since landowners' burden is smaller since they do not need to pay tax, and it can still achieve the same efficiency outcome as a development tax.

4.6. References

Andersona, S. T., and S. E. West. “Open space, residential property values, and spatial context.” *Regional Science and Urban Economics* 36(2006):773–789.

Bento, A. M., S. F. Franco, and D. Kaffine. “The efficiency and distributional impacts of alternative anti-sprawl policies.” *Journal of Urban Economics* 59 (2006):121-141.

Brueckner, J. K. “Urban sprawl: Diagnosis and remedies.” *International Regional Science Review* 23 (2000): 160-171

Capozza, R. Dennis., and Helsley, W. Robert. “The Stochastic City.” *Journal of Urban Economics* 27 (1990):187-203

Crampton, G. R. “Local Government Structure and Urban Residential Location.” *Urban Studies* 33 (1996): 1061-1076

Crampton, G. R. “Labour-Market Search and Urban Residential Structure.” *Environment and Planning A* 29 (1997): 989-1002

Epple, D., and Romer, Thomas. “Mobility and Redistribution.” *Journal of Political Economy* 99 (1991): 828-858

Irwin, E. G. “The Effects of Open Space on Residential Property Values.” *Land Economics* 78(2002): 465-480

Liu, H., Parton, K, Zhou, Z., and Cox, R. “At-Home Meat Consumption in China: An

Empirical Study." *Australian Journal of Agricultural and Resource Economic*s 53(2009): 485-501

Lubowski, R, N., Plantinga, A. J., and Stavins, R. "What Drives Land-Use Change in the United States? A National Analysis of Landowner Decisions." *Land Economics* 84 (2008): 529-550

McConnell, V., and M. Walls. "Policy Monitor U.S. Experience with Transferable Development Rights." *Review of Environmental Economics and Policy* 3(2009): 288-303

Mills, D. E. "Growth, speculation and sprawl in a monocentric city." *Journal of Urban Economi*cs 10(1981): 201-226

Natural Resource Conservation Service. "Land Capability Classification." *U.S. Dept. of Agriculture, Natural Resource Conservation Service, Washington DC* (1971)

Parkhurst, G. M, and J. F. Shogren. "Spatial incentives to coordinate contiguous habitat." *Ecological Economics* 64(2007): 344-344.

Plantinga, A. J., R. N. Lubowski., and R. N. Stavins. "The effects of potential land development on agricultural land prices." *Journal of Urban Economics* 52(2002): 561-581

Sasaki, Komei. "Nuisance Zoning, the Labor Market and Capital Gain." *Annals of*

Regional Science 38 (2004): 675-686

Shibusawa, Hiroyuki. “Cyberspace and Physical Space in an Urban Economy.” *Papers in Regional Science* 79 (2000): 253-270

Shultz, S. D., and D. A. King. ”The use of census data for hedonic price estimates of open-space amenities and land use.” *The Journal of Real Estate Finance and Economics* 22(2001):239-252.

Sinclair, H. R. and H. P. Terpstra. “Soil Rating for Plant Growth.” *Iowa State Univ. Statistical Laboratory* (1995)

Solow, R. M., and Vickrey, W. S., “Land Use in a Long Narrow City.” *Journal of Economic Theory* 3(1971): 430-447

Taylor, C. and Wagman, L., “Consumer Privacy in Oligopolistic Markets: Winner, Losers, and Welfare.” *International Journal of Industrial Organization* 34(2014): 80-84

Thomas, D. L. “Coordinating opposite approaches to managing urban growth and curbing sprawl: A Synthesis.” *American Journal of Economics and Sociology* 60(2001): 229-243

U.S. Forest Service, “Forest Service Open Space Conservation Strategy.” *U.S. Dept. of Agriculture, Forest Service, Washington DC* (2007)

Wu, J. “Environmental amenities, urban sprawl, and community characteristics.”

Journal of Environmental Economics and Management 52 (2006): 525-547

Wu, J., and W. G. Boggess. "The optimal allocation of conservation funds." *Journal of Environmental Economics and Management* 38(1999):302-321

Wu, J., and E. J. Irwin. "Optimal land development with endogenous environmental amenities." *Amer. J. Agr. Econ*. 90(1) (2008): 232–248

Wu, J., and A. J. Plantinga. "The influence of public open space on urban spatial structure." *Journal of Environmental Economics and Management* 46 (2003): 288–309

Wu, J., R. M. Adams, D. Zilberman, and B. Babcock. "Targeting resource conservation expentidures." *Choices* 15, 2(2000): 33-37

Appendix 1: Derivation under tax

Open space under tax

$$\text{(A.1)} \qquad \mathrm{A_t} = \int_{\underline{\mathrm{x}}_\mathrm{t}}^{\overline{\mathrm{x}}_\mathrm{t}} \int_{\mathrm{r^u - t < r^a}} f(\varepsilon)\, \mathrm{d\varepsilon\, dx} + (\overline{m} - \overline{\mathrm{x}}_\mathrm{t}) = \int_{\underline{\mathrm{x}}_\mathrm{t}}^{\overline{\mathrm{x}}_\mathrm{t}} \int_{\varepsilon_t}^{b} f(\varepsilon)\, \mathrm{d\varepsilon\, dx} + (\overline{m} - \overline{\mathrm{x}}_\mathrm{t})$$

The random parameter ε_t that equalizes urban rent minus tax at x and agricultural rent is defined by:

$$\mathrm{r^u(Y, s, \overline{V}, A_t\, x) - t = r^a}(r_0^a, \varepsilon_t)$$

$$Y - sx - V + \mathrm{A_t} - \mathrm{t} = r_0^a + \varepsilon_t$$

$\varepsilon_t = Y - sx - V + \mathrm{A_t} - r_0^a - \mathrm{t}$

Since $0 \le \varepsilon_t \le$ b, within this range, PDF is always $f(\varepsilon_t) = \frac{1}{b}$

At the lower boundary of development, urban rent minus a tax and maximum agricultural rent are equalized:

$$\mathrm{r^u}\left(\mathrm{Y, s, \overline{V}, A_t, \underline{x}_t}\right) - \mathrm{t} = max\ \mathrm{r^a}$$

$$Y - s\underline{\mathrm{x}}_{\mathrm{t}} - V + \mathrm{A_t} - \mathrm{t} = r_0^a + b$$

$\underline{\mathrm{x}}_{\mathrm{t}} = (Y - V + \mathrm{A_t} - r_0^a - b - t)/s$

At the upper boundary of development, urban rent minus a tax and minimum agricultural rent are equalized:

$$\mathrm{r^u}(\mathrm{Y, s, \overline{V}, A_t, \overline{x}_t}) - \mathrm{t} = m\mathrm{in\ r^a}$$

$$Y - s\underline{\mathrm{x}}_{\mathrm{t}} - V + \mathrm{A_t} - \mathrm{t} = r_0^a$$

$\overline{\mathrm{x}}_{\mathrm{t}} = (Y - V + \mathrm{A_t} - r_0^a - t)/s$

Substituting these soil quality and boundaries into open space under a tax yields:

$$(\mathrm{A.2}) \qquad \mathrm{A_t} = \int_{(Y-V+\mathrm{A_t}-r_0^a-\boldsymbol{b}-t)/s}^{(Y-V+\mathrm{A_t}-r_0^a-t)/s} \int_{Y-sx-V+\mathrm{A_t}-r_0^a-\mathrm{t}}^{b} \frac{1}{b}\, \mathrm{d\varepsilon\, dx} + (\overline{m} - \overline{\mathrm{x}}_{\mathrm{t}})$$

$$= \frac{b}{2s} + \overline{m} - (Y - V + \mathrm{A_t} - r_0^a - t)/s$$

Solve for $\mathrm{A_t}$ yields

$$(A.3) \qquad \mathrm{A_t} = \frac{r_0^a + \bar{m}s + t + V - Y + \dfrac{b}{2}}{1+s}$$

Expected total rent under tax is:

$$(\mathrm{A.4})\mathrm{ER}_t = \int_0^{\underline{\mathrm{x}}_\mathrm{t}} \int_0^b \mathrm{r^u}(\mathrm{Y, s, \overline{V}, A_t, x}) f(\varepsilon)\, \mathrm{d}\varepsilon \mathrm{dx} + \int_{\underline{\mathrm{x}}_\mathrm{t}}^{\overline{\mathrm{x}}_\mathrm{t}} \int_{\mathrm{r^u - t > r^a}} \mathrm{r^u}(\mathrm{Y, s, \overline{V}, A_t, x}) f(\varepsilon)\, \mathrm{d\varepsilon\ dx}$$

$$+ \int_{\underline{\mathrm{x}}_\mathrm{t}}^{\overline{\mathrm{x}}_\mathrm{t}} \int_{\mathrm{r^u - t < r^a}} \mathrm{r^a}(r_0^a, \varepsilon) f(\varepsilon)\, \mathrm{d\varepsilon\ dx} + \int_{\overline{\mathrm{x}}_\mathrm{t}}^{\overline{\mathrm{m}}} \int_0^b \mathrm{r^a}(r_0^a, \varepsilon)\, f(\varepsilon)\, \mathrm{d}\varepsilon \mathrm{dx}$$

$$= \int_0^{\underline{\mathrm{x}}_\mathrm{t}} \mathrm{r^u}(\mathrm{Y, s, \overline{V}, A_t, x})\, \mathrm{dx} + \int_{\underline{\mathrm{x}}_\mathrm{t}}^{\overline{\mathrm{x}}_\mathrm{t}} \frac{\mathrm{r^u}(\mathrm{Y, s, \overline{V}, A_t, x})\varepsilon_t}{b}\, \mathrm{dx}$$

$$+ \int_{\underline{\mathrm{x}}_\mathrm{t}}^{\overline{\mathrm{x}}_\mathrm{t}} \frac{(b - \varepsilon_t)(2r_0^a + b + \varepsilon_t)}{2b}\, \mathrm{dx} + \int_{\overline{\mathrm{x}}_\mathrm{t}}^{\overline{\mathrm{m}}} \left(r_0^a + \frac{b}{2}\right) \mathrm{dx}$$

$$= \int_0^{(Y - V + \mathrm{A_t} - r_0^a - b - t)/s} (Y - sx - V + \mathrm{A_t})\, \mathrm{dx}$$

$$+ \int_{(Y - V + \mathrm{A_t} - r_0^a - b - t)/s}^{(Y - V + \mathrm{A_t} - r_0^a - t)/s} \frac{(Y - sx - V + \mathrm{A_t})(Y - sx - V + \mathrm{A_t} - r_0^a - \mathrm{t})}{b}\, \mathrm{dx}$$

$$+ \int_{(Y - V + \mathrm{A_t} - r_0^a - b - t)/s}^{(Y - V + \mathrm{A_t} - r_0^a - t)/s} \frac{\big(b - (Y - sx - V + \mathrm{A_t} - r_0^a - \mathrm{t})\big)\big(2r_0^a + b + (Y - sx - V + \mathrm{A_t} - r_0^a - \mathrm{t})\big)}{2b}\, \mathrm{dx}$$

$$+ \int_{(Y - V + \mathrm{A_t} - r_0^a - t)/s}^{\overline{\mathrm{m}}} \left(r_0^a + \frac{b}{2}\right) \mathrm{dx}$$

$$= \frac{\mathrm{A_t}^2 + b^2/3 - \mathrm{A_t}(b + 2(r_0^a + V - Y)) + ({r_0^a}^2 - t^2 + (V - Y)^2 + 2r_0^a(\bar{m}s + V - Y)) + b(r_0^a + \bar{m}s +}{2s}$$

Substitute open space into expected total rent yields:

$$(\mathrm{A.5}) \qquad \mathrm{ER}_t$$

$$= \frac{\left[\left(\dfrac{r_0^a + \bar{m}s + t + V - Y + \dfrac{b}{2}}{1+s}\right)^2 + \dfrac{b^2}{3} - \left(\dfrac{r_0^a + \bar{m}s + t + V - Y + \dfrac{b}{2}}{1+s}\right)\big(b + 2(r_0^a + V - Y)\big) + \big({r_0^a}^2 - t^2 + (V - Y)^2 + 2r_0^a(\bar{m}s + V - Y)\big) + b(r_0^a + \bar{m}s + V - Y)\right]}{2s}$$

Solving first order condition with respect to t yields:

$$\frac{d\mathrm{ER}_t}{d\mathrm{t}} = \frac{-2t - \frac{\left(b + 2(r_0^a + V - Y)\right)}{1+s} + \frac{2\left(r_0^a + \overline{m}s + t + V - Y + \frac{b}{2}\right)}{(1+s)^2}}{2s} = 0$$

$$(\mathrm{A.6}) \qquad \mathrm{t}^* = \frac{\overline{m} - (b/2 + r_0^a + V - Y)}{s+2}$$

Substitute this optimal tax and get optimal open space under tax:

$$(A.7) \qquad A_t^* = \frac{\frac{b}{2} + r_0^a + V - Y + (s+1)\overline{m}}{s+2}$$

Finally substitute optimal tax t^* to expected total rent yield optimal expected total rent

under tax:

$$(\mathrm{A.8}) \quad \mathrm{ER}_t =$$

$$\frac{b^2(1+2s) + 6bs(\overline{m} + r_0^a + \overline{m}s + V - Y) + 6s(\overline{m}^2 + (r_0^a + V - Y)^2 + 2\overline{m}(r_0^a + r_0^a s - V + Y))}{12s(2+s)}$$

Appendix 2: Derivation under strict UGB

Open space under strict UGB:

$$(\mathrm{A.9}) \qquad \mathrm{A_{gs}} = (\overline{m} - \mathrm{g})$$

Expected total rent under UGB is defined as

$$(\mathrm{A.10}) \quad \mathrm{ER}_{gs} = \int_0^{\mathrm{g}} \int_0^{b} \mathrm{r^u}\left(\mathrm{Y}, \mathrm{s}, \overline{\mathrm{V}}, \mathrm{A_{gs}}, \mathrm{x}\right) f(\varepsilon) \mathrm{d}\varepsilon \mathrm{dx} + \int_{\mathrm{g}}^{\overline{\mathrm{m}}} \int_0^{b} \mathrm{r^a}(r_0^a, \varepsilon)\, f(\varepsilon) \mathrm{d}\varepsilon \mathrm{dx}$$

$$= \int_0^{\mathrm{g}} \left(Y - sx - V + \mathrm{A_{gs}}\right) \mathrm{dx} + \int_{\mathrm{g}}^{\overline{\mathrm{m}}} \left(r_0^a + \frac{b}{2}\right) \mathrm{dx}$$

Substitute open space and solve integral yields:

$$(A.11) \qquad \mathrm{ER}_{gs} = -\left(1+\frac{\mathrm{s}}{2}\right)\mathrm{g}^2 + \left(Y - V + \bar{m} - r_0^a - \frac{b}{2}\right)\mathrm{g} + \left(r_0^a + \frac{b}{2}\right)\bar{\mathrm{m}}$$

Solve first order condition with respect to g:

$$(A.12) \qquad \frac{d\mathrm{ER}_{gs}}{dg} = (Y - V + \bar{m} - 2\mathrm{g}) - \mathrm{sg} - \left(r_0^a + \frac{b}{2}\right) = 0$$

This yields optimal g that maximizes total rents:

$$(A.13) \qquad g^* = \left[\left(Y - V + \bar{m} - r_0^a - \frac{b}{2}\right)/(2+\mathrm{s})\right]$$

Substitute this into open space:

$$(A.14) \qquad A_{gs}^* = (\bar{m} - \mathrm{g}) = \bar{m} - \left[\left(Y - V + \bar{m} - r_0^a - \frac{b}{2}\right)/(2+\mathrm{s})\right]$$

Substitute this into expected total rents yields maximized expected total rent under strict UGB

$$(A.15)\ \mathrm{ER}_{gs} = -\left(1+\frac{\mathrm{s}}{2}\right)\left[\frac{\left(Y - V + \bar{m} - r_0^a - \frac{b}{2}\right)}{2+\mathrm{s}}\right]^2$$
$$+ \left(Y - V + \bar{m} - r_0^a - \frac{b}{2}\right)\left[\left(Y - V + \bar{m} - r_0^a - \frac{b}{2}\right)/(2+\mathrm{s})\right] + \left(r_0^a + \frac{b}{2}\right)\bar{m}$$

From $(A.7)$ and $(A.14)$, open space under optimal tax and optimal strict UGB are equal:

$$(A.16) \qquad A_t^* = \frac{\frac{b}{2} + r_0^a + V - Y + (s+1)\bar{m}}{s+2} = A_{gs}^*$$

Subtract expected total rent under optimal strict UGB $(A.15)$ from expected total rent under optimal tax (A.8),

$$(A.17) \qquad \mathrm{ER}_t - \mathrm{ER}_{gs} = \frac{b^2}{24\,s} > 0$$

Appendix 3: Derivation under moderate UGB

Open space under moderate UGB:

$$(A.18) \qquad \mathrm{A_{gm}} = \int_{\underline{\mathrm{x}}_\mathrm{g}}^{\mathrm{g}} \int_{\mathrm{r^u<r^a}} f(\varepsilon)\, \mathrm{d\varepsilon\, dx} + (\overline{m} - \mathrm{g}) = \int_{\underline{\mathrm{x}}_\mathrm{g}}^{\mathrm{g}} \int_{\varepsilon_g}^{b} f(\varepsilon)\, \mathrm{d\varepsilon\, dx} + (\overline{m} - \mathrm{g})$$

The random component ε_{gm} that equalizes urban rent at x and agricultural rent is defined by:

$\mathrm{r^u}\left(\mathrm{Y, s, \overline{V}, A_{gm}\ x}\right) = \mathrm{r^a}\left(r_0^a, \varepsilon_{gm}\right)$

$Y - sx - V + \mathrm{A_{gm}} = r_0^a + \varepsilon_{gm}$

$\varepsilon_{gm} = Y - sx - V + \mathrm{A_{gm}} - r_0^a - \mathrm{t}$

Since $0 \leq \varepsilon_{gm} \leq$ b, within this range, PDF is always $f\left(\varepsilon_{gm}\right) = \frac{1}{b}$

At the lower boundary of development, urban rent and maximum agricultural rent are equalized:

$\mathrm{r^u}\left(\mathrm{Y, s, \overline{V}, A_{gm}, \underline{x}_{gm}}\right) = max\ \mathrm{r^a}$

$Y - s\underline{\mathrm{x}}_{\mathrm{gm}} - V + \mathrm{A_{gm}} = r_0^a + b$

$\underline{\mathrm{x}}_{\mathrm{gm}} = \left(Y - V + \mathrm{A_{gm}} - r_0^a - b\right)/s$

At the upper boundary of development, urban rent and minimum agricultural rent are equalized:

$$\mathrm{r^u}\left(\mathrm{Y, s, \overline{V}, A_{gm}, \overline{x}_{gm}}\right) = min\ \mathrm{r^a}$$

$$Y - s\overline{\mathrm{x}}_{\mathrm{gm}} - V + \mathrm{A_{gm}} = r_0^a$$

$$\underline{\mathrm{x}}_{\mathrm{gm}} = \left(Y - V + \mathrm{A_{gm}} - r_0^a\right)/s$$

$$\mathrm{A_{gm}} = \int_{(Y-V+\mathrm{A_{gm}}-r_0^a-b)/s}^{\mathrm{g}} \int_{Y-sx-V+\mathrm{A_{gm}}-r_0^a}^{b} \frac{1}{b} \mathrm{d\varepsilon\, dx} + (\overline{m} - \mathrm{g})$$
$$= \int_{(Y-V+\mathrm{A_{gm}}-r_0^a-b)/s}^{\mathrm{g}} \frac{\mathrm{b} - (Y - sx - V + \mathrm{A_{gm}} - r_0^a)}{b}\ \mathrm{dx} + (\overline{m} - \mathrm{g})$$

Rearranging this yields:

$$(A.19) \qquad \mathrm{A_{gm}}^2 + 2(Y - gs - V - r_0^a - b - bs)\mathrm{A_{gm}} + 2(\overline{m} - \mathrm{g})\mathrm{bs}$$
$$+ (-Y + gs + V + r_0^a + b)^2 = 0$$

Solving above equation yield two possible open space $\mathrm{A_{gm}}$:

$$(\mathrm{A}.20.1)\ \ \mathrm{A}_{gm}^{-} = b + r_0^a + bs + V - Y + gs$$
$$- \sqrt{bs}\sqrt{2g + 2gs + 2b - 2\overline{m} + 2r_0^a + bs + 2V - 2Y}$$

$$(\mathrm{A}.20.2)\ \ \mathrm{A}_{gm}^{+} = b + r_0^a + bs + V - Y + gs$$
$$+ \sqrt{bs}\sqrt{2g + 2gs + 2b - 2\overline{m} + 2r_0^a + bs + 2V - 2Y}$$

Expected total rent under moderate UGB is defined as:

$$(\mathrm{A}.21)\ \ \mathrm{ER}_g\ = \int_0^{\underline{\mathrm{x}}_{\mathrm{g}}} \int_0^{b} \mathrm{r^u}\left(\mathrm{Y, s, \overline{V}, A_{gm}, x}\right) f(\varepsilon)\mathrm{d}\varepsilon\mathrm{dx}$$

$$+ \int_{\underline{\mathrm{x}}_{\mathrm{g}}}^{\mathrm{g}} \int_{\mathrm{r^u} > \mathrm{r^a}} \mathrm{r^u}\left(\mathrm{Y, s, \overline{V}, A_{gm}, x}\right) f(\varepsilon)\ \mathrm{d\varepsilon\ dx} + \int_{\underline{\mathrm{x}}_{\mathrm{g}}}^{\mathrm{g}} \int_{\mathrm{r^u} < \mathrm{r^a}} \mathrm{r^a}(r_0^a, \varepsilon) f(\varepsilon)\ \mathrm{d\varepsilon\ dx}$$

$$+\int_{\mathrm{g}}^{\bar{\mathrm{m}}}\int_{0}^{b}\mathrm{r^a}(r_0^a,\varepsilon)\,f(\varepsilon)\mathrm{d}\varepsilon\mathrm{dx}$$

$$=\int_{0}^{(\mathrm{Y-V+A_{gm}}-r_0^a-\mathrm{b})/\mathrm{s}}(Y-sx-V+\mathrm{A_{gm}})\,\mathrm{dx}$$

$$+\int_{(\mathrm{Y-V+A_{gm}}-r_0^a-\mathrm{b})/\mathrm{s}}^{\mathrm{g}}\int_{0}^{Y-sx-V+\mathrm{A_{gm}}-r_0^a}\big((Y-sx-V+\mathrm{A_{gm}})/b\big)\,\mathrm{d\varepsilon\,dx}$$

$$+\int_{(\mathrm{Y-V+A_{gm}}-r_0^a-\mathrm{b})/\mathrm{s}}^{\mathrm{g}}\int_{Y-sx-V+\mathrm{A_{gm}}-r_0^a}^{b}\frac{r_0^a+\varepsilon}{b}\mathrm{d\varepsilon\,dx}$$

$$+\int_{\mathrm{g}}^{\bar{\mathrm{m}}}\int_{0}^{b}\frac{r_0^a+\varepsilon}{b}\mathrm{d}\varepsilon\mathrm{dx}$$

$$(\mathrm{A}.22)\qquad=\frac{1}{6bs}\Big\{-\mathrm{A_{gm}}^3+b^3$$

$$-3\mathrm{A_{gm}}[b^2+2b(r_0^a+V-Y)+(r_0^a+gs+V-Y)^2]$$

$$+3b\big[{r_0^a}^2+(V-Y)^2+2r_0^a(\bar{m}s+V-Y)\big]+(r_0^a+gs+V-Y)^3$$

$$+3\mathrm{A_{gm}}^2(b+r_0^a+gs+V-Y)+3b^2(r_0^a+\bar{m}s+V-Y)\Big\}$$

Substitute open space and solve first order conditions with respect to g yield three possible UGBs where the result is same for either UGB, $(\mathrm{A}.20.1)$ and $(\mathrm{A}.20.2)$

$$g_1^-=g_1^+=\frac{b+2\bar{m}s-2r_0^as-2sV+2sY}{2s(1+s)}$$

$$g_2^-=g_2^+=\frac{1}{8s}\Big\{2b-2bs+2bs^2+2bs^3$$

$$-\sqrt{}[(-2b+2bs-2bs^2-2bs^3)^2-16s(-2b^2+2b\bar{m}-2br_0^a$$

$$+3b^2s-4b\bar{m}s+4br_0^as+2b\bar{m}s^2-2br_0^as^2-2bV+4bsV-2bs^2V$$

$$+2bY-4bsY+2bs^2Y)]\Big\}$$

$$g_3^- = g_3^+ = \frac{1}{8s}\{2b - 2bs + 2bs^2 + 2bs^3$$

$$+ \sqrt{[(-2b + 2bs - 2bs^2 - 2bs^3)^2 - 16s(-2b^2 + 2b\bar{m} - 2br_0^a}$$

$$+ 3b^2s - 4b\bar{m}s + 4br_0^a s + 2b\bar{m}s^2 - 2br_0^a s^2 - 2bV + 4bsV - 2bs^2V$$

$$+ 2bY - 4bsY + 2bs^2Y)]\}$$

Depending on parameter values, many of UGB are out of range:

$$\underline{x}_{gm} \leq g \leq \bar{x}_{gm}$$

According to robustness check, only combinations of g_1^- and A_{gm}^- or g_2^- and A_{gm}^- are within the upper and lower boundaries for all cases and g_2^- and A_{gm}^- yields higher expected total rent when the solution is interior:

$$\underline{x}_{gm} < g < \bar{x}_{gm}$$

Expected total rent under optimal moderate UGB g_2^- is

(A.23) $\mathrm{ER}_g^{rA2} =$

$$\frac{1}{48s}\{48\bar{m}r_0^a s + b^2(3s^6 - 6s^5 - 15s^4 - 14s^3 - 63s^2 + 9)$$

$$+ 2\sqrt{2}b^{3/2}\sqrt{s}(s^4 - s^3 + 5s^2 + 7s - 2)\sqrt{\theta}$$

$$- 2\sqrt{2bs}(4\bar{m}s - 4r_0^a s - 4sV + 4sY + s\delta - 2\delta)\sqrt{\theta}$$

$$- 3b[-4r_0^a s^3 + 24r_0^a 0s^2 - 4r_0^a s + 4\bar{m}s(s^2 - 6s - 1) - 4s^3V$$

$$+ 24s^2V - 4sV + 3\delta + s^3\delta - 3s^2\delta - s\delta + 4s^3Y - 24s^2Y + 4sY]\}$$

where $\delta = \sqrt{b(-1+s)^2(b(1+8s+6s^2+4s^3+s^4)+8s(-\overline{m}+r_0^a+V-Y))}$

Without imposing parameter values, expected total rent under optimal moderate UGB is hard to compare with expected total rent under optimal tax and optimal strict UGB.

Chapter 5

Conclusions

The first essay conducted a regional-scale analysis to identify the factors that affect land use in Japan. In addition to own land use returns, the analysis uses a unique data set that includes land use, soil quality, slope, elevation, distance to train station and metropolitian area and conducted analysis using multinomial logit model to analyze factors that affect land use choices. The result suggests that both socioeconomic and geological variables affected land use in Japan. This land use model is used for policy simulation that changes returns for each land use, such as afforestation payment, development taxes and subsidy for agriculture. According to the simulation, only afforestation payment is economically meaningful: to increase the forest area 1%, 32787 yen is required. This data is then combined with per ha pollution for COD, T-N, and T-P for each land use. According to the result, afforestation payment is most effective policy to reduce water pollution for three (Lake Tega, Lake Inba, and Lake Biwa) out of five watersheds for all pollutants. However, afforestation payment increases COD in the other watersheds (Lake Kojima and Lake Kamafusa) which suggests the importance of using regional specific policy. This abatement cost from land use is then compared with engineering data of sewage treatment plants. Comparison of abatement cost for given targets shows that PS abatement has more capacity to reduce pollution. For controlling T-N in watersheds Inba (watershed-1) and Biwa (watershed-3), a NPS abatement policy is cost effective, but for controlling COD, modifying and constructing new sewage plants is more cost effective. For T-P, NPS is cost effective in watershed Inba while PS is cost effective in watershed Biwa. Therefore, the choice of policy depends on the specific pollutant and watershed, and sometimes combining both NPS and PS policies such as reducing NPS pollution at first and then switch to PS pollution reduction is cost effective rather than focusing on a single source which suggests the importance of cover several major sources of pollutant.

The second essay analyzes another major source of water pollution, which is agriculture. Using fixed effect panel, the effect of agri-environmental scheme used in Shiga prefecture, which subsidizes farmers who adopted greener practice is analyzed. The main result suggests that Shiga AES only increases the proportion of farmers who reduced nitrogen more than half by 5.5% and it is not very effective policy. The possible explanation is that the policy was not well known because the adoption ratio is only 8.1% in 2005. Combining with per ha pollution data, water pollution reduction is estimated. The budget of the local government is two hundred and twelve million yen for 2005 and this is used as abatement cost. Since Shiga AES abatement is a single data for each pollutant, the abatement cost to reduce same amount of pollution is calculated for land use subsidy and upgrading and construction of sewage plants. The result suggests that for each pollutant, afforestation payment is the most cost effective policy but AES is more cost effective than sewage treatment plants to reduce pollution in Shiga. Therefore, rather than investing traditional PS, sewage treatment plants, it is good to spend more budget on NPSs to reduce water pollution in Shiga. However, this result is not identical to entire Japan. The reason for high abatement cost from sewage treatment plants are because in this watershed, treatment plants are already efficient and to reduce pollution further, big amount of investment is necessary. On the other hand, due to stochastic nature of NPS pollution, land use subsidy and AES payment is not so reliable compared to PS pollution and therefore, if a policy maker is risk averse, he might not prefer NPS to PS.

The third paper investigates the relationship between land use and open space. Even though there is considerable public interest in preserving open space, and governments spend significant resources to do so, the relative efficiency of development taxes and UGB are not fully understood. Using urban development model, this paper analyzes the effect of heterogeneity in agricultural rent and imperfect information in terms of total rents under development taxes and UGB. When there is heterogeneity in agricultural rent and a regulator does not know site specific information about agricultural rent, then the regulator does not have perfect information to efficiently regulate open space. Under those circumstances, the regulator cannot maximize total rent and maximize expected total rent instead. In contrast to Bento et al. (2006), I use two counter examples to illustrate the possibility that the policies are no longer equivalent once randomness is introduced under development taxes and UGBs using functional forms and parameter values.