A Cost-Benefit Analysis of Sea-level Rise Protection in Taiwan[#]

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Abstract

Sea-level rise is one of global warming's major impacts on Taiwan island. This paper develops an optimal adaptation model of sea-level rise in order to estimate the social cost of sea-level rise based on Fankhauser's (1994, 1995) model and Taiwan's special features. We divide Taiwan's coastline into 240 sections and collect the data of physical, ecological and economic variables for each section such as lengths, slopes, eco-systems, land uses, land prices, and the costs of seawalls. Then we estimate the optimal protection proportion for each coastal section, i.e., the protection proportion that would result in the minimum social cost of adaptation including adaptation costs and remaining damage costs. It is found that the optimal protection proportion to against a 50cm sea-level rise is 9% in Taiwan. Total cost is 35.7 billion NT$ in terms of 1998 NT$.

1 Introduction

Global warming effect is caused by increasing emissions of greenhouse gases (GHGs) from anthropogenic sources since the industrial revolution.[1] At present, the observed CO2 concentration is 360 parts per million by volume (ppmv), compared with preindustrial levels of around 280 ppmv. According to the Intergovernmental Panel on Climate Change (IPCC) (Houghton, et al., 1996), by 2100, carbon levels in the atmosphere will soar above 600 ppmv which will yield a temperature rise of 2°C and sea level rise (SLR) of around 50 cm with a range from 23 to 96 cm for the midrange case of projection. The full range of potential temperature rise by 2100 is from 1°C to 4.5°C. Even if global emissions were to level off by the year 2000, CO2 concentrations and, consequently, temperature and sea level would continue to rise indefinitely beyond 2100.

[#] Paper presented at the International Conference on Global Economic Transformation after the Asian Economic Crisis, May 26-28, 2000, Chinese University of Hong Kong and Peking University, Hong Kong.

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[1] Greenhouse gases primarily are carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O).

Among global warming's possible impacts on the environment and the economy, SLR poses perhaps the greatest potential threat to Taiwan island. Taiwan's 22 million population is concentrated along narrow coastal plains which occupy less than one-quarter of its total land area of 3.6 million hectares. Most cities and industrial infrastructures are built by the coast. The potential loss of coastal land is likely to have severe economic, social and cultural impacts. The looming possibility of more frequent and intense hurricanes further exacerbates the problem.

There are two kinds of approaches that have been taken in the literature to evaluate the impacts and cost of SLR. The first is the static approach that simply compares the two snapshot scenarios of coastal land uses for the year 2100 and the present and calculates the total, current cost of SLR (for example, see Schneider and Chen (1980), Nordhaus (1991), Cline (1992), Titus (1992), Tol (1994)). The second one is the dynamic approach that takes into account the trajectories of SLR, land inundation, coastal land development, land price rises, and optimal abatement and adaptation policies and activities between the present and the year 2100. Fankhauser (1994, 1995), Yohe and Marshall (1999) take the second approach. The total cost of SLR based on the dynamic approach is much lower than those estimates using the static approach due to its more comprehensive considerations.

In this paper we evaluate the possible impacts and, consequently, social costs of potential SLR in Taiwan. Fankhauser's (1994, 1995) model of optimal SLR protection is modified to accommodate Taiwan's special features and data availability. Since we do not know the trajectories of potential SLR and land inundation in Taiwan, we take the scenario of SLR, land subsidence and land rise in the year 2100 as exogenously given instead of dynamic adaptation to the trajectories in the next 100 years.[2] By assuming this scenario happens at present, we derive the rule of optimal protection based on the model and estimate the cost of adaptation and damages.

2 Model Structure

Total costs of climate change consist of three items: the costs of emission abatement, the costs of adaptation, and the costs of damage. Policymakers can either to abate emissions, i.e., to limit the amount of greenhouse gases emitted, or to adapt to the climate change through appropriate protection or adaptation measures. However, climate change damages are inevitable even though optimal efforts of abatement and

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[2] Land subsidence and land rise are two special features in Taiwan. Land subsidence is very serious in some coastal areas due to heavy pumping of ground water for aquacultural uses. Most areas in Taiwan are rising continuously with rates between 0.5 and 7 mm per year.

adaptation have taken place.

Optimal efforts of abatement and adaptation can be derived by minimizing the following total costs of climate change:[3]

(1) $\min AC(e) + P(e, m) + D(CC, m)$

$\text{s.t. } CC = f(e)$

where AC is the costs of emission abatement, P is the costs of adaptation, D is the damage costs, e is the level of GHG emissions' abatement, m is the degree of adaptation, CC is the degree of climate change. CC is a function of e, $f_e < 0$. Further we assume $AC_e > 0$, $P_e < 0$, $P_m > 0$, $D_{CC} > 0$, $D_m < 0$. All functions are assumed to be convex. Thus, the optimal combination of abatement and adaptation (e* and m*) is derived by solving the following first order conditions:

(2) $AC_e = - P_e - (D_{CC} f_e)$,

$P_m = - D_m$

Marginal abatement costs (AC_e) should equal its marginal benefits ($- P_e – D_{CC} f_e$) and marginal costs of adaptation (P_m) should equal the marginal benefits of adaptation ($-D_m$). Since the costs of adaptation is a function of the two sets of policy measures, optimal values of e* and m* depend on each other. They should be determined simultaneously.

In fact, it is not possible to determine the two sets of policy measures simultaneously since the decision makers of e* and m* are usually located at different political levels. On the one hand, optimal emission levels is a global issue. Since the benefits of GHG emission abatement are pure international and intergenerational public goods, no one country and people would abate emissions voluntarily. Thus, the determination and enforcement of GHG emission's abatement requires international agreements, such as the Framework Convention on Climate Change of 1992 and the Kyoto Protocol of 1997, to avoid the usual free rider problem of public goods. On the other hand, optimal adaptation level is a local issue since its benefits are local public goods. It is the responsibility of local authorities to make decisions on optimal adaptation strategies. For them, climate change (CC) and emission abatement (e) are exogenous variables. Their decision problem is to

(3) $\min P(m)+D(m | CC = f(e))$

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[3] The model is modified after Fankhauser (1994, 1995). We think the adaptation cost is a function of e and m, whereas it is a function of m only in Fankhauser (1994, 1995). Our result indicates that the marginal benefit of abatement is the sum of reduced marginal adaptation cost and marginal damage cost, whereas the reduced marginal adaptation cost is not one component of the marginal benefit of abatement in Fankhauser (1994, 1995). Our treatment of the damage costs for drylands and wetlands is

The first order condition requires that the marginal adaptation costs (P_m) equal its marginal benefits ($- D_m$). Since D_m is a function of CC, optimal m* is a function of CC too. We define:

(4) $V(CC) = \min [P(m) + D(m \mid CC = f(e))] = P(m^*) + D(m^*(CC), CC)$

where V(CC) is the minimum total cost of SLR caused by climate change including the costs of adaptation and damages.

In the following we will derive a V(CC) function for Taiwan.

1. Costs of Adaptation

In order to simplify the model, we assume there are only two adaptation options available. One is to protect the coastal land with sea walls.[4] The other is to retreat, i.e., to abandon the land that will eventually be lost to the rising sea.

There are two kinds of coastal lands, dryland and wetland. Drylands can be protected by sea walls. Although wetlands cannot be protected by sea walls, they can migrate inland without protection measures.

Thus, the decision policy makers have to make is the proportion of coastlines worth protection, denoted by L, $0 \leqq L \leqq 1$, which would minimize the total costs of adaptation and damages. We assume that the present proportion of coastlines protected is zero.

According to Weggle et al. (1989) and Sorenson et al. (1984), construction costs of sea walls increase proportionally with length and exponentially with height. Gleick and Maurer (1990) assume that annual maintenance costs are a fixed proportion (a) of their construction costs. We assume that the height of sea walls is proportional to SLR. We also assume that there is an additional maintenance cost in the land subsidence area. The adaptation cost function is therefore as follows:

(5) $$C(L,S) = LKfS^r + \sum_{t=1}^{Td} [(aLKfS^r)(1 - bGsTs)]/(1+i)^t$$

where K is the length of coastline, S is the SLR in the year 2100, ψ and γ are two construction cost parameters, a is the constant proportion between annual maintenance costs and construction costs, Gs, a negative number, is the annual rate of land subsidence, Ts is the number of years land will subside, i is the discount rate, t is time (year), Td is the life length of sea walls, b is the maintenance cost parameter due to land subsidence. The first term on the right hand side is the construction cost and

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also different from Fankhauser.

[4] Of course there are other available protection measures such as beach nourishment, building dams and dikes. Following Fankhauser (1994, 1995), we assume building sea wall is the only measure for the

the second term is the present value of annual maintenance costs.

The SLR, S, in the year 2100 in Taiwan is a function of three forces. In addition to the usual force of global warming, land subsidence and land rising are two other prevalent forces in Taiwan. Thus,

$$(6) \qquad S = G_s T_s + G_u T_u + S_g$$

where G_u is the annual rate of land rising and S_g is the height of SLR in 2100 due to global warming, T_u is the number of years land rises.

2. Damage Costs

<u>Dryland loss</u>

SLR damage from dryland loss is the opportunity cost of the lost dryland which is the present value of the annual return on land in the indefinite future, R. Therefore,

$$(7) \qquad D(L,S) = (1-L)KSjR(L)$$

where D is the dryland damage, ϕ is the slope of coastal lands, R is the value of the lost dryland. R is assumed to be a function of L since more valuable land will be protected first and the value of unprotected land will decrease with increasing L. Thus, R (L) = (1-L)X.

If L=0, then the value of lost lands equal the overall expected value of land, X. As L increases the value of unprotected lands decreases and approaches zero. Finally, the dryland damage becomes

$$(7.1) \qquad D(L,S) = (1-L)^2 KSjX$$

<u>Wetland Loss</u>

As noted before, wetlands will be destroyed by protected measures such as sea walls. When it is not protected and left along, wetlands can migrate inland, i.e., adjacent drylands will become wetlands while the original wetlands are inundated. Therefore, the damage function for wetlands is

$$(8) \qquad W(L,S) = \left(\sum_{t=1}^{T} \frac{1}{(1+i)^t} \right) [KSj - (1-L)KSj] R_t^W(L)$$

$$= \left(\sum_{t=1}^{T} \frac{1}{(1+i)^t} \right) LKSjR_t^W(L)$$

where W is the wetland damage costs which is the present value of the annual value

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purpose of simplicity and illustration.

of wetlands lost over the accounting period T, K is the length of coastlines, R_t^W (L) is the value per unit of wetland at year t. The first item in the bracket on the right hand side is the wetlands lost and the second item is the area of adjacent drylands that become wetlands. An implicit assumption in (8) is that the slope is the same for the wetlands and their adjacent drylands.

As in the case of drylands, the unit value of wetlands is a function of L. However, it is different from the case of drylands, the value of unprotected wetlands increases as L increases because the remaining wetlands will become more scarce and valuable. Therefore,

$$R_t^W (L) = (1+L)\, Y_t^W$$

where Y_t^W is people's willingness to pay for the wetlands in year t. Then, the damage costs of wetlands equal

$$(8.1) \qquad W(L,S) = \left(\sum_{t=1}^{T} \frac{1}{(1+i)^t} \right) (1+L) LKSj\, Y_t^W$$

Total Cost

The total social cost of SLR is the sum of equations (5), (7.1) and (8.1):

$$(9) \qquad V = (C(L,S)) + (D(L,S) + W(L,S))$$

Policy makers' problem is to minimize V given exogenous variable S. In this objective function, the only decision variable is the proportion of each section of coastline to be protected, L. If equations (5), (7.1), and (8.1) are expressed as Lc, $(1-L)^2$d, and (1＋L)Lw, respectively, then the first order condition of (9) is

$$L = \frac{2d - c - w}{2(d + w)}$$

3 Data Sources and Parameters to be Estimated

We divide Taiwan's coastline into 240 sections and collect the data of physical, ecological and economic variables for each section. The physical variables include lengths, slopes (ϕ), rates of land subsidence (G_s) and land rising (G_u). We then calculate S for each section based on equation (6). We use two estimates of the height of SLR (S_g) caused by global warming for the year 2100 in IPCC (1996): 50 cm and 86 cm. The duration of land subsidence (T_s) is set to be 15 years.[5] Three other

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[5] According to the experience in Taipei City, land subsidence was gradually stopped when ground water pumping was forbidden for 15 years.

duration variables, T_d, T_u and T, are set to be 100 years since it is long enough to represent their impacts in the indefinite future.

ψ, γ, a and b are parameters to be estimated in equation (5). We let γ equal 1.988 and a equal 4%. Both figures come from Yohe and Marshall (1999, p. 185) and the first one is calculated using their figures of construction costs and respected SLR scenarios. We assume the annual maintenance costs in land subsidence areas are twice the figures in no land subsidence areas, then b is 0.01.

Existing figures show that the construction costs of sea walls per meter which are able to protect against 50 cm SLR range from NT$50,000 to 250,000 in Taiwan depending on the geophysical environment of each coastal area. Then parameter ψ can be calculated to be 20.96, 41.92, and 104.81, respectively, for three different figures of unit construction cost of NT$50,000, 100,000, and 250,000.

There are two economic variables to be estimated. We have conducted a thorough survey of land prices (R) in Taiwan's coastal areas (Figure 1). Chen (1999) provides the value of wetlands along the coast in Taiwan by combining the contingent valuation method and ecological evaluation method. It is found that each person is willing to pay NT$749 per year to protect 28 wetlands along Taiwan's coastlines. We allocate the total value to the total area of the 28 wetlands and get the average value of wetlands (Y_t^w) which is around NT$ 13,217/m^2 per year.

Finally, the social rate of discount i is chosen to be 2%, 2.5%, and 3% for the purpose of sensitivity analysis.

4 Empirical Results

Figure 2 and Tables 1-6 display the empirical results of applying the above model in Taiwan. It is found that if 50 cm SLR happened today, then the total cost including adaptation and damage would be NT$ 35.7 billion in terms of 1998 dollars and the optimal protection proportion would be 9 % in Taiwan. The annuity cost would be NT$ 1.07 billion which is around 0.36 % of 1998 GDP, a quite small number.

Among the 240 sections of coastlines, only 47 sections have optimal protection proportions greater than zero. As expected, those 47 sections are in urban areas and port cities because of their higher land prices and lower slopes. All wetlands need not to be protected since their value is quite high and sea walls would destroy the wetlands.

The results of sensitivity analyses are shown in Tables 1-6. It is found that the total cost would jump to NT$ 63.8 billion for the scenario of 86 cm SLR today. Total costs are not so sensitive to other variables. As expected, the lower the construction costs or the higher the land prices, the higher the protection proportions of the coastal lands (Tables 2-3). Tables 4 and 5 indicate that protection proportions are not sensitive to land subsidence variables. This may be due to the fact that the high construction and maintenance costs for land subsidence areas prevent their further protection. Table 6 shows that the higher the discount rate, the higher the protection proportion. This is because the higher discount rate would make the present value of future maintenance costs cheaper.

The allocation of protected areas among the four regions in Taiwan is quite different. The protection proportions in the South and the Middle areas are higher. This may be due to their higher land prices and smaller slopes.

5 Conclusions and Discussion

The purpose of paper is to estimate the total costs and the proportion of coastlines worth protection if we face the scenario of the year 2100 SLR, land subsidence and land rising today. The total cost of NT$ 35.7 billion is not an unaffordable number even though we suspect that SLR may pose perhaps the greatest potential threat to Taiwan island.

It is found that the optimal protection proportion of Taiwan's coastlines is 9% for the year 2100 SLR and it should be lower for higher adaptation costs. However, much more than 9% of Taiwan's coastlines are protected by sea walls already. This mainly is due to political, not efficiency, consideration. In order to avoid further waste of scare resources, it is necessary to make decisions about coastal land management based on benefit-cost analyses. We should discourage further investments of human and man-made resources in the coastal areas. We should also control ground water pumping in the coastal areas to avoid further land subsidence.

The approach used in this study is highly aggregate. The high level of aggregation and abstraction allows us to make a preliminary estimate of the impacts of SLR for Taiwan. More precise data of geophysical and economic variables are needed for us to do a detailed and dynamic plan of adaptation for each area.

References

Arrow, K. J. and Lind, R. C. (1970). Uncertainty and the Evaluation of Public Investment Decisions. American Economic Review, 60, 364-378.

Chen, Kai-Lih (1999). Combination of Ecological Evaluation and Economic Valuation of Wetlands in Taiwan. Journal of Environmental Economics and Policy Studies, 2(1).

Cline, W.R. (1992). *The Economics of Global Warming.* Washington. D.C.: Institute for International Economics.

Fankhauser, S (1994). *Valuing Climate Change: The Economics of the Greenhouse Effect*. London: Earthscan.

Fankhauser, S (1995), "Protection versus Retreat: the Economics Costs of Sea-level Rise," Environment and Planning A, 27.

Gleick, P.H. and Maurer, E.P. (1990). Planing for Sea Level Rise Under Uncertainty: A Case Study of San Francisco Bay. Pacific Institute for Studies in Development and the Environment, Oakland, CA.

Hirshleifer, J. (1964). Efficient Allocation of Capital in An Uncertain World. American Economic Review, Papers and Proceedings, 54, 77-85.

Hoffman, J.S., Keyes, D. and Tutis, J.G. (1983). *Planning for Future Sea Level Rise*. Washington, DC: U.S. Environmental Protection Agency.

Houghton, J.T., et al. (1996). *Climate Change 1995: The Science of Climate Change.* Contribution of Working Group I to the Second Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press.

IPCC (1996). *Climate Change 1995: Impacts, Adaptation, and Mitigation of Climate Change: Science –Technical Analysis.* Cambridge: Cambridge University Press.

Nordhaus, W. (1991). To Slow or Not to Slow. Economic Journal, 101, 920-937.

Oppenheimer, Michael (1998). Global warming and the stability of the West Antarctic Ice Sheet. Nature, 393, 325 – 332.

Samuelson, P. A. (1964). Discussion. American Economic Review, Papers and Proceedings, 59, 93-96.

Sandmo, A. (1972). Discount Rates for Public Investment under Uncertainty. International Economic Review, 13, 287-302.

Schneider, S. and Chen, R. (1980). Carbon Dioxide Warming and Coastline Flooding. Annual Review of Energy, 5, 107-140.

Sorenson, R.N., Weisman, R., and Lennon, G. (1984). in: Barth, M. and Titus, J. (eds.). *Greenhouse Effect and Sea Level Rise.* New York: Van Nostrand Reinhold Company.

Titus, J.G. (1992). The Cost of Climate Change to the United States. in Majumdar, S.K., Miller, E.W., and Rosenfeld, L.M. (eds.). *Global Climate Change: Implications, Challenges, and Mitigation Measures.* Pennsylvania: Pennsylvania Academy of Science.

Tol, R.S.J. (1994). *The Damage Costs of Climate Change: Towards More Comprehensive Calculations.* Amsterdam: Free University.

Vickrey, W. (1964). Discussion. American Economic Review, Papers and Proceedings, 59, 93-96.

Weggle, J., Brown, S., Escajadillo, J.C., Breen, P. and Doheny, E. (1989). The Cost of Defending Developed Shoreline Along Sheltered Shores. in Smith, J.B. and Tirpak, D. (eds.). *Potential Effects of Global Climate Change on the United States. Appendix B: Sea Level Rise.* Washington, DC: U.S. Environmental Protection Agency.

Yohe, G., Neumann, J. and Marshall, P. (1999). The economic damage induced by sea level rise in the United States. *The Impact of Climate Change on the United States Economy.* Cambridge University Press.

Table 1. Sensitivity Analysis – Height of SLR

Height of SLR (cm)	Protection Proportion in Taiwan	Protection Proportion in the Middle and the South	Protection Proportion in the East	Protection Proportion in the North	Total Cost (NT$ million)
50	0.09	0.13	0.07	0.07	35701
86	0.03	0.06	0.01	0.02	63806

Table 2. Sensitivity Analysis – Unit Construction Cost of Sea Walls

ψ, Parameter in the Construction Cost Function	Protection Proportion in Taiwan	Protection Proportion in the Middle and the South	Protection Proportion in the East	Protection Proportion in the North	Total Cost (NT$ million)
20.96*	0.09	0.13	0.07	0.07	35701
41.92**	0.05	0.06	0.04	0.03	38065
104.81***	0.01	0.01	0.00	0.00	39131

Note:* unit cost of sea walls to protect against 50 cm SLR is NT$ 50,000 per meter.

** unit cost of sea walls to protect against 50 cm SLR is NT$ 100,000 per meter.

*** unit cost of sea walls to protect against 50 cm SLR is NT$ 250,000 per meter.

Table 3. Sensitivity Analysis – Land prices

Land Prices as the Ratio of the Surveyed Prices	Protection Proportion in Taiwan	Protection Proportion in the Middle and the South	Protection Proportion in the East	Protection Proportion in the North	Total Cost (NT$ million)
0.8	0.08	0.10	0.06	0.05	29187
1.0	0.09	0.13	0.07	0.07	35701
1.2	0.12	0.16	0.08	0.09	42143
1.5	0.15	0.21	0.09	0.13	51348

Table 4. Sensitivity Analysis – Duration of Land Subsidence

Duration of Land Subsidence (number of years)	Protection Proportion in Taiwan	Protection Proportion in the Middle and the South	Protection Proportion in the East	Protection Proportion in the North	Total Cost (NT$ million)
15	0.09	0.13	0.07	0.07	35701
20	0.09	0.12	0.07	0.08	40679
30	0.09	0.11	0.07	0.08	50621

Table 5. Sensitivity Analysis – b, Maintenance Cost Parameter due to Land Subsidence

Maintenance Cost Parameter due to Land Subsidence (b)	Protection Proportion in Taiwan	Protection Proportion in the Middle and the South	Protection Proportion in the East	Protection Proportion in the North	Total Cost (NT$ million)
0.00	0.10	0.13	0.07	0.07	35596
0.01	0.09	0.13	0.07	0.07	35701
0.02	0.09	0.12	0.07	0.07	35786

Table 6. Sensitivity Analysis – Discount rate

Discount Rate	Protection Proportion in Taiwan	Protection Proportion in the Middle and the South	Protection Proportion in the East	Protection Proportion in the North	Total Cost (NT$ million)
3.0%	0.09	0.13	0.07	0.07	35701
2.5%	0.09	0.12	0.06	0.06	35991
2.0%	0.08	0.11	0.06	0.05	36352

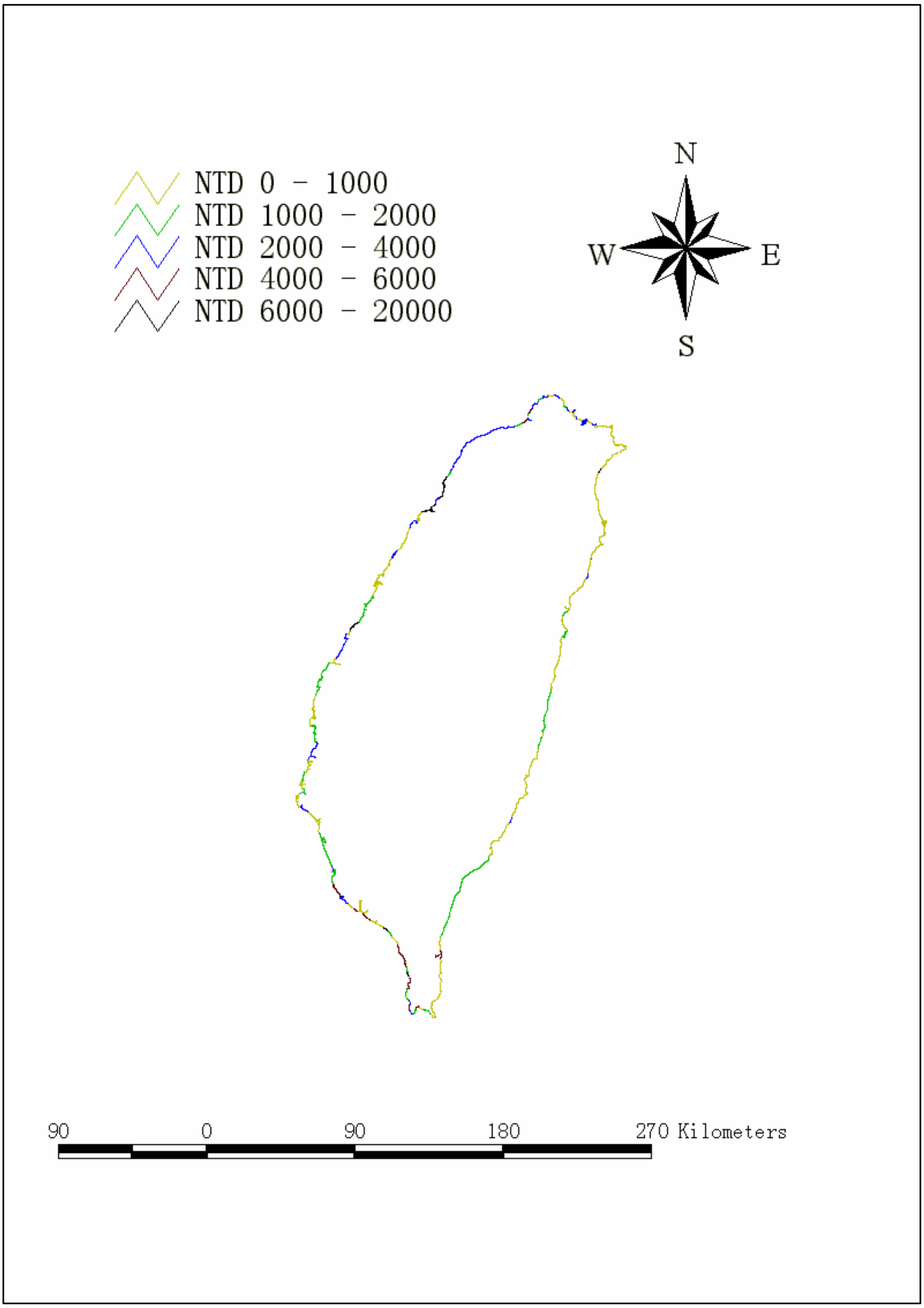

Figure 1. Land prices of coastal areas in Taiwan

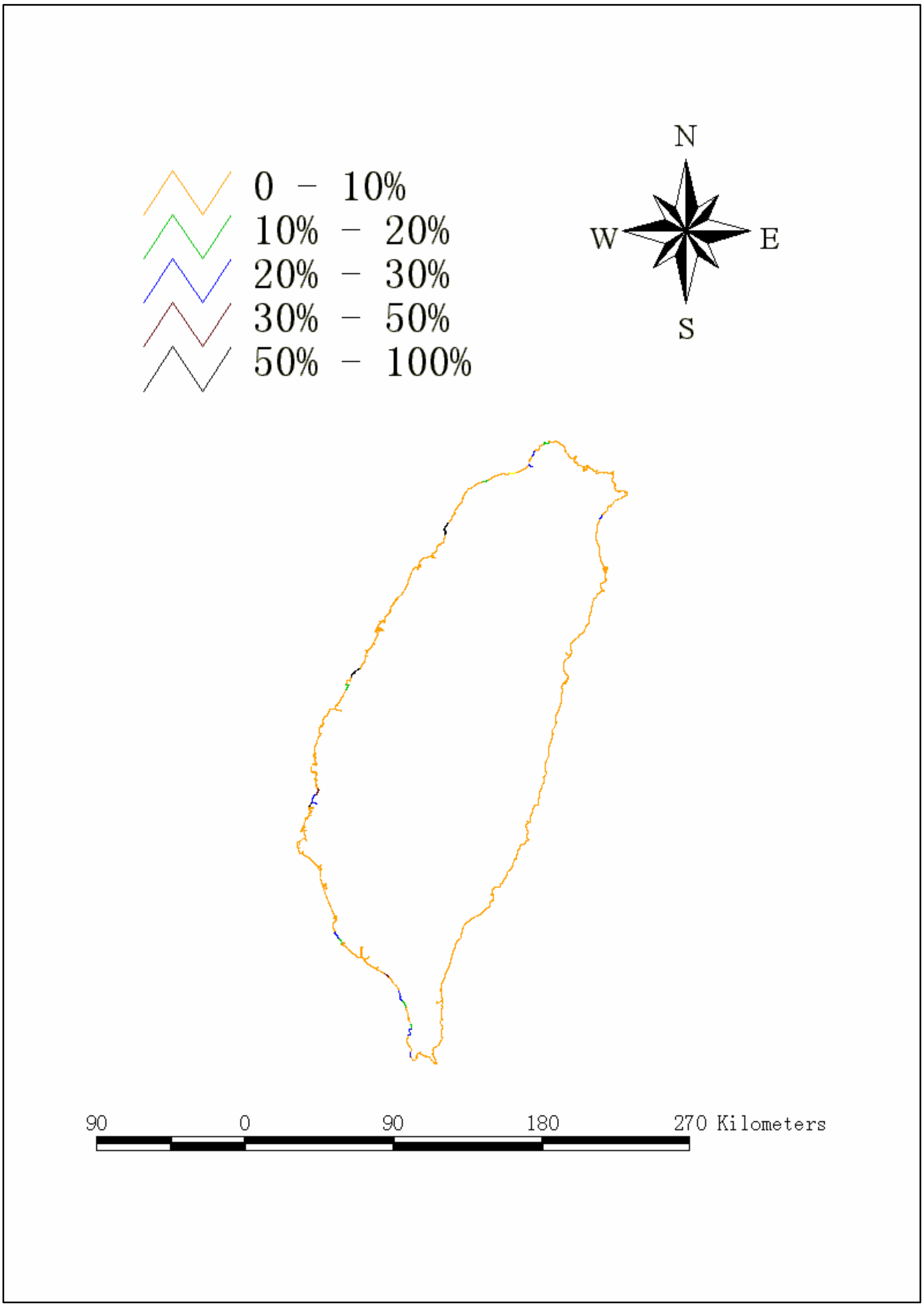

Figure 2. Proportion of Coastlines Protected in Each Section