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COOLING THE METROPOLIS: AN ECONOMIC ANALYSIS TO ALLEVIATE URBAN HEAT ISLAND

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ABSTRACT

This paper shows the necessary conditions to efficiently produce nongaseous *Gorman-Lancasterian characteristics* embodied in goods, and to optimally emit heat, and trace gases as *gaseous attributes* combined in the urban atmosphere. Sen's capability approach is used to define personal well-being, since the impacts of urban warming upon each resident affect his/her functionings *à la* Sen. Any inhabitant consumes goods and emits heat and gases in the urban air. It is demonstrated that any inhabitant maximizes his/her *happiness function* by consuming goods and emitting heat and gases in the ambient urban air. This paper introduces heat island integral to represent the magnitude of heat island and an urban warming function. Also, producers and landscape gardeners in the metropolis provide goods or plant trees in metropolitan residents' gardens. A tax-subsidy scheme is proposed to cope with urban heat island, which aims to optimally adjust heat in the urban atmosphere.

Key Words: Goods as a complex of Gorman-Lancasterian gaseous and nongaseous attributes, Heat as an intangible attribute, Heat island integral, Urban heat island tax and subsidy scheme, Sen's functionings and happiness function

1. INTRODUCTION

1.1 The Issue of Urban Heat Island

Tokyo is now a gigantic *Urban Heat Island* with peaks such as Otemachi and Shinjuku which are the central business districts of Tokyo. Whereas, the Imperial Palace, the Meiji Shrine, and the Shinjuku Gyoen National Garden as *Cool Islands* are cooler, and the temperature of these areas remains rather low compared to the hotter spots mentioned above. By using a concept of *Heat Island Integral*, formal definitions of an urban heat island and a cool island are given in Section 2.3.

In the 1930s there were only seven hot nights called *tropical nights* in which the temperature in the nighttime rose over 25°C. Tokyo had 14 or 15 tropical nights per year in the 1960s and this doubled in the 1990s. We experienced 67 tropical nights in 2000. In 2002, 53 days were observed in which the temperature rose over 30°C, and this number greatly exceeded that of an ordinary year, i.e., 38.4 days. The average number of tropical nights in Hiroshima City was 4.9 in the 1930s and increased to 28.8 in the 1990s. Kumagaya City in the Saitama Prefecture had ten times the amount of days over 30°C than it had just a half-decade ago. The average temperature of Japan hit a new high in November 2003.

The global mean temperature has risen 0.74°C in the past hundred years. It is 0.9°C in Japan and 3°C in Tokyo, thus, Tokyo has been warming more than four times faster than the Earth. The area of Tokyo's urban district and its artificial emission became one hundred times in the 20th century. These are direct causes of an urban heat island. Whereas, the increase in the temperature in Paris and New York were respectively about 0.9°C and 1.6°C in the same period. Tokyo's urban warming has a remarkable value which is above the rising rate of the past ten thousand years.

The Tokyo Metropolitan Research Institute for Environmental Protection estimated that the heat emitted from cars and air conditioners has resulted in an increase of 0.4°C and that from the loss of greenery by 1.4°C in one hundred years. The green area was halved in Japan from 1930 to 1990, thus, there has been an increase in radiant heat and a decrease in radiational cooling. It is therefore a pressing need to manage the urban thermal pollution due to an urban warming in large cities of Japan.

Urban agglomeration has been increasing the number of houses and condominiums, which entails a loss of greenery and water. Factories have been decreasing, but houses have been increasing: half of the 23 wards of Tokyo (60,000 ha.) share housing which has augmented by 30%. Heat from houses and buildings has increased to three times as much as three decades ago. It is now far ahead of heat from cars. The diffusion rate of air conditioners was 30% thirty years ago, however, it is 120% now, i.e., many households have more than two air conditioners.

Tokyo's floor space of buildings and their energy consumption has considerably augmented in the past 100 years, so that high-rise buildings are limited to several areas. However, due to the progress of urbanization and the augmentation of energy intensity of office automation business machines, energy consumption has grown rapidly. As the capacity intensity and floor area ratio increase, the total energy released to the ambient atmosphere grows remarkably. Agreeability of urban life is markedly lost when the temperature exceeds 35°C, when a human would have serious problems of health. Tokyo with horribly high humidity will experience such unpleasantness in the near future, as approaching year 2030.[1]

1.2 Proposal of an Urban Heat Island Model

Different from the results of Rouillon(2000) and (2001) on irreversibility of global warming, urban warming would be reversible within the not so distant future by employing some appropriate countermeasures against an urban heat island. As there are some surgical operations for our warming metropolises, some recovery may be expected. We do not have to accept this as an incurable disease. Human beings are unable to have a "zero emission solution, "because they emit heat and CO_2 even when breathing and consuming goods. They are also by-products in numerous manufacturing procedures. Hence, we must aim to find a "livable/viable"combination of socially optimal levels of the ambient air quality and heat emissions. The environmental managers of many cities have been utilizing the command and control as well as the tax and subsidy systems. Efficiency of these systems, however, is likely to be lost because they cannot be made cost-effective without exact knowledge of pollution emitted by each household or each firm. Furthermore, if it is impossible to directly observe the amount of each emission, the environmental managers cannot deal with the incentive problem, since relevant information is privately held and must be elicited. Thus, very often, a pollution abatement scheme can be neither informationally efficient nor incentive compatible.

However, heat emitted by each emitter is assumed to be observed somehow or other, so this paper proposes a tax-subsidy system to deal with an urban heat island, which can do without the exact knowledge of the heat emitted by each economic agent. Moreover, since urban warming has become a socially significant issue in recent years, an increased attention has been paid to scientific breakthroughs and powerful remedies that may be more immediate than economic instruments, such as greening methods and other technological developments to cool down the urban atmosphere.

It has been so far a general case in public economic theory that there is no public good at the beginning of the model, and the issue is how to decide on an optimal quantity of the public good by using the private information, i.e., consumers' preferences. Our case in the present paper is, however, that the urban atmosphere exists as a public good at the outset, and the problem is how to choose both an acceptable atmospheric quality and a sensory endurable heat emission. Hence, I propose a model to provide an optimal amount of heat as an urban public good. In order that this model be operational, necessity compels us to devise a tax-subsidy scheme to determine the sum of heat emissions released by metropolitans into the urban atmosphere.

The urban environment should now be perceived to be an intergenerational public good that we have to protect. Metropolitan residents are to be involved in the problem of urban warming which is now confirmed to be caused by the emission of enormous heat, i.e., all the households living in metropolises are polluters as well as victims of the warming climate. The metropolitan government is in charge of controlling the total amount of heat emitted by residents and producers to keep the urban climate not so unpleasant in the very near future.

1.3 Some Incidents due to Urban Heat Island

The ecological system has undergone great changes in metropolitan areas. The cherry-blossom front has changed, i.e., Tokyo could be the first city where the cherry trees bloom in Japan irrespective of its latitude. Tokyo could now be inhabitable for tropical parakeets and hemp palms too. The cicadas have been observed to change from those that like the damp soil to those which are fond of the dry soil, so that intermittent choruses of cicadas have been differing in recent summers of Tokyo. Green-banded swallowtails originally from the torrid zone are protected to propagate in the center of Tokyo with the urban heat island. Palm trees can tune themselves to life in Japan and now winter in the Botanical Garden of Tohoku University in the Sendai city which lies north of Tokyo. Furthermore, something unusual has been happening in the marine ecosystem, i.e., some types of poisonous plankton have increased due to an early outbreak of red tides, which occured not in July nor August, but in May. The temperature of the surface of brine has increased these past several years.

An incident of heavy rain occured in Nerima in Tokyo in September 3, 2003. It was 33.9°C in Nerima where there was no sea wind. Whereas a sea breeze with a wind velocity of 3 meters per second blew to Otemachi in the midst of Tokyo, where it was 32°C, and littoral Shinkiba with a breeze of 4m/s had 28.6°C. The mercury touched 33.4°C in Tokyo, but 19mm per 10 minutes of heavy rain from 18:30 to 18:40 decreased its temperature from 31°C to 24.2°C, and it was accompanied by thunder and flashes of lightning. It was reported that Otemachi had more rain than the twenty-one suburban areas: it was 30% more than the other areas at the maximum. The Tokyo Metropolitan Government has appointed priority areas where it endeavors to prepare rainpool improvement projects to raise the drainage capacity of the sewers. There is also an increasing possibility that underground shopping centers will be submerged by urban floods.

Large cities such as Tokyo, Osaka, Sendai, Hiroshima, Fukuoka, Nagoya, and Sapporo consume an enormous amount of energy by using cars and air conditioners, hence, urban warming has now become notable. Cars have been multiplying unusually in Japan, and the 7 million cars are in circulation every day, which end in huge energy consumption. It follows that there is also an increase in emissions of heat from car air conditioners. One fifth of cars are now RVs that drivers can buy cheaper than before the introduction of an auto tax. A few decades ago, each family owned a car, but now it is more common for each *person* to possess a car. Thus, the number of drivers has augmented by 24% in this decade.

Urban heat island remarkably reveals itself in winters, when the temperature does not go under the freezing point. One of the main factors of urban heat island is the alteration of land usage, since the heat stored crucially depends upon what ground covering materials are used.

[1] For simulations of future Tokyo, see, for example, Saitoh, Shimada and Hoshi(1996), Saitoh and Yamada(1999), (2000) and (2001).

The temperature is higher with concrete covering than with bare and turf grounds, as artificial covering takes in heat. Dryness has been advancing in supercities, because the roads and grounds are paved with asphalt and concrete which give off heat during the day and take it in at night. Also because of this paving, the water vaporized by the ground has decreased and the reflection of heat is severe in the summertime.

It has been reported that urban heat island has been accelerating air pollution, which has resulted in a *dust dome*: dust pollution is shut in as if it forms a dome. Photochemical smog occured for 23 (30, resp.) days in Tokyo (in the Saitama Prefecture, resp.). However, the emission of NO_x was 51,000 tons in Saitama, whereas it was 65,000 tons in Tokyo. This inverse of phenomena could be explained by urban heat island. Hence, countermeasures for tackling the issue of urban heat island have the positive side effect of mitigating urban air pollution. It is observed that urban heat island is closely related to pollinosis or hay fever, and urban air pollution. The pollen scattered much in 2005, which may be due to the precedent summer's heat wave, and thus an increase of pollen allergy was worried in 2005.

1.4 The Approach of This Paper

"Integral" and "exponential "are two key adjectives given to the present state of the large cities in peril of urban heat island, e.g., population explosion, build up of noxious nitrogen dioxides due to increasing cars, and decreasing natural green resources. All of these phenomena in the metropolitan areas, which have been induced by human activities, especially agglomeration due to urbanization and motorization share common integral and exponential features, particularly after the drastic economic growth three decades ago. The atmosphere of the supercities has been revealing the similar integral and exponential trends most prominent in these past decades. In order to alleviate the warming tendency in the metropolises, every economic agent may well pay as a user charge of the urban atmospheric air, i.e., a "heat island tax, "introduced below.[2]

Temperature revealed an exponential trend most prominently in recent decades. The atmosphere is a composite of gases such as nitrogen (N_2), oxygen (O_2), hydrogen (H_2), water vapor(H_2O), and Greenhouse gases (GHGs) such as carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and chlorofluorocarbons (CFCs). These gases can be considered as *gaseous attributes à la Gorman-Lancaster*, precisely defined below. The urban atmosphere is made up of 78% nitrogen, 21% oxygen, water vapor, trace gases supra, etc.

This paper proposes to consider urban atmosphere as a complex of intangible attributes such as heat and gases, and the goods combined by nongaseous attributes that are produced by the firms and the green areas as a composite of biological attributes supplied by *landscape gardeners*. The paper also shows that each resident has his/her land planted by a landscape gardener and simultaneously emits heat and trace gases. For this, I adopt an analytical framework of the New Consumer Theory by Gorman and Lancaster, and Sen's Capability Theory.

The paper proceeds as follows: Section 2 presents the periurban model of regional warming in the attributes/ functionings framework *à la* Gorman-Lancaster-Sen and proposes the concept of *Heat Island Integral*. The model involves residents, producers such as offices, hotels, manufacturers and farmhouses as producers, and landscape gardeners who play a very important role to cool down the metropolis by roof-top gardening and tree-planting activities, etc.

2. URBAN HEAT ISLAND IN A PERIURBAN CITY

2.1 Heat Island Intensity

Urban heat island is represented by a contour line on a map joining points of equal temperature in the inside and the outside of a city. It is an analogy of a contour line of an island in a sea. *Heat Island Intensity* is defined as the highest height of an island.

Let τ_u and τ_r be the temperature of urban and periurban or urban areas of a city. Urban temperature can be represented by $\Delta\tau$ or $(\Delta\tau/\tau_r) \times 100$, where $\tau_u = \tau_r + \Delta\tau$ or $\Delta\tau = \tau_u - \tau_r$. The following notation is also used.

Ξ : heat capacity radiated from the surface to the atmosphere, i.e., sensible heat flux [W/m^2]; Π : city size [m]; $\Delta T/\Delta m$: the difference in temperature [ΔT] between the places vertically separated [°C]; Q : air specific heat [Wh/kg°C]; M : atmospheric density [kg/m^3]; V : wind velocity [m/s].

Summers(1965) proposed a procedure to easily calculate heat island intensity, which was further simplified by Takeo Oka as the formula:

$$\Delta\tau = \sqrt{\frac{\Xi\Pi\Delta T/\Delta m}{1800QMV}}.$$

It has been confirmed that this equation can be adapted to such cities as Lund in Sweden.

Oke(1973) also proposed the formula:

$$\Delta\tau = 1.93\log P - 4.76$$

where P is the population of a city. This function means that population and urban temperature are closely related. He believed that this formula would be applicable to European and North American cities. Sundborg(1951) was the first to introduce a traveling observation in Uppsala. He statistically verified the difference of temperature among the midtown area and rural points as a function of cloudiness, temperature, absolute humidity, and wind velocity. These factors can be considered to be attributes of the urban air. Duckworth and Sandberg(1954) lept suddenly to fame by showing the urban high temperature in an aeriel photo of San Francisco. It was after their paper that the phenomenon was named "urban heat island "in which there has been a growing interest since then. Park(1987) verified the correlation for Japanese and Korean cities, and Yamashita(1988) observed urban heat islands in Japanese cities such as Kawagoe City in the Saitama Prefecture.

Heat Island Intensity for the center of Sendai City in the Tohoku District in Japan will be about 10.5°C, since the temperature is anticipated to increase by 5°C by 2030.

[2]See, for example, Hourcade et al.(1997) for an international carbon tax to moderate global warming. See also Henry(1989) for a market of emission rights as an alternative to the tax scheme.

The temperature rose 2.1°C in Sendai in the past hundred years. It is the second highest record next to Tokyo. However, it is reported that the zelcova trees planted in the main streets in Sendai can make a decrease in the sensory temperature of 5°C. In Tokyo, the center of urban heat island is found in the Nakano or Suginami Wards in wintertime and heat island intensity is 3°C. It is 10∼15km in diameter and its form is the same all day long.

2.2 A Model of Urban Heat Island in a Periurban City

This section introduces the Attributes/Functionings model based on the Gorman-Lancasterian theory where goods are regarded as a composition of characteristics. For the sake of simplicity, the two terms, "attributes " and "characteristics,"are used interchangeably throughout this paper. All trace gases such as GHGs can be interpreted as *intangible gaseous attributes* in our framework, since they partially compose the urban atmosphere as an urban public good. Characteristics of urban climate are in order: pollution substances, solar radiation, cloudiness, precipitation, temperature, absolute and relative humidity, and wind velocity. These attributes compose the urban ambient atmosphere. This paper focuses upon heat as an attribute, since it is the main cause of urban warming. Before rushing into our theoretical model, let me introduce some basic concepts of attributes.

Let us consider a monocentric periurban city which is supposed to be a "climatically closed city," i.e., there are no climatic influences from and on the neighboring cities. "Periurban"means the peripheral zone of the urban area, where reside inhabitants, manufacturers, farmhouses and landscape gardeners.[3] For the sake of simplicity, assume that our periurban city is composed of two regions, i.e., the urban area and the periurban area, which are divided into many blocks, $\beta \in \boldsymbol{\beta} = \{1, ..., B\}$: the set of blocks. In other words, our periurban city is represented by a mesh of blocks, such as a grid of the center of Chicago. Assume that whatever size and shape can be chosen for a block, as a smaller size in Tokyo or a larger one in Chicago.

Let there be N residents indexed by $i \in \mathbf{N} = \{1, ..., N\}$: the set of inhabitants who live in the periurban belt. Each individual emits heat and trace gases when consuming goods or services indexed by j and its set is $\mathbf{J} = \{1, ..., J\}$. For the sake of simplicity, it is assumed that each producer j supplies only one good j which is composed of C characteristics indexed by $c \in \mathbf{C} = \{1, ..., C\}$: the set of attributes. Denote as q_{jc} an amount of attribute c embodied in one unit of good j. There are producers: e.g., offices, hotels, manufacturers, and farmhouses.

Suppose that resident i chooses a landscape gardener named ℓ to have a part of his/her land planted with trees, and $\boldsymbol{\Lambda} = \{1, ..., \Lambda\}$ is the set of gardeners. Define $q_{\ell s}$ as a biomass of species s in one square meter supplied by gardener ℓ, and $\mathbf{S} = \{1, ..., S\}$ as the set of species of flora and fauna as *biological attributes*. Let x_{ij} be resident i's consumption of good j, and $A_{i\ell}$ be his/her demand for the green area supplied by landscape gardener ℓ, then, $x_i = (x_{i1}, ..., x_{iJ}, A_{i\ell})$ is his/her consumption vector. There is also the metropolitan government whose task is to reduce heat emission by making effective use of an *urban heat island tax/subsidy scheme* defined below.

Not to mention, every inhabitant, producer or landscape gardener resides in some block, so that an index β will be omitted hereafter in almost all the cases, except for describing some variables related to block β.

Different from von Thünen(1826), or usual urban economic theory, it is hypothesized that our periurban city as follows:[4]

H1. The city is formed in a heterogeneous plain, where the climate could differ among its areas.

H2. The city is not necessarily circular and its center is called the Central Business District(CBD).

H3. Its urban and periurban transportation systems are available in whatever direction.

H4. Land in the city is all owned by absentee landlords.

H5. All periurban residents commute to work for an office in the CBD, a gardener or in a farmhouse.

H6. All gardeners plant areas in a part of lands of residents in the periurban zone.

H7. Manufacturers produce goods and farmhouses make agricultural products in the periurban region.

The urban atmosphere is regarded as a complex of gaseous attributes including trace gases which are to be mainly generated by production and consumption activities. It is naturally assumed that the amount of gases such as N_2, O_2, H_2 are stationary, so I can focus upon heat and trace gases as attributes in this paper. An index q_{jg} is also used hereafter to identify the gth gaseous attribute, and q_{jh} is an amount emitted of heat as an attribute when producing one unit of good j. Let $\mathbf{G} = \{C+1, ..., C+G\}$ be the set of trace gases which compose the urban atmosphere.

Taking urban warming into consideration, let us extend and generalize the framework developed by Sato(2006a). When producing one unit of good, each firm does not choose but to jointly emit heat and trace gases as vexing by-products, $q_{jh} \geq 0$, which is producer j's unit emission of heat. Thus, $q_{jh}x_j$ is firm j's amount emitted of heat when it produces x_j units of good j. Landscape gardeners also emit heat and gases, $q_{\ell h} \geq 0$ and $q_{\ell g} \geq 0, \forall g \in \mathbf{G}$, which are gardener ℓ's unit emission of heat and any gas. Hence, $q_{\ell g}A_\ell$ and $q_{\ell h}A_\ell$ are gardener ℓ's emitted quantity of a gas or heat in his/her production of A_ℓ units of greening service ℓ. Inhabitants also emit heat and gases, $q_{ih} \geq 0$ and $q_{ig} \geq 0, \forall g \in \mathbf{G}$, which is city dweller i's unit emission of heat and gas. Hence, $q_{ih}A_{i\ell}$ and $q_{ig}A_{i\ell}, \forall g \in \mathbf{G}$, is individual i's emitted quantity of heat and a gas in his/her consumption of $A_{i\ell}$ units of greening service ℓ.

Let z_{i0} be resident i's available time as a *numéraire characteristic* that he/she possesses, by which other attributes can be utilized. Amounts of each attribute embodied in the goods and the atmosphere which are consumed by resident i are given for any $c \in \mathbf{C}$ and for any $g \in \mathbf{G}$

$$z_{ic} = \sum_{j \in \mathbf{J}} q_{jc} x_{ij} \tag{1}$$

$$z_g = \sum_{j \in \mathbf{J}} q_{jg} \sum_{i \in \mathbf{N}} x_{ij} + \sum_{j \in \mathbf{J}} q_{jg} A_j + \sum_{\ell \in \boldsymbol{\Lambda}} q_{\ell g} A_{i\ell} + \sum_{i \in \mathbf{N}} q_{ig} \sum_{j \in \mathbf{J}} x_{ij} + \sum_{\ell \in \boldsymbol{\Lambda}} \sum_{i \in \mathbf{N}_\ell} q_{ig} A_{i\ell} \tag{2}$$

[3]See Cavailhès et al.(2003) and (2004) for the concept of "periurban. "

[4]See Samuelson(1983) and Huriot(1994) for the Thünen model.

and

$$z_h = \sum_{j\in\mathbf{J}} q_{jh} \sum_{i\in\mathbf{N}} x_{ij} + \sum_{j\in\mathbf{J}} q_{jh} A_j + \sum_{\ell\in\mathbf{\Lambda}} q_{\ell h} A_{i\ell}$$
$$+ \sum_{i\in\mathbf{N}} q_{ih} \sum_{j\in\mathbf{J}} x_{ij} + \sum_{\ell\in\mathbf{\Lambda}} \sum_{i\in\mathbf{N}_\ell} q_{ih} A_{i\ell}. \qquad (3)$$

In the above equation, z_{ic} means the consumption of tangible nongaseous attributes which compose goods, while z_g and z_h represent the total amount of a trace gas and heat emitted by all residents, producers and gardeners. Note that the values of $z_g, \forall g \in \mathbf{G}$, and z_h can be measured via ton or kilojoule. Heat and gases are generated both in the consumption and production of goods. Every inhabitant is made to consume not only his/her emission but also the quantity emitted by the rest of the city. When he/she uses goods, he/she emits heat and gases, which were already released when the goods were made by producers.

Both of the above equations may be interpreted as *characteristics availability functions*, which convert commodities into attributes. The amount of any characteristic in each good can be regarded as a parameter that is objective and common to all consumers, i.e., it has a public-good property. Thus, the inhabitants as consumers must behave as "quality takers", since they can only change their consumption of z_{ic}, z_{ih} and z_{ig}, via the choice of x_{ij} and $A_{i\ell}$. Producers and landscape gardeners can choose the composition of attributes embedded in their goods and their greening service.

A part, $\eta_g z_g$, $0 < \eta_g < 1$, of an aggregate emission of gases is observed to stay in the urban atmosphere and the rest, $(1 - \eta_g)z_g$, is perceived to disintegrate. Of this amount, about 46% of CO_2 emission is absorbed by the oceans and forests as carbon sinks. An integration rate or an inverse of a lifetime of each trace gas is denoted as λ_g, with $0 < \lambda_g < \eta_g, \forall g \in \mathbf{G}$, so that the mass of the gth gas that stays in the urban air is represented by $(\eta_g - \lambda_g)\, z_g, \forall g \in \mathbf{G}$.

Let θ_g be a conversion parameter from mass(ton/year) to concentration(ppmv), and $z_g(\gamma)$ be an amount emitted at time γ of the gth trace gas. Then an amount of trace gas accumulated from time t_0 to time t, which is converted into a concentration is given by

$$\zeta_g^t = \int_{t_0}^{t} \theta_g(\eta_g^t - \lambda_g^t) z_g(\gamma)\; d\gamma,\ \forall g \in \mathbf{G}. \qquad (4)$$

This can be written as

$$\zeta_g^t = \int_{t_0}^{t} \Theta_g^t z_g(\gamma)\; d\gamma,\ \forall g \in \mathbf{G} \qquad (5)$$

where $\Theta_g^t \equiv \theta_g(\eta_g^t - \lambda_g^t)$ is a climatical parameter related to the gth trace gas. An argument of time t is omitted hereafter, unless necessary. Therefore one observes

$$\mathbf{Z} = (\zeta_1, ..., \zeta_G) \qquad (6)$$

which affects all residents, producers and landscape gardeners in the periurban city.

Another equation is proposed for heat as a flow in the next subsection. It is the microclimate in the block, which most influences any economic agent who resides or works in β. However, climatical incidents depend upon not only the concentrations in each block, but also those in the entire metropolis, as examplified in the Nerima incident in the Introduction.

2.3 Heat Island Integral

The problem of how to represent the heat in the city was analyzed in Sato(2006a) who introduced the concept of "Heat Island Integral."[5] In effect, there must be differences in the temperature of building surface, back alleys, rooftops, streets, and green tracts of land, which are directly exposed to the solar radiation. However, these differences of the surface temperature of the ground coverage can be measured by utilizing the thermography.

Let F_β be an area of a block β and S_β be its level surface projection, i.e., the area which could absorb the solar radiation. More precisely, it is the sum of developable areas of the ground coverage, e.g., the streets, the tree crowns, the rooftops and walls of the buildings, which exist in F_β. Denote $\pi_\beta\,(u, w)$ as a function of the surface temperature of S_β and $\eta_\beta(u, w)$ as a function of atmospheric temperature over F_β, where u and w are the plane coordinates. Then, the Riemann sum led me to propose a concept of *Heat Island Integral* which reads, $\forall \beta \in \boldsymbol{\beta}$:

$$\Upsilon_\beta = \frac{1}{S_\beta} \left\{ \iint_{S_\beta} \pi_\beta(u, w) du dw - \iint_{F_\beta} \eta_\beta(u, w) du dw \right\}.$$

Needless to say, the existence condition of this multiple integral is that the functions, $\pi_\beta(u, w)$ and $\eta_\beta(u, w)$, are continuous and compact in the domains S_β and F_β, and it is easily seen that this condition is satisfied.

Remark 1. Υ_β is not the result of heat emission on the part of the economic agents, but it stems from the ground coverage of the metropolis. Υ_β measures the force of urban heat island in each block β, since the temperature of asphalt and concrete is very often higher than that of the atmosphere. Asphalt and concrete as meterials are observed to absorb approximately 90% of the solar radiation, hence, the walls of buildings made of concrete absorb the same amount of heat, which result in urban warming. Let me give numerical examples of the values in Υ_β. The mercury stood at 27.5 degrees at an observation point in Shinjuku at 14:00 on June 6, 2002, where the wall of a building made of concrete was observed to have the heat of 38°C and a street of asphalt had 45°C. The central area of Shinjuku ($F_\beta = 4\text{km}^2$) must be extended to its plane of projection ($S_\beta = 9.3\text{km}^2$), which is exposed to the solar radiation. Also, heat is emitted from the underground shopping malls in Shinjuku. By thermography, $\pi_\beta(\cdot)$ and $\eta_\beta\,(\cdot)$ can be constructed.

The following formula is physically supposed: *Sensible Heat Flux of Block* $\beta(\Xi_\beta)$ = *Heat Island Integral*$(\Upsilon_\beta)\times$ *Convective Heat Conductivity*(κ), $\forall \beta \in \boldsymbol{\beta}$, where κ varies according to the temperature. *Sensible heat flux* from the ground coverage of the metropolis therefore is represented by

$$\sum_{\beta\in\boldsymbol{\beta}} \Xi_\beta(A, W) = \kappa \sum_{\beta\in\boldsymbol{\beta}} \Upsilon_\beta\,(A, W)\,. \qquad (7)$$

Note that this function depends on the planted areas and the amount of water. Both of them can diminish the

[5] "Heat Island Potentail" developed by Iino and Hoyano (1995) incited me to propose this concept.

value of Υ_β by cooling down the ground coverage of the city.

Let ε_i, ε_j and ε_ℓ be heat emitted by resident i, firm j, and landscape gardener ℓ in the metropolis. The definitions of ε_i, ε_j, and ε_ℓ are implicit in Eq.(3). Total heat emission E which affects all economic agents in the large city is thus represented as

$$E(A, W) = \sum_{i \in \mathbf{N}} \varepsilon_i + \sum_{j \in \mathbf{J}} \varepsilon_j + \sum_{\ell \in \mathbf{\Lambda}} \varepsilon_\ell + \sum_{\beta \in \boldsymbol{\beta}} \Xi_\beta \qquad (8)$$

The first three terms represent artificial emissions of heat and the last term is the sensible heat flux generated from the ground coverage, all of which are assumed here to depend upon the amounts of vegetation and water. Note that heat contributes to urban warming, hence, a differentiability assumption is posed on the above equation.

Assumption 1. (i) E is convex and twice continuously differentiable with $\partial E/\partial A < 0$ and $\partial E/\partial W < 0$. (ii) $\varepsilon_i, \varepsilon_j, \varepsilon_\ell$ and Ξ_β are convex and twice continuously differentiable with $\partial \varepsilon_e/\partial A < 0$ and $\partial \varepsilon_e/\partial W < 0$, for any $e = i, j, \ell$, $\partial \Xi_\beta/\partial A < 0$ and $\partial \Xi_\beta/\partial W < 0$.

2.4 Vegetation, Water and the Urban Warming Function

Let L_i, L_j and L_ℓ be the land leased by resident i, producer j, and landscape gardener ℓ. Also let $A_i \equiv \rho_i L_i$ and $A_j \equiv \rho_j L_j$ be greening areas of their land required to be planted with trees, where ρ_i and ρ_j are greening rates for city dweller i and producer j, which are legally determined, e.g., at least 20% of the rooftop on the houses and buildings, when they are newly built, enlarged or reconstructed in Tokyo. Suppose that landscape gardeners are exempted from the obligation of greening a part of their own lands in our model.

As I assumed that inhabitant i chooses one landscape gardener ℓ to green a part of his/her land A_i with plants, at a cost of σ_ℓ/m^2. Then, each person is to have his/her green area planted with plants, insects and microorganisms in the soil. These living things are regarded as *biological attributes* that may be offered by gardener ℓ as by-products, and let $A_{i\ell}$ be his/her area A_i planted by gardener ℓ. City dweller i therefore consumes biological attributes by possessing the green area in his/her land as represented by

$$z_{is} = q_{\ell s} A_{i\ell}, \ \forall s \in \mathbf{S}, \ \forall \ell \in \mathbf{\Lambda}. \qquad (9)$$

Resident i can enjoy seeing creatures in his/her green area: they may be trees, flowers, insects, birds, or minute animals.

Suppose that each producer has an environmental branch which is in charge of planting trees in a part of its lot size A_j, with its cost σ_j. Let $A_P \equiv \sum_{\beta \in \boldsymbol{\beta}} A_\beta$ be the area to be planted with street trees and tree lawns undertaken by public works, and $\Gamma(A_p)$ is its cost. Summing these green areas yields

$$A = \sum_{i \in \mathbf{N}} \sum_{\ell \in \mathbf{\Lambda}} A_{i\ell} + \sum_{j \in \mathbf{J}} A_j + \sum_{\beta \in \boldsymbol{\beta}} A_\beta. \qquad (10)$$

Incidentally, passers-by can see hedges of others' houses, and can have beautiful views of parks. Children can amuse themselves in small parks which would stud the cities to and fro. These green areas are regarded as *amenities*, which may be clubs or excludable public goods.

As I mentioned in the Introduction, the quantity of water existing in the metropolis is crucially important to cool supercities, so underdrained rivers must be resuscitated. Let W be the total amount of water in the metropolis represented by

$$W = W_0 + W_P \qquad (11)$$

where W_0 is the quantity of water that already exists and W_p is the amount which is to be revived by public enterprises with a cost $\Omega(W_p)$, e.g., resuscitating culverts.

By physics, it is easily concluded that the more abundant the amounts of A and W, the cooler the metropolis, i.e., the more, the better. Notice that A and W have a public-good property, since their cooling effects can prevail all the blocks of the metropolis as beneficial externalities. This paper focuses on greening as one of the important natural factors which plays a significant role in cooling down the supercity. Modeling the water management in more detail is presented in Sato(2006b).

Total heat emission defines the *Urban Warming Function* which represents the urban temperature:

$$U = U(E). \qquad (12)$$

The following assumption is needed.

Assumption 2. U is convex and twice continuously differentiable with $dU/dE > 0$.

Remark 2. Urban warming is a typical example of a public good which is both nonrival and nonexcludable. However, its impacts on each resident differ among regions, which can be treated as *regional public goods*. Urban heat island with 33.5$degc$ occured in some blocks of the Nerima Ward, Tokyo on July 21, 1999, which was not necessarily due to the consumptions and productions of goods in that area, but due to those of districts in Tokyo, as well as the climate conditions of the block at that time. Consequently, the worst that could happen to any block where some meteorological conditions are satisfied at some point in time, as in the above unforeseen incident.

Let $\lambda_{\beta\beta'}$ be the difference of the temperature between one block β and the other block $\beta' \in \boldsymbol{\beta}$. Discussions so far eventuate in the following conditions. Urban heat island could occur if there are at least three conditions, i.e., i) $\Upsilon_\beta > 0$ and $\Upsilon_\beta - \Upsilon_{\beta'} > 0, \forall \beta, \beta' \in \boldsymbol{\beta}$, ii) $\lambda_{\beta\beta'} > 0, \forall \beta, \beta' \in \boldsymbol{\beta}$, and iii) some meteorological incidents happen at some time in a day on rare occasions. Whereas, *Cool Island* is present if $\Upsilon_\beta \leq 0$ and $\Upsilon_\beta - \Upsilon_{\beta'} > 0, \forall \beta, \beta' \in \boldsymbol{\beta}$ and if $\lambda_{\beta\beta'} \leq 0, \forall \beta, \beta' \in \boldsymbol{\beta}$. As was mentioned in the Introduction, the Imperial Palace, the Meiji Shrine, and the Shinjuku Gyoen National Garden as cool islands are cooler than the center of Shinjuku, i.e., the sensible heat flux of the latter was observed to be about $300\mathrm{W/m}^2$, whereas it was less than $200\mathrm{W/m}^2$ in the Shinjuku Gyoen National Garden.

2.5 Beings and Functionings of Residents Menaced by Urban Heat Island

The city itself is a complex of an infinite number of attributes. The Gorman-Lancasterian characteristics theory is the most suitable to analyze goods and the urban atmosphere which is perfectly divisible and decomposable as gaseous attributes. The characteristic availability functions can be applied to any resident whose utilization differs from person to person. Consequently, each inhabitant's *functionings* should be introduced as one of the important concepts *à la* Sen(1985) to fully appraise the value of goods or characteristics. Each resident's physical and climatical situations differ, so I must introduce the *functionings* which are represented below.

Metropolitan consumers use personal computers, printers, drive cars and cook meals. They also watch televisions, listen to music, and make photocopies. All of these behaviors may be considered as functionings, thus, city dwellers emit heat and gases when they use their functionings. Much heat is emitted from air-conditioners, and large-sized refrigerators in houses and supermarkets to store many things such as fruits, vegetables, fish, meat, poultry, dairy produces and frozen foods.

Different from Sen, an inhabitant's beings can be represented as a vector of functionings. Let f_i be a vector of resident i's functionings. The set of person i's functionings is denoted as $\mathbf{K}_i$. $\mathbf{K}_i$ includes resident i's physical ability which heavily depends upon its climate in the block where he/she lives or works, e.g., the temperature of more than 40°C in the daytime would bring critical situations for human bodies: an increase of body temperature, heat exhaustion, bad circulation, etc. Not to mention, the number of functionings K_i differs among persons. If he/she chooses a vector of functionings, then his/her beings are generated by his/her functionings,$f_{ik}, \forall k = 1, ..., K_i \in \mathbf{K}_i$. As for heat emission, there are two subsets, $\mathbf{K}_i^E$ and $\mathbf{K}_i^N$ ($\mathbf{K}_i = \mathbf{K}_i^E \cup \mathbf{K}_i^N$), i.e., the functionings belonging to $\mathbf{K}_i^E$ are those that emit heat, whereas, those in $\mathbf{K}_i^N$ do not. Different from the above examples of urban warming, some functionings can cool the cities. Drawing water from wells to sprinkle on the rooftops also cools the houses. Generally, 20∼30% of heat enters from the windows and 10% of it flees from them. So we could make efficient use of air conditioning by employing blinds and curtains, since pulling down blinds provides excellent protection against the sun. Window glass type may well be changed to one which does not easily accept heat. These are examples for some functionings of metropolitan residents. One liter of water per hour could be discharged from the body when the thermometer shows above 30°C; some people could die of dehydration. Also indicated is that victims of heatstroke will exponentially increase when the mercury exceeds more than 34°C. City dwellers will want to have more water and cold drinks, to swim in a pool or in the sea, to see tropical fish in an aquarium. When the temperature approaches 40°C, the number of sunstroke victims will increase. Urban heat island will cause many residents' deaths in metropolises. The number of people conveyed by ambulance was more than four hundreds in 2003, which was the maximum in the five years, since the observation was started. Many people will be sick because they stay in rooms extremely air-cooled for a long time. Heat-sensitive persons will have to pay medical expenses when they suffer from heatstroke or other diseases. Electricity consumption can be reduced by raising the set point of the temperature of air conditioners in the rooms.[6] Medical methods can be developed to help alleviate the possible spread of tropical contagious diseases carried by vermin. These are examples of functionings, too.

Remark 3. I would like to point out that the following fact is very important. Residents emit heat by utilizing some of their functionings, and at the same time, they suffer from the heat they emit. That is, some functionings $f_{ik} \in \mathbf{K}_i^E$ of a person could inflict pain upon his/her other functionings $f_{ik} \in \mathbf{K}_i^N$, by prioritizing too much the convenience and the comfortableness as immediate profits in his or her everyday life. Humans are apt to think only of the present and take a short view of things, and this mentality may be one of the main causes which have brought urban heat island in the metropolises.

Denote $z_i^C = (z_{i1}, ..., z_{iC})$, $z_i^G = (z_{iC+1}, ..., z_{iC+G})$, and $z_i^S = (z_{iC+G+1}, ..., z_{iC+G+S})$. Amounts of each characteristic embodied in the goods, the plants in the green area, the atmosphere and the greenery consumed by resident i in the periurban metropolis is given by

$$z_i = \left(z_{i0}, z_i^C, z_i^G, z_i^S, z_{ih}\right). \tag{13}$$

The sum of green area A is composed by plants and other living things as biological attributes and the total amount of water is also regarded as a composite of characteristics, which may be called generically as waterness as above. A and W not only cool down cities, but also give residents a tasteful life instead of a prosaic life, so that they enter in city dweller i's consumption vector of attributes as public goods.

Personal beings of inhabitant i may be representable as:

$$b_i = \left(f_{i1}(z_i, U), ..., f_{iK_i}(z_i, U)\right) \tag{14}$$

Hence, the following assumption is needed.

Assumption 3. For any $i \in \mathbf{N}$ and for any $f_{ik} \in \mathbf{K}_i$, f_{ik} is concave and twice continuously differentiable on the closed convex consumption set $\mathbf{M}_i$.

Remark 4. It is considered that a change in the numéraire attribute z_{i0} can vary resident i's functionings. For example, consuming a huge amount of goods in high consumption societies in developed countries can be supported from combusting enormous quantities of fossil fuels, which can be acquired by utilizing the numéraire characteristic z_{i0} and functionings. The signs of $\partial f_{ik}/\partial z_{ic}$ and $\partial^2 f_{ik}/\partial z_{ic}^2$ depend upon what characteristic c is, i.e., it can take a sign $\{+, 0, -\}$ according to attribute c which is good, irrelevant, or bad, respectively, for resident i's well-being. If c is heat, then the sign may now be minus for many metropolitan residents in summertime because of health problems due to an increasing level of urban heat island. Assumption 3 means that the more heat emitted into the urban air, the less functionings that residents can utilize to enjoy their metropolitan lives. They feel quite aggravated by the sweltering heat during the day, and they may suffer from heatstroke. Summer nights with more than 25°C often keep them from sleep, so that they have to endure sleepless nights.

[6] The power saving policies are enforced in the ward offices in Tokyo and the municipal institutions where the temperature of the air conditioners is set at 28°C. The same is true for many companies.

2.6 Resident's Happiness Function and Valuing Personal Well-Being

Let any inhabitant i have his/her *Happiness Function* which is assumed to depend upon his/her being, thus, one observes

$$H_i = H_i\left(b_i\right). \tag{15}$$

Any person's use of functionings can vary his/her personal happiness. In order to obtain our desired results, I need another differentiability assumption.

Assumption 4. For any $i \in \mathbf{N}$, H_i is strictly concave and twice continuously differentiable with $(\partial H_i/\partial f_{ik}) \cdot (\partial f_{ik}/\partial z_{i0}) \neq 0$ for at least one $k \in \mathbf{K}_i$.

Denote resident i's *hedonic shadow price* or *hedonic marginal willingness-to-pay (HMW)* of any gaseous and nongaseous characteristic c, and of any biological attribute s in greenery as an attribute:

$$\pi_{ic} = \frac{\sum_{k\in\mathbf{K}_i} \left(\partial H_i/\partial f_{ik}\right)\left(\partial f_{ik}/\partial z_{ic}\right)}{\sum_{k\in\mathbf{K}_i} \left(\partial H_i/\partial f_{ik}\right)\left(\partial f_{ik}/\partial z_{i0}\right)},\ \forall c \in \mathbf{C}$$

$$\pi_{is} = \frac{\sum_{k\in\mathbf{K}_i} \left(\partial H_i/\partial f_{ik}\right)\left(\partial f_{ik}/\partial z_{is}\right)}{\sum_{k\in\mathbf{K}_i} \left(\partial H_i/\partial f_{ik}\right)\left(\partial f_{ik}/\partial z_{i0}\right)},\ \forall s \in \mathbf{S}$$

$$\pi_{ig} = \frac{\sum_{k\in\mathbf{K}_i} \left(\partial H_i/\partial f_{ik}\right)\left(\partial f_{ik}/\partial z_{g}\right)}{\sum_{k\in\mathbf{K}_i} \left(\partial H_i/\partial f_{ik}\right)\left(\partial f_{ik}/\partial z_{i0}\right)},\ \forall g \in \mathbf{G}$$

$$\pi_{ih} = \frac{\sum_{k\in\mathbf{K}_i} \left(\partial H_i/\partial f_{ik}\right)\left(\partial f_{ik}/\partial U\right)(dU/dE)}{\sum_{k\in\mathbf{K}_i} \left(\partial H_i/\partial f_{ik}\right)\left(\partial f_{ik}/\partial z_{i0}\right)}.$$

Remark 5. (i) $\pi_{ic}, \pi_{is}, \pi_{ig}$ or π_{ih} is a marginal contribution of each attribute to resident i's *marginal happiness* through his/her functionings in terms of the numéraire characteristic z_{i0}. It may correspond to a "marginal rate of substitution(MRS)"between each attribute and the numéraire characteristic z_{i0} in the utility theoretical context.

(ii) Note that our "MRS" is totally different from Drèze and Hagen(1978), since it involves the concepts of functionings and a happiness function *à la* Sen, and moreover, it can be applied to detrimental attributes too. Hence, in Sato(2000) I had to replace a happiness function for a utility function. Note also that the analysis of Drèze and Hagen allows for negative MRSs of some consumers, with an additional assumption that $\sum_i \pi_{ic} > 0$ as expressed in our notation. This means that even if some person(s) put(s) negative marginal evaluation $\pi_{ic} < 0$ on some characteristic c, the aggregate value of MRSs over residents can still be positive, i.e., they admit this attribute.

(iii) Whether inhabitant i considers a commodity or a service as good, irrelevant, or bad to his or her functionings is confirmed by the sign of $\sum_{c\in\mathbf{C}\cup\mathbf{G}} \pi_{ic} q_{jc}$ for each good j and $\sum_{c\in\mathbf{B}\cup\mathbf{G}} \pi_{ic} q_{\ell c}$ for any service ℓ. Moreover, whether a commodity or a service is socially good or not may also be examined by summing over individuals of $\sum_{c\in\mathbf{C}\cup\mathbf{G}} \pi_{ic} q_{jc}$ for any good j and $\sum_{c\in\mathbf{B}\cup\mathbf{G}} \pi_{ic} q_{\ell c}$ for any service ℓ. Now, to keep the room open to the cool air, an air conditioner is one of the necessities for our comfortable urban life under urban heat island, even if it does emit heat as a vexing by-product. Consequently, $\pi_{ih} < 0$ holds for many people, who feel displeased by the scorching heat due to urban warming. However, they wish to avoid this, thus, $\sum_{c\in\mathbf{C}\cup\mathbf{G}} \pi_{ic} q_{jc} \gg 0$ still prevails for j if it is an air conditioner. It cannot be helped, since everybody wants to keep his/her room cool, especially under a burning sun. It is not only heat but also the resulting high humidity, and an actual and sensary high temperature due to an increase of heat, that could lower some functionings of residents. This fact can be represented by $(\partial f_{ik}/\partial U)(dU/dE) < 0, \forall i \in \mathbf{N}, \forall f_{ik} \in \mathbf{K}_i$.

The set of feasible functionings vectors for any person is the *personal capability set*, i.e., opportunities to achieve personal well-being. Residents live in some block, and many of them work in other block. When they move in summertime, they may suffer from the sweltering heat. Hence, urban warming exerts an influence on residents, wherever they live in large cities.

Let x_i be resident i's entitlements of goods, and $\mathbf{X}_i$ be its set. Given x_i and U, one can represent the set of feasible beings vector, or the *personal capability set* of inhabitant i under urban warming as:

$$\begin{aligned}\mathbf{B}_i\left(x_i, U\right) = \{b_i | b_i = \left(f_{i1}\left(z_i, U\right), ..., f_{iK_i}\left(z_i, U\right)\right),\\ \textit{for some } k_i \textit{ in } \mathbf{K}_i \textit{ and for some } x_i \textit{ in } \mathbf{X}_i\}.\end{aligned}$$

Limiting our analysis to the persons' risky aspects of living which are menaced by urban warming due to human activities, one may interpret b_i as a *"personal wellness index,"* since b_i, *ceteris paribus*, corresponds to some personal being. In our context an inhabitant enjoys his or her life by using his/her functionings, which enhance his/her happiness and well-being. The health of the population in the metropolis is not only an ultimate objective, but also a means which permits people to experience agreeable urban lifestyles. The crucial problem is that many residents' personal capability sets would shrink due to the accelerating urban warming in the near future, i.e., $\mathbf{B}_i^{t+1}(x_i^{t+1}, U^{t+1}) \subset \mathbf{B}_i^{t}(x_i^{t}, U^{t})$.

In Sato(2000) I characterized the conditions for a socially optimal consumption of goods as well as the global ambient air in terms of characteristics including gaseous attributes. I added "climatical constraints" to confirm an optimal composition of the global atmosphere to maximize a personal happiness function, which depends upon his/her functionings. Section 3 presents the main results, i.e., a derivation of optimality conditions for the urban climate and a design of heat island tax/subsidy scheme.

3. HEDONIC OPTIMALITY CONDITIONS FOR METROPOLITANS UNDER URBAN HEAT ISLAND

3.1 Periurban Residents

Consider that city dwellers know the risks of man-made future urban climate changes, and that they have an incentive to optimize the composition of the urban atmosphere in order to aim at achieving their personal best-being in the metropolis. Let δ be a distance from the center of the CBD. Denote $r_i(\delta)$ as the rent of one square meter of land, and each inhabitant's rent is $r_i(\delta)L_i$, when he/she leases a lot L_i from an absentee landlord. $\xi_i(\delta)$ is the transportation cost to go to whatever place the resident i likes, by using his/her private car(s), and public transportation systems such as buses, subways, trains, and streetcars. For example, with his/her family, he/she visits museums or concert halls in the CBD or natural parks in the periurban zone. It is assumed that his/her commuting cost is payed by the firm in which he/she works, and that it is involved in z_{i0}.[7]

Denote $\varepsilon_{-i}(\alpha_{-i}) = (\varepsilon_1(\alpha_1), \ldots, \varepsilon_{i-1}(\alpha_{i-1}), \varepsilon_{i+1}(\alpha_{i+1}), \ldots, \varepsilon_{N+J+\Lambda}(\alpha_{N+J+\Lambda}))$. Let $\nu_i(\varepsilon_i(\alpha_i), \varepsilon_{-i}(\alpha_{-i}))$ be resident i's heat abatement cost which depends upon his/her emission of heat as well as those of others. A parameter $\alpha_i > 0$ is associated with his/her effort to reduce heat emission. It is assumed that α_i is known only to him/her. Functionings to cool cities are, for example, economizing in power by reducing the use of electrical fittings and by using a bicycle or public transportations instead of a car. As urban heat island accelerates, city dwellers will want to buy newly developed, more efficient air conditioners, which result in reduction of heat emission. These are examples of functionings to explain α_i. Resident i has to pay $t_i(\alpha_i)$ as a *heat island tax*, in order for the urban atmosphere not to be warmed so much as to be unendurable to live in.[8]

As is well-known, greening lands and rooftops are one of the most effective ways to cool the metropolis. Let the metropolitan government determine $0 < \varphi < 1$ as the refund rate for greening the area $A_{i\ell}$ that resident i requests landscape gardener ℓ. Assume that the value of φ is decided by the scientific data about tree-planting. As defined, σ_ℓ is landscape gardener ℓ's greening cost per square meter, hence, $\sigma_\ell A_{i\ell}$ is resident i's greening cost, and $\varphi\sigma_\ell A_{i\ell}$ is i's refund for the effort to plant trees.

The set $\mathbf{J}$ includes all the goods and services such as electricity and water but land and transportation, and p_j is a unit price of good j, then each inhabitant's budget constraint is given by

$$\begin{aligned} z_{i0} = {} & \sum_{j\in\mathbf{J}} p_j x_{ij} + \sigma_\ell A_{i\ell} - \varphi\sigma_\ell A_{i\ell} + t_i(\alpha_i) \\ & + \nu_i(\varepsilon_i(\alpha_i), \varepsilon_{-i}(\alpha_{-i})) + r_i(\delta)L_i + \xi_i(\delta). \end{aligned}$$

The left-hand side of the above equation signifies the value of numéraire attribute whose price is normalized to be one.

Assumption 5. For any $i \in \mathbf{N}$, r_i, ν_i, ε_i and t_i are convex and ξ_i is concave. Moreover, they are continuously differentiable, with $dr_i/d\delta < 0$, $\partial\nu_i/\partial\varepsilon_i < 0$, $d\varepsilon_i/d\alpha_i < 0$ $dt_i/d\alpha_i < 0$ and $d\xi_i/d\delta > 0$.

This assumption means that $r_i(\delta)$ has a distance decay curve, and that $\xi_i(\delta)$ has an increasing curve of distance. The more heat is emitted, the more the urban air warms, and the more costly life becomes. This signifies that the more damages due to urban heat island augment, the more residents have to pay for cool air, the more tax they have to pay for alleviating the urban warming. Each resident's effort can diminish his/her tax payment.

[7] Usually in the urban economics, a commuting cost is not implicitly included in the income, but explicitly defined instead of our traffic cost. Our model is somewhat different from that in an ordinary urban economic theory.

[8] See Sandmo(2000) for some related issues of taxes and alternatives to improve the environment.

The maximand is the personal happiness function. Each periurban resident solves the following optimization problem:

$$\begin{aligned} Max \quad & H_i = H_i(b_i) \\ s.t.\ & z_{i0} = \sum_{j\in\mathbf{J}} p_j x_{ij} + \sigma_\ell A_{i\ell} - \varphi\sigma_\ell A_{i\ell} + t_i(\alpha_i) \\ & \quad + \nu_i(\varepsilon_i(\alpha_i), \varepsilon_{-i}(\alpha_{-i})) + r_i(\delta)L_i + \xi_i(\delta). \end{aligned}$$

Now the first result is presented.

Lemma 1. *For any periurban resident $i \in \mathbf{N}$, an individually optimal consumption of goods jointly composed by Gorman-Lancasterian gaseous and nongaseous attributes, and of the green area as a complex of biological attributes is characterized as: $\forall j \in \mathbf{J}$, $\forall \ell \in \mathbf{\Lambda}$*

$$\sum_{c\in\mathbf{C}\cup\mathbf{G}\cup\{h\}} \pi_{ic} q_{jc} \le p_j, \left(\sum_{c\in\mathbf{C}\cup\mathbf{G}\cup\{h\}} \pi_{ic} q_{jc} - p_j \right) x_{ij} = 0$$

$$\sum_{c\in\mathbf{S}\cup\mathbf{G}\cup\{h\}} \pi_{ic} q_{\ell c} \le \sigma_\ell(1-\varphi),$$

$$0 = \left\{ \sum_{c\in\mathbf{S}\cup\mathbf{G}\cup\{h\}} \pi_{ic} q_{\ell c} - \sigma_\ell(1-\varphi) \right\} A_{i\ell}$$

$$\begin{aligned} & \frac{dt_i}{d\alpha_i} \le -\frac{\partial\nu_i}{\partial\varepsilon_i}\frac{d\varepsilon_i}{d\alpha_i}, \quad \left(\frac{dt_i}{d\alpha_i} + \frac{\partial\nu_i}{\partial\varepsilon_i}\frac{d\varepsilon_i}{d\alpha_i} \right) \alpha_i = 0 \\ & L_i \le -\frac{d\xi_i/d\delta}{dr_i/d\delta}, \quad \left(L_i + \frac{d\xi_i/d\delta}{dr_i/d\delta} \right) \delta = 0 \\ & r_i \le -\rho_i\sigma_\ell(1-\varphi), \quad \{r_i + \rho_i\sigma_\ell(1-\varphi)\} L_i = 0. \end{aligned}$$

Remark 6. (i) The conditions presented are not only necessary but also sufficient from the assumptions on the functions. In the first equations, π_{ic} signifies a hedonic shadow price of an attribute acquired by utilizing inhabitant i's *numéraire characteristic* through his/her functionings. The left-hand side of the first equation is the sum of resident i's marginal evaluations of the nongaseous attributes embodied in one unit of a good, as well as of the tangible attributes released when the good is produced. Notice that the first formulae verify that any resident considers heat and gases as gaseous characteristics emitted when consuming one unit of good j. The first conditions mean that the unit price of the good is equal to the sum of marginal contributions of attributes to his/her happiness through his/her functionings. The conditions assure a Pareto optimality for a quantity of each good, and give a basis upon which goods household i chooses to buy.

(ii) The second conditions signify that individual i's marginal evaluation of species as biological attributes by having the area $A_{i\ell}$ of his/her land L_i, planted by landscape gardener ℓ is equal to his/her greening cost per square meter minus the refunded cost. The term, $\varphi\sigma_\ell$ may be called a "heat island (alleviating) subsidy," since it represents the reward according to the person's effort to plant trees in a part of his/her land. Many residents suffer from the fierce heat in summertime, if he/she feels very displeased by the boiling weather due to urban warming.

(iii) The conditions about t_i show that city dweller i's marginal evaluation of emitting a unit of heat is a match for his/her marginal heat island tax. The next conditions let us know the lot size that the resident decides to lease from an absentee landlord. These are the equilibrium conditions of residential location. It is easily seen that L_i is determined by the distance, the rent and the traffic cost that inhabitant i has to pay. The last two formulae determine the equilibrium rent in the metropolis. Note that the more rent increases, the more the area is greened, and the less heat is emitted. Greening a rooftop or a garden as a part ρ_i of his/her lot size, any resident can cool his/her house, which results in saving power. Thus, an incentive is given to an inhabitant to have a part of his/her land planted with trees and flowers from motives of selfishness.

3.2 Offices, Manufacturers and Farmhouses as Producers

A framework that I earlier employed in Sato(2000) is used to involve the phenomenon of urban warming due to heat released by the producers. I present the optimization by profit maximizing producers to supply one good with an optimal product quality to consumers. Let producer j (landscape gardener ℓ) produce good j (service ℓ) by using L_j and x_{j0} (L_ℓ and $x_{\ell 0}$) as inputs, and the price of x_{j0} ($x_{\ell 0}$) is normalized to be one, with $\sum_{j\in\mathbf{J}} x_{j0}+\sum_{\ell\in\mathbf{\Lambda}} x_{\ell 0} \leq \sum_{i\in\mathbf{N}} z_{i0}$. Then, x_{j0} ($x_{\ell 0}$) is a *numéraire attribute* that producer j (landscape gardener ℓ) uses as an input.

Let $y_j = (x_{j0}, L_j, x_j, q_{j1}, ..., q_{jC}, q_{jC+1}, ..., q_{jC+G}, q_{jh})$ be producer j's input-outout vector, then it produces a good j as an output to maximize its profit subject to the production function

$$\psi_j = \psi_j(x_{j0}, L_j, x_j, q_{j1}, ..., q_{jC}, q_{jC+1}, ..., q_{jC+G}, q_{jh}) \leq 0 \qquad (16)$$

where $q_{jc}, \forall c \in \mathbf{G}$, is an amount of a gas and q_{jh} is a quantity of heat emitted in the urban atmosphere when it produces one unit of good j, and $(q_{jC+1}, ..., q_{C+G})$ is a vector of gaseous attributes. Meanwhile, $(q_{j1}, ..., q_{jC})$ is a vector of nongaseous characteristics embodied in one unit of good j. Any producer therefore jointly produces heat and gaseous attributes. The production function may not be convex, but the difficulties arising from nonconvexities are not treated here, so I must make an assumption.

Assumption 6. For any $j \in \mathbf{J}$, ψ_j is convex and twice continuously differentiable on the closed convex production set $\mathbf{Y}_j$, with $\partial x_{j0}/\partial q_{jc} > 0$, $\forall c \in \mathbf{C}\cup\mathbf{G}$, $c \neq j'$. Furthermore, $x_j > 0$ implies $x_{j0} > 0$ and $L_j > 0$, and $\forall \Delta \in \mathbf{R}_+, \{y_j|\psi_j\,(y_j) \leq 0, x_{j0} \leq \Delta,\, L_j \leq \Delta\}$ is compact.

It is assumed that π_{ic} and π_{ig} are truthful, since all goods are private goods or publicly provided goods such as gas, water and electricity, for which the residents have to pay public utility charges. Hence, they cannot have for free.

When $x_{ij} > 0$, p_j could be computed as $\sum_{c\in\mathbf{C}\cup\mathbf{G}} \pi_{ic}q_{jc}$ from **Lemma 1**, then the profit maximization problem for the producers are given by[9]

$$\begin{aligned} Max \ \ P_j = \sum_{i\in\mathbf{N}}\sum_{c\in\mathbf{C}\cup\mathbf{G}\cup\{h\}} & \pi_{ic}q_{jc}x_{ij} - x_{j0} - r_j(\delta)L_j \\ & - \mu_j\delta x_j - t_j(\alpha_j) - \nu_j(\varepsilon_j(\alpha_j), \varepsilon_{-j}(\alpha_{-j})) \\ & - \chi\sigma_jA_j + \chi\varphi\sigma_jA_j + (1-\chi)\omega L_{jF} \\ & \chi = 0 \ \text{ if } \ j \in \mathbf{J}_F \ \text{ and } \ \chi = 1 \ \text{ if } \ j \notin \mathbf{J}_F. \end{aligned}$$

The first term of the R.H.S. is revenue. x_{j0} is the amount of labor used as an input, and $r_j(\delta)L_j$ is the rent of land, where L_j is a variable as an input. Denote $\varepsilon_{-j}(\alpha_{-j}) = (\varepsilon_1(\alpha_1), \ldots, \varepsilon_{j-1}(\alpha_{j-1}), \varepsilon_{j+1}(\alpha_{j+1}), \ldots, \varepsilon_{N+J+\Lambda}(\alpha_{N+J+\Lambda}))$. Let $\nu_j(\varepsilon_j(\alpha_j), \varepsilon_{-j}(\alpha_{-j}))$ be j's heat abatement cost, where $\alpha_j > 0$ is a parameter only known to j to reduce heat emission. Note that ν_j depends on the heat emissions of the rest of the city. It may be interpreted as an external cost to buy, for example, more efficient power saving air conditioners. Heat island tax t_j is a function of α_j which represents firm j's effort to decrease an emission of heat when producing and transporting $x_j = \sum_{i\in\mathbf{N}} x_{ij}$ units of good j. More examples to explain α_j are in order: producer j encourages his/her staff to commute by bicycle, to use hybrid or fuel cell cars as delivery vans, and to choose energy-saving type of personal computers and printers in the office.

Let $\mu_j > 0$ be a unit cost of transportation. It is necessary to include $\mu_j\delta x_j$ as transportation cost in the above equation, since delivery of goods result in emitting heat, GHGs such as CO_2 and CH_4, and noxious gases such as SO_2 and NO_x.[10] It is generally accepted that midtown hotels and office buildings use more computers and air conditioners than residents and landscape gardeners in the periurban belt. The former would emit more heat and gases into the urban atmosphere so as to cool hotels and offices, as urban heat island accelerates in the near future. As producers, offices offer services, manufacturers supply products, and farmhouses make agricultural products.

σ_jA_j is firm j's greening cost, and $\varphi\sigma_jA_j$ is the refund to firm j. Denote L_{jF} as j's farmland. Let ωL_{jF} $(0 < \omega < 1)$ be a reward given by the metropolitan government to farmhouse j which has not turned its farmland into housing. Let also $\mathbf{J}_F$ be the set of farmhouses that are exempted from the obligation to green a part of their own lands.

Here I need another assumption.

Assumption 7. For any $j \in \mathbf{J}$, r_j, ν_j *and* t_j *are convex and* ε_j *is concave. Moreover, they are twice continuously differentiable with* $dr_j/d\delta < 0$, $\partial\nu_j/\partial\varepsilon_j < 0$, $dt_j/d\alpha_j < 0$ *and* $d\varepsilon_j/d\alpha_j < 0$.

In the presence of gaseous and nongaseous attributes, I have the following result.

Lemma 2. *For any periurban producer* $j \in \mathbf{J}$, *necessary conditions for Pareto optimal product quality in terms of gaseous and nongaseous attributes are:* $\forall c \in \mathbf{C}$, $c \neq j', \forall g \in \mathbf{G}$, $g \neq j'$, $h \neq j'$

$$\sum_{i\in\mathbf{N}} \pi_{ic}x_{ij} \leq \frac{\partial x_{j0}}{\partial q_{jc}} + r_j\frac{\partial L_j}{\partial q_{jc}} + \mu_j\delta\frac{\partial x_j}{\partial q_{jc}}$$

[9] To construct the producer's profit function, I followed Drèze and Hagen(1978, p.510) who wrote that "the implicit price could be computed... and they would in equilibrium be the same for all consumers. So we do not have to make price differentiation among consumers."This fact follows from their assumption of nonsingularity of the technological matrix. If the matrix $\mathbf{q_j}$ and $\mathbf{q}_\ell$ are nonsingular, then they have an inverse matrix. In our model $\mathbf{q_j}$ and $\mathbf{q}_\ell$ are not nonsingular, so we assume the truthful revelation of $\pi_{ic}, \forall c \in \mathbf{C}\cup\mathbf{G}$, and $\pi_{is}, \forall s \in \mathbf{S}, \forall i \in \mathbf{N}$.

[10] CO_2 emitted from the transportation branch is 20% in Japan.

$$0 = \left(\sum_{i \in \mathbf{N}} \pi_{ic} x_{ij} - \frac{\partial x_{j0}}{\partial q_{jc}} - r_j \frac{\partial L_j}{\partial q_{jc}} - \mu_j \delta \frac{\partial x_j}{\partial q_{jc}} \right) q_{jc}$$

$$\sum_{i \in \mathbf{N}} \pi_{ig} x_{ij} \leq \frac{\partial x_{j0}}{\partial q_{jg}} + r_j \frac{\partial L_j}{\partial q_{jg}} + \mu_j \delta \frac{\partial x_j}{\partial q_{jg}}$$

$$0 = \left(\sum_{i \in \mathbf{N}} \pi_{jg} x_{ij} - \frac{\partial x_{j0}}{\partial q_{jg}} - r_j \frac{\partial L_j}{\partial q_{jg}} - \mu_j \delta \frac{\partial x_j}{\partial q_{jg}} \right) q_{jg}$$

$$\sum_{i \in \mathbf{N}} \pi_{ih} x_{ij} \leq \frac{\partial x_{j0}}{\partial q_{jh}} + r_j \frac{\partial L_j}{\partial q_{jh}} + \frac{\partial \nu_j}{\partial \varepsilon_j} x_j + \mu_j \delta \frac{\partial x_j}{\partial q_{jh}}$$

$$0 = \left(\sum_{i \in \mathbf{N}} \pi_{ih} x_{ij} - \frac{\partial x_{j0}}{\partial q_{jh}} - r_j \frac{\partial L_j}{\partial q_{jh}} - \frac{\partial \nu_j}{\partial \varepsilon_j} x_j - \mu_j \delta \frac{\partial x_j}{\partial q_{jh}} \right) q_{jh}$$

$$\frac{dt_j}{d\alpha_j} \leq -\frac{\partial \nu_j}{\partial \varepsilon_j} \frac{d\varepsilon_j}{d\alpha_j}, \quad \left(\frac{dt_j}{d\alpha_j} + \frac{\partial \nu_j}{\partial \varepsilon_j} \frac{d\varepsilon_j}{d\alpha_j} \right) \alpha_j = 0$$

$$L_j \leq -\frac{\mu_j x_j}{dr_j / d\delta}, \quad \left(L_j + \frac{\mu_j x_j}{dr_j / d\delta} \right) \delta = 0$$

$$r_j \leq -\chi \rho_j \sigma_j (1 - \varphi) - \mu_j \delta \frac{\partial x_j}{\partial L_j} - (1 - \chi) \omega \Pi_j$$

$$0 = \left\{ r_j + \chi \rho_j \sigma_j (1 - \varphi) + \mu_j \delta \frac{\partial x_j}{\partial L_j} + (1 - \chi) \omega \Pi_j \right\} L_j$$

$$\chi = 0 \;\; if \;\; j \in \mathbf{J}_F \;\; and \;\; \chi = 1 \;\; if \;\; j \notin \mathbf{J}_F.$$

Remark 7. (i) The first equations establish a Pareto optimality for an amount of each attribute and determine a vector of optimal nongaseous characteristics embodied in the goods supplied by producer j. The L.H.S. of the first equation is the marginal revenue which is the aggregate of the residents' marginal evaluations of an infinitesimal change in an attribute embedded in x_j. Its R.H.S. is the marginal cost in terms of the numéraire characteristic and the land to produce q_{jc}, as well as j's marginal transportation cost. $\sum_i \pi_{ic} x_{ij}$ is the marginal social value of good j, which is the sum of the personal evaluations of a change in an attribute when the quantity of good x_j is produced.

(ii) The second two formulae verify a Pareto optimal amount of of each gas as a gaseous attribute. The L.H.S. is the social value of any gas, and the R.H.S. consists of three terms: the first two terms are the marginal cost in terms of x_{j0} and L_j, and the last term is the marginal transportation cost when producing x_j units of good j.

(iii) The next two equations show a Pareto optimal quantity of heat as an intangible attribute. The L.H.S. is the social value of heat, and the R.H.S. consists of four terms: the first two terms are the marginal cost in terms of x_{j0} and L_j, the third term means the marginal damage to emit heat, and the last term is the marginal transportation cost when producing x_j units of good j.

(iv) As in **Lemma 1**, t_j is the heat island tax of producer j, and the formulae of L_j determine the equilibrium lot size. The last two equations determine the equilibrium land rent, which is equal to the sum of the terms of greening cost σ_j/m^2 and marginal transportation cost(MTC) of producer $j \notin \mathbf{J}_F$. Whereas it equals to the terms of MTC and the reward given to farmhouse $j \in \mathbf{J}_F$. The amount of $\omega \pi_j$ is given as a subsidy to farmhouse j for preserving its farmland in the periurban area, which could be expected to somewhat mitigate urban heat island.

3.3 Periurban Landscape Gardeners

Next, efficiency conditions for periurban landscape gardeners are derived. Their job is to plant trees in areas of lands that residents or producers possess, so they are exempted from the obligation of greening a part of their own lands in our model. They supply plants as biological, and therefore nongaseous attributes. Let $r_\ell(\delta) L_\ell$ be the land rent, where $r_\ell(\delta)$ is the rent per square meter and L_ℓ is the land leased from the absentee landlord.

Denote $\varepsilon_{-\ell}(\alpha_{-\ell}) = (\varepsilon_1(\alpha_1), \ldots, \varepsilon_{\ell-1}(\alpha_{\ell-1}), \varepsilon_{\ell+1}(\alpha_{\ell+1}), \ldots, \varepsilon_{N+J+\Lambda}(\alpha_{N+J+\Lambda}))$. Let $\nu_\ell(\varepsilon_\ell(\alpha_\ell), \varepsilon_{-\ell}(\alpha_{-\ell}))$ be gardener ℓ's abatement cost, where $\alpha_\ell > 0$ is a parameter only known to gardener ℓ. Landscape gardeners can attempt to serve green areas to residents by using a new technology which does not emit too much heat. Let $\mu_\ell \delta A_\ell$ be their transportation cost, where μ_ℓ is a unit cost of transportation and $A_\ell = \sum_{i \in \mathbf{N}} A_{i\ell}$. Thus, they emit trace gases such as CO_2, CO, NO_x and SO_2 into the air, when they use fertilizers, serve and transport their garden plants. Any gardener serves a green area to residents to maximize his/her profit subject to the production function

$$\psi_\ell = \psi_\ell(x_{\ell 0}, L_\ell, A_\ell, q_{\ell C+1}, ..., q_{\ell C+G}, q_{\ell C+G+1}, ..., q_{\ell C+G+S}, q_{\ell h}).$$

Hence, each gardener solves the optimization problem:

$$Max \;\; P_\ell = \sum_{i \in \mathbf{N}} \sum_{c \in \mathbf{S} \cup \mathbf{G} \cup \{h\}} \pi_{ic} q_{\ell c} A_{i\ell} - \{x_{\ell 0} + \mu_\ell \delta A_\ell + t_\ell(\alpha_\ell) + \nu_\ell(\varepsilon_\ell(\alpha_\ell), \varepsilon_{-\ell}(\alpha_{-\ell})) + r_\ell(\delta) L_\ell\}.$$

Two assumptions are needed for this maximization problem.

Assumption 8. For any $\ell \in \mathbf{\Lambda}$, ψ_ℓ is convex and twice continuously differentiable on the closed convex production set $\mathbf{Y}_\ell$, with $\partial x_{\ell 0}/\partial q_{\ell c} > 0$, $\forall c \in \mathbf{S} \cup \mathbf{G}$, $c \neq \ell'$. Furthermore, $A_\ell > 0$ implies $x_{\ell 0} > 0$ and $L_\ell > 0$, and $\forall \Delta \in \mathbf{R}_+$, $\{y_\ell | \psi_\ell(y_\ell) \leq 0, x_{\ell 0} \leq \Delta, L_\ell \leq \Delta\}$ is compact.

Assumption 9. For any $\ell \in \mathbf{\Lambda}$, r_ℓ, ν and t_ℓ are convex and ε_ℓ is concave. Moreover, they are twice continuously differentiable with $dr_\ell/d\delta < 0$, $\partial \nu_\ell / \partial \varepsilon_\ell < 0$, $d\varepsilon_\ell / d\alpha_\ell < 0$ and $dt_\ell / d\alpha_\ell < 0$.

We state the following result.

Lemma 3. *For any periurban landscape gardener $\ell \in \mathbf{\Lambda}$, necessary conditions for Pareto optimal quality of planted green area as a complex of biological attributes are:* $\forall s \in \mathbf{S}$, $s \neq \ell'$, $\forall g \in \mathbf{G}$, $g \neq \ell'$

$$\sum_{i \in \mathbf{N}} \pi_{is} A_{i\ell} \leq \frac{\partial x_{\ell 0}}{\partial q_{\ell s}} + r_\ell \frac{\partial L_\ell}{\partial q_{\ell s}} + \mu_\ell \delta \frac{\partial A_\ell}{\partial q_{\ell s}}$$

$$0 = \left(\sum_{i \in \mathbf{N}} \pi_{is} A_{i\ell} - \frac{\partial x_{\ell 0}}{\partial q_{\ell s}} - r_\ell \frac{\partial L_\ell}{\partial q_{\ell s}} - \mu_\ell \delta \frac{\partial A_\ell}{\partial q_{\ell s}} \right) q_{\ell s}$$

$$\sum_{i \in \mathbf{N}} \pi_{ig} A_{i\ell} \le \frac{\partial x_{\ell 0}}{\partial q_{\ell g}} + r_\ell \frac{\partial L_\ell}{\partial q_{\ell g}} + \mu_\ell \delta \frac{\partial A_\ell}{\partial q_{\ell g}}$$

$$0 = \left(\sum_{i \in \mathbf{N}} \pi_{ig} A_{i\ell} - \frac{\partial x_{\ell 0}}{\partial q_{\ell g}} - r_\ell \frac{\partial L_\ell}{\partial q_{\ell g}} - \mu_\ell \delta \frac{\partial A_\ell}{\partial q_{\ell g}} \right) q_{\ell g}$$

$$\sum_{i \in \mathbf{N}} \pi_{ih} A_{i\ell} \le \frac{\partial x_{\ell 0}}{\partial q_{\ell h}} + r_\ell \frac{\partial L_\ell}{\partial q_{\ell h}} + \mu_\ell \delta \frac{\partial A_\ell}{\partial q_{\ell h}}$$

$$0 = \left(\sum_{i \in \mathbf{N}} \pi_{ih} A_{i\ell} - \frac{\partial x_{\ell 0}}{\partial q_{\ell h}} - r_\ell \frac{\partial L_j}{\partial q_{\ell h}} - \mu_\ell \delta \frac{\partial A_\ell}{\partial q_{\ell h}} \right) q_{\ell h}$$

$$\frac{dt_\ell}{d\alpha_\ell} \le - \frac{\partial \nu_\ell}{\partial \varepsilon_\ell} \frac{d\varepsilon_\ell}{d\alpha_\ell}, \quad \left(\frac{dt_\ell}{d\alpha_\ell} + \frac{\partial \nu_\ell}{\partial \varepsilon_\ell} \frac{d\varepsilon_\ell}{d\alpha_\ell} \right) \alpha_\ell = 0$$

$$L_\ell \le - \frac{\mu_\ell A_\ell}{dr_\ell / d\delta}, \quad \left(L_\ell + \frac{\mu_\ell A_\ell}{dr_\ell / d\delta} \right) \delta = 0$$

$$r_\ell \le - \mu_\ell \delta \frac{\partial A_\ell}{\partial L_\ell}, \quad \left(r_\ell + \mu_\ell \delta \frac{\partial A_\ell}{\partial L_\ell} \right) L_\ell = 0.$$

Remark 8. As in **Lemmata 1** and **2**, some of the equations are reminiscent of Samuelson's Conditions, since attributes, including biological ones are public goods. Gardeners make their products and transport them, so they have to pay for transportation, $\mu_\ell \delta A_\ell$, where μ_ℓ is a unit cost of transportation. They plant trees on the lands of private houses. The equations establish a Pareto optimality for an amount of each attribute and determine a vector of optimal quality characteristics that any gardener can supply its biological product to residents. The R.H.S. of the first equation is the marginal cost composed of three terms: the first is the marginal cost of the numéraire attribute and the second is the marginal cost of land to supply one unit of plant as a biological attribute, and the third is the marginal transportation cost. The first two equations signify the marginal social value in terms of the numéraire attribute, where the marginal social value is the sum of the personal evaluations of a change in each biological characteristic. The next eight equations have the similar implications as for the producers. As in the above propostions, the last two formulae define the equilibrium rent, which is equal to gardener ℓ's MTC.

3.4 The Metropolitan Government with an Urban Heat Island Tax/Subsidy Scheme

Here I explain a heat island tax/subsidy scheme. For that purpose, define the monetary damages due to urban heat island as the sum of costs to deal with public damages: $\Phi \equiv \sum_{\beta \in \boldsymbol{\beta}} D_\beta(U(E))$ and the sum of abatement costs to cope with private damages: $\Psi \equiv \sum_{e \in \mathbf{N} \cup \mathbf{J} \cup \mathbf{\Lambda}} \nu_e(\varepsilon_e(\alpha_e), \varepsilon_{-e}(\alpha_{-e}))$, where e is a generic index for any heat emitter in the metropolis. Examples of public damages and private damages are the inundation of a subway station, houses flooded above floor level or up to the floorboards. Φ embraces economic losses in the deaths of people and domesticated animals due to heat waves.[11] Also, Ψ includes the costs of cooling installations in stockyards and of increasing water consumption due to cooling them. The social damage due to heat island therefore is $\Phi + \Psi$. Hence, our problem of social cost to be minimized is

$$Min \ \{\Phi + \Psi + \Gamma + \Omega\}$$

where $\Gamma(A_P)$ is the cost to plant the area A_P with trees, and $\Omega(W_P)$ is the cost to revive the amount of water, W_P, in our periurban metropolis.

Assumption 10. D_β, Γ, and Ω are concave and twice continuously differentiable with $dD_\beta/dU > 0, \forall \beta \in \boldsymbol{\beta}$, $d\Gamma/dA_P > 0$ and $d\Omega/dW_P > 0$.

Since I seek for socially optimal quantities of greenery, water and heat emission, the first order conditions are:

$$\sum_{\beta \in \boldsymbol{\beta}} \frac{dD_\beta(U)}{dU} \frac{dU}{dE} \frac{\partial E}{\partial A_P} + \frac{d\Gamma(A_P)}{dA_P} = 0 \tag{17}$$

$$\sum_{\beta \in \boldsymbol{\beta}} \frac{dD_\beta(U)}{dU} \frac{dU}{dE} \frac{\partial E}{\partial W_P} + \frac{d\Omega(W_P)}{dW_P} = 0 \tag{18}$$

and

$$\sum_{\beta \in \boldsymbol{\beta}} \frac{dD_\beta(U)}{dU} \frac{dU}{dE} \frac{\partial E}{\partial \varepsilon_e} + \sum_{e \in \mathbf{N} \cup \mathbf{J} \cup \mathbf{\Lambda}} \frac{\partial \nu_e(\varepsilon_e(\alpha_e), \varepsilon_{-e}(\alpha_{-e}))}{\partial \varepsilon_e} = 0. \tag{19}$$

The first term of the formula (17) signifies the marginal damage of losing one square meter of green area, and the second term is the marginal cost of greening an area with an additional one square meter of the area. Similarly, the first term of Eq.(18) is the marginal damage of losing one cube meter of water, and the second term means the marginal cost to revive one cube meter of water in the metropolis.

Here presented is the main result.

Theorem. (i) *Urban heat island tax is of the form à la Groves represented by,* $\forall e \in \mathbf{N} \cup \mathbf{J} \cup \mathbf{\Lambda}$:

$$t_e(\alpha_e) = \int_0^{\alpha_e} \frac{\partial \nu_e(\varepsilon_e(a_e), \varepsilon_{-e}(\alpha_{-e}))}{\partial \varepsilon_e} \frac{d\varepsilon_e}{da_e} da_e + Q_e(a_{-e})$$

where $Q_e(a_{-e})$ is a constant of integration independent of a_e.

(ii) *Heat island subsidies are given by*

$$S = \sum_{\ell \in \mathbf{\Lambda}} \varphi \sigma_\ell A_{i\ell} + \sum_{j \in \mathbf{J} \setminus \mathbf{J}_F} \varphi \sigma_j A_j + \sum_{j \in \mathbf{J}_F} \omega \pi_j L_j.$$

Proof: By adopting the Laffont's (1982) differential method, one observes from **Lemmata 1∼3** that

$$\sum_{e \in \mathbf{N} \cup \mathbf{J} \cup \mathbf{\Lambda}} \left\{ \frac{\partial \nu_e(\varepsilon_e(\alpha_e), \varepsilon_{-e}(\alpha_{-e}))}{\partial \varepsilon_e} \frac{d\varepsilon_e}{d\alpha_e} + \frac{dt_e(\alpha_e)}{d\alpha_e} \right\} = 0. \tag{20}$$

[11] In 2003 Europe was overcome by abnormal weather with record fierce heat and fatalities numbered at more than 13,000 in France. Paris especially experienced violent heat wave with more than 40°C. A heavy death toll was recorded because many people did not have an air-conditioning in not so hot summers in Paris.

Integrating this yields

$$\sum_{e\in\mathbf{N}\cup\mathbf{J}\cup\mathbf{\Lambda}} t_e(\alpha_e) =$$
$$-\sum_{e\in\mathbf{N}\cup\mathbf{J}\cup\mathbf{\Lambda}} \left\{ \int_0^{\alpha_e} \frac{\partial\nu_e(\varepsilon_e(a_e), \varepsilon_{-e}(\alpha_{-e}))}{\partial\varepsilon_e} \frac{d\varepsilon_e}{da_e} da_e + Q_e(a_{-e}) \right\}. \tag{21}$$

Suppose that there exists a unique solution to the above problem of social cost. As we aim to find the heat island tax corresponding to the social optimum, integrating and substituting Eq.(19) into Eq.(21) gives

$$\sum_{e\in\mathbf{N}\cup\mathbf{J}\cup\mathbf{\Lambda}} t_e(\alpha_e) = \sum_{\beta\in\boldsymbol{\beta}} \int_0^{\alpha_e} \frac{dD_\beta(U)}{dU} \frac{dU}{dE} \frac{\partial E}{\partial\varepsilon_e} \frac{d\varepsilon_e}{da_e} da_e + Q \tag{22}$$

where Q is a constant of integration.

Consequently, the sum of *urban heat island taxes* is represented by

$$\sum_{e\in\mathbf{N}\cup\mathbf{J}\cup\mathbf{\Lambda}} t_e(\alpha_e) = \sum_{\beta\in\boldsymbol{\beta}} D_\beta(U(E)) + R \tag{23}$$

where R is a constant of integration.

It can be refunded to the collaborators of tree planting plus the rewards to farmhouses as:

$$S = \sum_{\ell\in\mathbf{\Lambda}} \varphi\sigma_\ell A_{i\ell} + \sum_{j\in\mathbf{J}\setminus\mathbf{J}_F} \varphi\sigma_j A_j + \sum_{j\in\mathbf{J}_F} \omega\pi_j L_j. \tag{24}$$

Hence, subsidies are given to residents and producers as cooperation for their efforts to have trees and flowers planted in the required percentage of their land lots. The third term is the sum of rewards given to farmhouses to preserve their farmlands. S is the sum of *heat island subsidies* to cool down the metropolis. An amount of $R - S$ is used to undertake public works at the cost of $\Gamma(A_P)$ and $\Omega(W_P)$. *Q.E.D.*

Remark 9. What is important is that the R.H.S. of the formula (23) does not depend upon any unobservable parameter α_e, thus, it is immune to whatever manipulation on the part of the residents, producers and gardeners. The problem of preference revelation problem under incomplete information need not be discussed here. As for monitoring, ε_e can be partially measured by the amounts of gas and electricity used by each agent. Then, our tax/subsidy scheme is said to be strategy proof. Another important feature is that the tax levied can fully cover the social damage, and the part of the tax overpaid R can be redistributed to the contributors in order to cool the metropolis as shown above.

Allow me to enumerate some issues for further research. First of all, urban economic theoretical analysis must be made to realistically involve urban heat island and land use with an exact knowledge of this phenomenon. Secondly, a model incorporating both greening and water management in more detail will be proposed in future research. Finally, whether an optimal urban atmospheric quality can be implemented in a dynamic context will be one of the main concerns of a consequent paper. It will show that the composition of characteristics in the urban atmosphere can be intertemporally optimized by adjusting each component. Thus, we have to design a dynamic process to implement our urban hedonic optimality conditions.[12]

Now is the time when our civilization and urbanization are changing the urban climate, which cannot but entail modifications of our lifestyles. The situation that we stand in is very different from that of Pre-Industrial Revolution.[13] I have shown efficiency conditions, but have not characterized the climatical optimality. I do not at all insist that we can artificially control the urban atmospheric compound of heat and gases as intangible characteristics. What I have done is just to theoretically derive the hedonic optimality conditions in an economic sense.

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[12] Sato(2005b) proposed the hedonic MDP Procedures for adjusting quality attributes and analyzed their incentive properties. Furthermore, Sato(2000), (2001) and (2007a) presented tâtonnement and nontâtonnement processes for the adjustment of GHGs as gaseous attributes which compose the global atmosphere. See also Fujigaki and Sato(1981), (1982) and Sato(1983) for dynamic procedures for public goods.

[13] Rifkin's(2003) idea of *The Hydrogen Economy* is superb, when it comes to the issue of how to renovate thoroughgoing ways of living and lifesyles concerning our utilization of energies. However, *The Solar Economy* is more desirable to come, which is sustainable in the strict sense of the word. See Scheer(1993), (2001) and (2002).

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