Light Pollution: Economic Valuation Methods and a Market Solution

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Abstract. Light pollution has not been a significant problem until the 1980s. This paper reviews literature focused on light pollution both from economic and technological perspectives. Prior studies mainly investigated the diverse impacts of light pollution on human health, ecosystem, energy loss and night sky and reasons for light pollution. But the studies focused on economic valuation of light pollution are rare and incomplete. Meanwhile, while legislation aimed at reducing light pollution has been exerted by many countries and areas and planing the lighting system scientifically has been suggested by some scholars, a market solution has not been proposed. This paper proposes methods to quantify economic cost of light pollution and the market solutions to reduce light pollution, including giving property right to the environment and increasing electricity price. The proposed valuation methods will serve as important tools for calculating economic cost of light pollution. The market solution based on the economic cost figured out then will use economic incentives to mitigate light pollution in areas affected by it heavily.

Keywords: Light pollution · Economic valuation · Market solution · Electricity price

1 Introduction

1.1 Background

Over the last few decades, urban areas around the world has been expanded significantly. Glass buildings, through which light can easily trespass into atmosphere and be reflected, have been especially popular among metropolis. Plus street lamps are installed in every corner of city. Also, increasing number of LED screens are equipped for advertising. Despite artificial light at night extends duration of people's daily activities, it indeed has induced negative externalities. Residents' both mental and physical health are influenced; the number of sea turtles has decreased; observing stars has become a difficult thing; a large amount of energy has been wasted, after which the chain reaction happens(climate change becomes worse). However, light pollution has not been a significant problem until the 1980s and economists have not focused on it until recent years.

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1.2 Related Research

Brei et al. investigated the negative dynamic effect of light intensity on sea turtles using econometric model. They found that light pollution could reduce sea turtle nests significantly. The costs of rearing sea turtles in captivity in case studies of farms and marine conservation centers are considered as the monetary value of sea turtles, also the potential costs of light pollution. They pointed out that compensating the impact of light pollution by rearing sea turtles in captivity is costly and encouraged farther research on economic costs of reducing illumination [1]. Boslett et al. utilized econometric methods to analyze the relationship among shale boom, rural light pollution and human health, given the panel data from 2000 to 2011 in rural areas of United States. They found that with increased drilling in rural areas, the light pollution became severer and then contributed to insufficient sleep and poor health [2]. Isobe and Hamamura studied the data about light pollution from the Defense Metreological Satellite Program and figured out the total energy loss per year caused by light pollution both in developed and developing areas. They encouraged people to reduce such energy waste by decreasing useless light [3]. Gallaway reviewed literature about light pollution and emphasized the importance of value of night sky. Arguments displayed about the instrumental value of night sky beauty was the highlight [4].

Jin et al. proposed a light pollution assessment method of residential zone from a technical perspective, focusing on the light intensity and its influence on residents. They used Beijing as an example and emphasized the importance of scientifically planing the lighting system. Establishing distinguished compensation mechanisms for light pollution, based on the light contaminated area and the exceeding degree, was also suggested [5]. Papalambrou and Doulos conducted case study of first area protected from light pollution in Greece and used technical methods to measure lighting illuminance levels and sky brightness levels to prove the scientificity of selecting the Mount Parnon as an ideal place for the establishment of Greece's first dark sky park. They also pointed out that the causes of light pollution from both a cultural and a technical aspect and encouraged local government and business to participate in the night sky protection effort [6]. Jägerbrand and Bouroussis mentioned that not all places should be protected from light pollution with regard to biodiversity. Environments that are listed on the Red List and sensitive to light should be given priority, given examples of legislation that covers ecological light pollution. Current technical methods to measure light pollution were also reviewed [7].

Ngarambe et al. discerned that the correlation between light pollution and economic status is of no statistical significance using descriptive statistics analysis and applying the Environmental Kuznets Curve(EKC) hypothesis to local light pollution. They suggested that local light pollution policies should be equally stringent in all areas regardless of economic status [8]. Gallaway et al. used fractional logit models to quantify the economic causes of light pollution globally. They found that besides population, real per capital GDP, foreign investment and land use patterns were important explanations for light pollution as well. They also pointed out that the relationship between income and light pollution was non-linear as might be expected from an EKC [9]. Lyytimäki et al. reviewed literature focusing on types of unawareness about light pollution, impacts of light pollution on the environment and measures reducing light pollution. They pointed out that one of reasons why people neglected light pollution was that there was a lack of

information to value its importance and traffic lighting was an ignored problem. They finally suggested designing land use strategies aimed at reducing light pollution, which could also benefit monetary savings, preservation of biodiversity and ecosystem services and mitigation of climate change [10].

1.3 Objective

This study will focus on economic valuation methods of light pollution and suggest a completely new market solution to reduce light pollution (give property right to the environment and increase electricity price based on the monetary cost of light pollution). The structure of the paper is as follows. Firstly, the basic knowledge of light pollution including its types and impacts on the environment is identified by reviewing previous literature. Next section proposes economic valuation methods of light pollution. Revealed preference methods and stated preference methods are employed to calculate total cost of light pollution. Afterward, details about increasing electricity price based on the monetary cost are elaborated. The conclusion section reviews this current paper and points out the difference of this paper from other studies.

2 Knowledge of Light Pollution

Light pollution is defined as "the inappropriate or excessive use of artificial light", including skyglow, light trespass, glare and clutter. It can do harm to biodiversity, people's physical and mental health, astronomical research and the mitigation of climate change. One of reasons for light pollution is the increase of real per capital GDP [9]. With the progress of urbanization and industrialization, advances in lighting with low electricity price have made people's demand for lighting for other reasons other than basic illumination needs increase [6]. The another reason is the lighting malpractices [6]. If the lighting system is well designed and technical requirements are enforced earlier, light pollution may be not as severe as now.

2.1 Types of Light Pollution

There are four components of light pollution, skyglow, light trespass, glare and clutter respectively. Skyglow is the light that is reflected by atmospheric matter and increases the brightness of night sky over inhabited areas. Light trespass is the light that reaches unintended areas. Excessive brightness that causes visual discomfort is glare. Poor and excessive groupings of light sources are clutter [8]. All these forms of light pollution can affect biodiversity, human health, astronomical research and the mitigation of climate change.

2.2 Impacts on the Environment

Light pollution has negative externalities in various aspects. Firstly, residents nowadays suffer from insomnia at least and are diagnosed with cancer at most due to light pollution. Since light pollution disorders circadian rhythm, connected with people's sleep, and

reduces melatonin secretion at night, a crucial substance to immune system, people will have a poor quality of sleep and are prone to cancer [5]. Thus, cognition and labor market productivity will be reduced and mortality risks associated with dementia, heart attack and car accidents will be elevated. Financial and non-financial costs of insufficient sleep from 2016 to 2017 is estimated to be $680 billion in five OECD countries [2]. Besides, light pollution influences the plants as well. Although plants rely heavily on light to grow, strong light pollution at light can also disrupt their growth, flowering and wintering patterns [10]. In addition, light pollution will decrease biodiversity. For instance, coastal nighttime light reduces sea turtle population significantly proved by a case study in Caribbean [1]. According to this case study, approximately 18,000 sea turtles have been lost, worth up to $288 million, because of the increase in lighting over the last two decades, which not only reduces sea turtle nests, but also draws baby turtles away from ocean to downtown, as they utilize the light of moon reflected by the surface of ocean to navigate, but now they are confused by artificial light at night. As a result, sea turtle has already been an endangered species. Birds' migration and mosquitoes are also influenced by light pollution [5]. Meanwhile, light pollution begets the damage of aesthetic value. Since artificial light at night obscures havens, this will result in the loss of night sky filled with supernovas, which indeed has recreational and inspirational value [4]. Moreover, excessive light induces energy loss. With regard to the value of energy loss, an estimated money lost due to improper usage of light in Japan is about 20 billion yen per year [2]. Apart from monetary loss, the amount of electricity wasted can exacerbate the climate change [6]. This is mainly because most electricity around world is still produced by fossil fuels, releasing CO_2 while being burned.

3 Valuation

As light pollution induces negative impacts to the environment, it is important to take action to mitigate this problem. Actually, many governments throughout the world, especially those of developed countries, have already enacted legislation aimed at reducing light pollution, as national laws or local ordinances. Sweden [7], France, Japan, some American states and so on [8] have all stipulated the prevention of light pollution. Also, retrofitting or upgrading lighting system is proposed [6]. However, there is no market solution(give property right to the environment and increase the electricity price in protected area) proposed to light pollution currently. The crucial step to apply market solution to light pollution is to place a monetary value on the damage brought by light pollution first. Then, increase the electricity price according to the monetary value. Revealed preference methods and stated preference methods are applied to figure out the economic values of damages caused by other kinds of pollution [2]. These two valuation methods could be used to calculate the cost of light pollution as well. Different valuation techniques should be utilized to different impacts.

3.1 Revealed Preference

Revealed preference method is to use information revealed in real market transactions to calculate the damage cost, including market price, simulated markets, travel cost method,

Hedonic wage approaches, Hedonic property approaches and averting expenditures. The economic cost of light pollution on residents, nighttime sky and energy loss could be quantified through revealed preference.

Foremost, it has to be underlined that the correlation between light pollution and economic condition does not appear to be the EKC as other kinds of pollution, such as air pollution, do [8, 9]. Does this mean that people could not care less about light pollution even though their income has increased or actually they are not influenced by light pollution? Absolutely not. Patel investigated the correlation between light pollution and insufficient sleep, using 282,403 samples from 2,823 US counties both in 2013 and 2016. He finally found that the influence of light pollution on the sleep quality was so small that could be negligible. However, he pointed out that this result should be interpreted with caution as some factors, e.g. the use of shades, which might cause individuals exposed to various levels of light pollution, and mental health were not taken into consideration [11]. Therefore, when calculating the cost of light pollution, economists had better consider the impact of light pollution on human health. One way to figure out the cost on human health is to use averting expenditures. To be specific, people may install much more expensive curtains at home or buy eye patches against light pollution, so the market price times quantity of shades and eye patches consumed could be used as the cost of light pollution. Another way is to use the expenditure of people spent on curing insomnia and cancer caused by light pollution plus productivity losses(days off to recover times average earnings per day)[12].

As for the economic cost of damaged night sky, travel cost method can be utilized. Night sky has great recreational value [4]. Individual amateur astronomers usually visit places where light pollution is not so severe that they could observe stars with telescopes. Yet now people in some cities have to go father to find light pollution-free places, which means that more transport cost and time will be spent, and some just quit this hobby as light pollution from cities obscures the night sky above and around the city or even miles away. Therefore, the transport cost of people going to father places minus that before and then add opportunity cost(more time spent times average hourly wage) can be considered as the value of night sky. Or use the reduction of consumer surplus. In more details, people used to visit one park around the city to appreciate stars and there was a demand curve. But now, the number of visitors is decreasing since it is difficult to observe stars there, meaning the trip demand cure will shift to the left. So the reduction of consumer surplus (decreased willingness to pay) can be used as the economic cost of light pollution on night sky.

To calculate the economic cost of energy loss caused by light pollution, the amount of energy wasted should be figure out first and then times electric energy cost per kw/h [3].

3.2 Stated Preference

Stated preference method is to use survey techniques to revel people's willingness to pay for a marginal improvement, including contingent valuation and choice experiments. Contingent valuation is simply to ask respondents how much money they would spend to protect one species from extinction or would they pay certain amount of money to preserve species. While choice experiments are indirect. It is to design alternatives

first and then ask participants to rank or rate alternatives. Stated preference method is commonly used when the value of something is not directly observable. Jin et al. have used contingent valuation to value marine turtle conservation in five Asian cities [13]. Thus, it can work with calculating value of biodiversity reduction caused by light pollution, too. First, species affected by light pollution should be listed. Next step is to design surveys aimed at different species. Then, ask people. Finally, provided with surveys, people's willingness to pay can be figured out, which is then considered as the cost of biodiversity reduction. Given that this method could be costly, benefit transfer methods can be used. For instance, the value of marine turtle conservation figured out by Jin et al. can be applied to the cost of the decrease of turtles caused by light pollution.

These categories of monetary value mentioned above can be combined to produce total cost (TC) of light pollution:

$$\begin{aligned} \text{TC} = {} & \text{Cost on Human Health} + \text{Cost of Damaged Night Sky} \\ & + \text{Cost of Energy Loss} + \text{Cost of Biodiversity Reduction} \end{aligned} \tag{1}$$

4 Solution

The method to calculate the monetary cost of light pollution has been articulated. Next step is to increase electricity price with regard to the economic cost. The keys to this solution are that whether all cities should increase electricity price and if price is increased, should all the cities charge the same. Cost-benefit analysis should be employed firstly. International Dark-Sky Association lists places protected from light pollution based on their importance for the ecosystems, astronomy and activities and there are just more than 100 certified places globally [6]. Obviously, cities where sea turtles nest and migrate from the beach to the sea or birds will pass when migrating and that are of great importance for astronomical observation should be given priorities. Also, the increased price should vary with different income levels in different areas as elasticity will differ among residents with different economic status. In a word, whether a city should increase electricity price to reduce light pollution depends on its importance for ecosystems and astronomical observation and whether residents have been affected heavily. Meanwhile, the setting of electricity price should be based on specific economic status instead of the same in various cities.

Whether all citizens in the same city should pay for the cost of light pollution is also a big issue. People living or working in the glass buildings produce more light pollution than those in traditional constructions since trespassing glass, which will also reflect light into sky, is much easier. Also, light pollution from buildings with large windows is severer than that from skyscrapers with small windows. Hence, not every person in the urban areas should take the same financial burden, meaning that people in different kinds of buildings are supposed to face various levels of electricity price.

5 Conclusion

This paper summarizes the impacts of light pollution by reviewing prior studies. Poor sleeping quality, damaged night sky, loss of biodiversity and energy waste are negative

influences of light pollution. More importantly, this study proposes approaches to valuing the negative impacts of light pollution. In particular, influences on human health, night sky and energy loss can be valued by revealed preference methods, while stated preference methods can be applied to value the loss of biodiversity. Since utilizing stated preference methods could be costly sometimes, benefit transfer can be employed under such circumstance. In addition, increasing electricity price is suggested to reduce light pollution by this paper. Given the differences, such as the importance for the ecosystems, astronomical observation and activities, economic status, etc. and so on, between different areas, not all the city should push up electricity price against light pollution and the range of increased price should vary among cities with diverse income levels. Additionally, citizens in the same city living in different kinds of constructions should face different increased electricity price.

The prior studies are mainly focused on one particular field of light pollution. This paper, however, summarizes the impacts of light pollution and proposes methods, covering the existed aspects including human health, night sky, biodiversity and energy loss, to value its monetary cost, instead of being constrained in one specific area. Also, the new approaches of giving property right to the environment and increasing electricity price are suggested.

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