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Determining the 'optimal' level of pollution ($PM_{2.5}$) generated by industrial and residential sources

Cristian Mardones*

Industrial Engineering Department, University of Concepción, Chile

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ABSTRACT

This study provides an optimization model that explicitly determines the 'optimal' level of pollution of fine particulate matter ($PM_{2.5}$) by analyzing various options for reducing emissions from industrial and residential sources in the second largest urban area in Chile. Several conclusions that had not been previously addressed or sufficiently highlighted in the literature were discerned. The most notable conclusions included the importance of regulating all emission sources and not just industrial sources (which are typically fewer in number and easier to monitor), the homogeneity in 'optimal' levels of pollution from urban districts when considering the long-term effects on human health (which would support the adoption of uniform regulations), and the asymmetry in confidence intervals associated to the 'optimal' level of pollution.

1. Introduction

According to the laws of thermodynamics, pollution occurs because it is practically impossible to have a productive process that does not involve waste. However, from the economic point of view, pollution occurs because producing cleaner is normally more expensive (Helfand et al., 2003).

When economic agents emit pollutants that harm other agents, they don't consider all the costs caused by their behavior. However, from an economic perspective, if the pollution unit emitter pays exactly the value of the damage caused, the socially 'optimal' level of pollution can be reached (Kolstad, 2000).[1] Thus, the determination of environmental benefits and damages in monetary terms allows direct comparison to identify the 'optimal' level of pollution (Mishan, 1974). However, this theoretical solution is very difficult to achieve due to the difficulty of measuring the damage generated by each source according to its spatial location (Gray and Shadbegian, 2004; Cropper & Oates, 1992), the difficulties to monitor and enforce the environmental policies (Chávez et al., 2009), the uncertainty associated with the estimation of costs and benefits (Weitzman, 1974), the existence of previous distortions in the markets (Nie, 2012) and also, the political, distributive and financial costs required to implement environmental regulations.[2] Consequently, the environmental regulations of the countries do not seek to reach the 'optimal' level of pollution, but it is common to set environmental quality standards that allow certain health goals to be achieved, but in this case there could still have negative effects on the population, other species or ecosystems.

From an empirical point of view, estimating the costs of controlling pollution is very difficult since this not only involve the installation of abatement technology as filters, but also involve other options such as modifying the production process, reallocating productive activity to reduce emissions, substituting fuels, changing the characteristics of products and investing in R&D to control pollution, among others. On the other hand, the estimation of environmental damage from pollution includes premature deaths, diseases, days of restricted activity, loss of visibility, loss of productivity, damage to agricultural and forestry crops, damage to ecosystems, among others. In addition, the monetary quantification of the damages associated with pollution is a very controversial issue due to technical, political and ethical issues (Helfand et al., 2003). Furthermore, the effect of environmental pollution on health depends on the exposure of individuals to the pollutant. This is determined by previous health conditions, and also, by daily choices such as walking, exercising in days of high pollution, undertaking defensive activities such as buying filters or living in less polluted places

* Corresponding author.
E-mail address: crismardones@udec.cl.

[1] Environmental economics studies the possible ways to achieve the socially optimal level of pollution, or at least to reduce the social costs associated with its externalities.

[2] Another complication stated in the theoretical literature is the existence of non-convexities, which refers to sufficiently serious environmental damage that could cause the population to die, or move to another place, firms close or the ecosystem disappear. In this case the marginal damage of the pollution can change from a high positive value to zero, which would generate multiple local optimum and corner solutions.

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(McKitrick and Collinge, 2002). All this leads to the damages estimates and benefits generated by pollution are only approximations of the true impacts.

Therefore, it is not surprising that at the international level, most empirical studies conduct cost-benefit analyses of regulations to assess environmental policies without determining the 'optimal' level of pollution (Gao et al., 2016; Logar et al., 2014; Tse et al., 2004). Other studies only evaluate the costs of regulations (Zhang et al., 2016; Mardones and Saavedra, 2016; Mardones and Sanhueza, 2015; Amann et al., 2011; O'Ryan and Sánchez, 2008) or the health benefits associated with changes in environmental quality (Du and Li, 2015; Ara and Tekeşin, 2016; Zhao et al., 2015; Mardones and Jiménez, 2015). However, there are some recent studies which have a more integrated analysis. Xie et al. (2016) evaluate the $PM_{2.5}$ pollution-related health impacts on the national and provincial economy of China using a computable general equilibrium model and dose-response functions. Wu et al. (2017) examine the health and economic impacts from $PM_{2.5}$ pollution under various regulatory scenarios in Shanghai using an integrated model combining a greenhouse gas and air pollution, dose-response functions, and a computable general equilibrium model.

Oates et al. (1989) is among the few studies that attempted to determine an 'optimal' level of pollution. They estimated the marginal costs and benefits associated with the regulation of total suspended particles in Baltimore, Maryland, USA, to compare the results of different concentration levels under economic instruments and instruments of command and control (standard emissions). O'Ryan and Sánchez (2008) developed an optimization model for Santiago, Chile, that compares the net benefits of three instruments of environmental policy, with a goal of achieving a certain standard concentration of respirable particulate matter (PM_{10}). Both studies estimate the net benefits associated with ranges of different levels of pollution from industrial sources, but they do not explicitly determine 'optimal' levels of pollution.

To contribute to this line of research, this study estimates the 'optimal' concentration level of fine particulate matter ($PM_{2.5}$) and compares the results to the existing Chilean regulations.[3] Finally, the factors that may affect the 'optimal' level of pollution are discussed. In addition, unlike the aforementioned studies that only consider the costs of reducing pollution from industrial sources, this study includes abatement costs associated with industrial and residential sources (the main emitters in the study area). Specifically, the empirical strategy applied in this paper assumes that firms will continue producing the same level of production and that their best alternative is to install abatement technologies, which is a limitation for estimating the 'optimal' level of pollution, but it is a usual assumption in the empirical literature that analyzes cost-effective alternatives to reach pollution goals (see Mardones and Saavedra, 2016; O'Ryan, 1996). It should be noted that traffic emissions are not included in the modeling because their contribution to total emissions is very low (3.8%) and due to the complexity of the data required for their modeling.[4] Despite this limitation, the study results should not be affected since most of the options for regulating transportation have high cost-effectiveness indicators compared to the regulation of industrial and residential sources, so clearly these latter sources should be prioritized to reduce pollution. Also, it is assumed that the only damages generated by pollution are the health effects that have been estimated by epidemiological studies in the area under study, so no visual damage, loss of productivity or ecosystem damage are incorporated. Besides, this limitation neither should it alter the results too much considering that this type of damage commonly represents a tiny fraction of the environmental damage related to those generated by the premature mortality of the particulate material in Chile (MMA, 2017).

It should be noted that several studies have identified effects on the health of people exposed extendedly to high concentrations of particulate matter such as an increase in premature mortality (Huang et al., 2018; Mannucci et al., 2015; Pope et al., 2009), frequency of lung cancer (Lepeule et al., 2018; Shahadin et al., 2018) and respiratory and cardiovascular diseases (Kim et al., 2017; Maji et al., 2017). In addition, some of these studies establish that the concentrations considered acceptable to the majority of the population are not suitable for the elderly, pregnant women, infants and people with previous illnesses since they are especially susceptible to the harmful effects of air pollution (Khaniabadi et al., 2018). However, in this study only the effects on health detected by epidemiological studies in the Concepción Metropolitan Area are considered; such as premature mortality, hospitalization for respiratory diseases for children under 15 years of age and asthma for people over 65 years of age (see Mardones and Sanhueza, 2015).

The case study corresponds to the second largest urban area in Chile, known as the Concepción Metropolitan Area. The area comprises nine urban districts (See Fig. 1). In 2015, this area was inundated by high concentration levels of $PM_{2.5}$. This pollution was mainly associated with emissions from industrial combustion processes and biomass burning for residential heating (Center Mario Molina, 2008).

2. Description of the baseline scenario

2.1. Residential and industrial emissions

In 2014, an inventory of emissions from industrial sources in the Concepción Metropolitan Area (EULA, 2014) was performed. The database reports the locations (See Fig. 2), fuel types and annual emissions of 200 industrial sources that emit a total of 2121 tons of $PM_{2.5}$ per year.

Firewood is the major fuel for household heating in south-central Chile and combustion of firewood is the major source of air pollution emissions (Schueftan et al., 2016). To estimate residential emissions of $PM_{2.5}$ in each district, the most current information available regarding household firewood consumption was used. This information was collected by the National Socioeconomic Survey (CASEN, 2013). The database includes a sample of 2200 residential sources that are representative of 165,551 households in the study area. $PM_{2.5}$ emissions (tons/year) are estimated by multiplying the declared firewood consumption (kg/year), the number of households (with an expansion factor of the survey), the emission factors associated with heating equipment (grams of $PM_{2.5}$/kg wood) and the humidity of the firewood. The result is then divided by a million to convert from grams to tons.

The types of wood heaters used by households were not reported in the CASEN (2013) survey. For this reason, the types of heaters were randomly assigned based on the percentage distribution that exists in the Concepción Metropolitan Area according to IIT-UDEC (2012).[5] The information regarding the emission factors based on equipment type ($PM_{2.5}$ g/kg wood) and the moisture in wood was also reported in the

[3] In Chile, the air quality standard for $PM_{2.5}$ is considered exceeded when the annual concentration calculated based on three consecutive calendar years is greater than or equal to 20 $\mu g / m^3$. However, the standard of the World Health Organization for the average annual concentration of this pollutant is more restrictive (10 $\mu g / m^3$).

[4] If the thousands of mobile sources associated with vehicular traffic were included, it would be necessary to model the options that their owners have for reducing pollution: for example, sharing the vehicle, changing driving habits, using public transport, buying more efficient vehicles, among many others. Even if all this information were completely detailed at the individual level, then it would be necessary to carry out simulations with models of multimodal transport networks that would allow determining the final emissions.

[5] Heater types include cast iron wood stoves (23.5%), fireplaces (8.9%), single chamber wood stoves (35.7%), slow combustion wood stoves (6.8%), wood cooking stoves (19.3%) and braziers (0.7%). The rest of the households have more than one heater.