A case of environmental policy: Taxes vs Norms. A theoretical approach

Alejandro Rondero García ***Advisor: Carlos Guillermo Contreras Pissón*** ***ID: 140557***

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Abstract

The main idea of this document is to contrast the consequences of implementing an environmental tax and a norm as the instrument for an environmental policy; using as example the *Metropolitan Area of Valley of Mexico. The conclusion is that a tax brings out better results due to the imperfect information and the heterogeneity of the polluters. Also, a tax motivates to invest in R&D with the purpose of reducing the emissions and their impact over the society.*

Keywords: Environmental Policies, Cost-Benefits Analysis, Total Economic Value, Pigouvian Taxes, Environmental Taxes

JEL Classification**:** Environmental Economics, Government Policy, Pollution Control Adoption and Costs, Valuation of Environmental Effects.

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1. Introduction

The present document has the purpose to raise awareness about the importance of the environmental policies and show how high levels of pollution affect the Mexican society. This kind of research has not been widely explored in Mexico; as a consequence, neither the development of environmental policies has not been fully explored, nor it has not been promoted the measurement of the benefits and costs associated with the implementation environmental policies. In Mexico, the main agency to dictate the environmental policies is *Secretaría de Medio Ambiente y Recursos Naturales* (SEMARNAT), in which almost all of its actions to control the pollution is through direct regulatory instruments, that is, laws or norms[1].

Nevertheless, these policies have not been enough to improve the environmental quality; for example, according to the information from the World Bank, during the year of 1960, in Mexico, the CO_2 emissions was of 1.7 metric tons per capita, but in 2013, the number increased more than double, with a value of 3.9. In the same sense, the Clean Air Institution (2012) expresses that Mexico occupies the second place in Latin America with more deaths due to the air pollution, with 15,000 deaths per year; consequently, pollution causes high costs in terms of human life, so people, in general, should notice about the previous situation and take actions to reverse it.

Faced with this panorama, the use of others instruments such as incentive-based instruments, mainly the use Pigouvian taxes (or simply called tax), in which internalize the environmental costs associated with negative externalities, are popular in the European Union and Japan; they could bring different results in the Mexican context. Therefore, this research represents an opportunity to contribute to the literature with the objective to develop a theoretical model that emphasizes the use of taxes in the environmental policy of Mexico.

In the same sense, this research can be serving as guidance for the policy-makers or institutions in Mexico who are interested in the creation of efficient strategies or policies with the purpose of improving the environmental quality and the control of pollutant emissions. In addition, this could be also relevant, of course, for the economists because it shows how the economic instruments can be applied in different research areas and for the realization of future working papers of the same issues. Ultimately, this work provides information for the environmentalists, who have made several critiques against the neoclassical economy; thus, it is proposed a possible solution for the negative externalities that provoke the degradation of the natural resources.

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[1] For more information: Secretaría de Medio Ambiente y Recursos Naturales. (n.d.). *Leyes y Normas del Sector Medio Ambiente*. Retrieved March 27, 2017, from SEMARNAT: http://www.gob.mx/semarnat/archivo/acciones_y_programas

The general objective is to develop a theoretical model to contrast the environmental policies, taxes and norms, and then present a real case. With the above purpose, the specific objectives are:

1. Analyze the consequences of both environmental policies with the assumption of perfect information.
2. Analyze the consequences of both environmental policies without the assumption of perfect information and with many polluters.
3. Expose the case of the Valley of Mexico Metropolitan Area (VMMA) and its problem of atmospheric pollution; considering the implementation of a tax. This example is merely illustrative, and it helps to exemplify how a tax could be established.

The research questions are: Which environmental policy mechanism is best, the instruments of direct regulation or instruments based on incentives? What are the advantages and disadvantages of using a tax in the environmental policy? How do the polluters react when facing an environmental policy?

The main hypothesis of this work is that taxes represent a better instrument than normative regulations due to the following reasons:

1. A tax is less likely to suffer from the enforcement costs.
2. Polluters always achieve an efficient result, associated with a minimization of their costs.
3. Polluters are more motivated to invest in R&D and reduce their emissions and costs.

The methodology used in this work is based on a model that determines two functions. The first one, the Marginal Social Damage function, which it indicates the social damage associated with the increase of a unit of pollution. The second one, the Marginal Abatement Cost function, and it expresses the cost of reducing a unit of pollution. With both functions, it is possible to analyze the impact of environmental regulations.

The first results show that under the assumption of perfect information, there is equivalence between a tax and norm; therefore, there is no superiority of one against the other. However, the norms are susceptible to enforcement costs; this fact disturbs the optimal emission level. Additionally, the effectiveness is further diminished when the norm faces heterogeneous sources, i.e., with different Marginal Social Damage and Marginal Abatement Cost functions. On the other hand, a tax works well in a context of heterogeneous polluters and polluters are more motivated to invest in R&D with the purpose of decreasing their emissions and costs.

The document continues with the following order: 2) The theoretical framework focuses on to explain the different tools for an environmental policy, highlighting the taxes, as well as how to measure the benefits and costs of the environmental policy. 3) It will be presented the model of this research and it will be exposed in different scenarios. 4) It will be introduced a general panorama of the atmospheric pollution in the VMMA. 5) The case of VMMA assessed by a Pigouvian tax. 6) Finally, the document will end with the conclusions.

2. Theoretical Framework

In the first instance, according to He, Zhou and Zhu (2017), the government politics still support the economic growth rather than resolve environmental issues; as a consequence, people face problems such as damage to the environment, additional costs for medical services, early death, loss income, abnormal climates and depletion of the natural resources (Barghouthi and Marie, 2016). Before such situation, the costs due to the environmental damage may be prevented if it is possible to develop the correct environmental policies; hence, it will be explored the effects of the environmental policies.

Due to the lack of the environmental policies, Aidt (1998) and Cheng, Mu and Zhang (2017) express that economic agents claim for better environmental quality; therefore, they offer support to the implementation of this kind of policies. In that scenario, the lobby groups play an important role in the environmental policies due to the impact of pollution on the welfare of those groups; hence, the interests of lobby groups can be a reason of why the firms internalize the externalities. In that sense, the government agrees to the lobby groups demands because they have the possibility to offer support for electoral campaigns in exchange for the fulfillment of the government promises. Also, it is possible the existence of the opposite case, in which the authorities fail to establish efficient environmental policies due to the influence of powerful interest groups and their interest (Goulder and Parry, 2008).

Additionally, Aidt (1998) finds that since lobby groups care about others objectives, such as the distribution of income; as a result, the successful to achieve environmental goals is reduced. In the same sense, Kallbekken, Kroll and Cherry (2011) express an evident contradiction among the agents of society, in which people wish the improvement of the environmental quality and support the implementation of environmental policies, but people do not support the mechanism to achieve environmental goals, especially when the tool is a tax.

2.1. Environmental tools: Direct regulatory instruments

Now, it is important to express that the environmental policies have at their disposal a variety of tools; the instruments are divided into two big branches. In the first branch of environmental policies are cataloged *direct regulatory instruments* that cover technology mandates and performance standards. The technology mandates refer to the obligation by the firms to install a specific equipment or method of production. On the other hand, performance standards or norms stipulate that the output of each firm possesses certain features that guarantee the quality of the product. Hence, these instruments have as general objective to establish a maximum level of pollution.

2.2. Environmental tools: Incentive-based instruments

The second of environmental policies are named *incentive-based instruments* and it includes "all the instruments that act through the market mechanism" (Kosonen and

Nicodème, 2009) such as tradable emissions allowances, taxes and subsidies, such as encourage the use of less-harmful inputs and increase the initiative the research of clean technologies (Goulder and Parry, 2008).

One of the actions that have gained greater popularity in the last years is the tradable emissions allowances or also called "cap-and-trade system", with this instrument, firms have to justify their amount of emissions with submitting allowances (Cheng, Mu and Zhang, 2017; Goulder and Parry, 2008). When the allowances are distributed among the firms (by auction or free allocation), they are able to buy or sell them. Therefore, an additional unit of pollutant represents a cost equal to the value of the allowance: on the other, the sale of one allowance represents forgoes revenue.

Subsidies try to encourage the producers and consumers the use of inputs and products with none or less negative consequences to the environment. The subsidies have the function of decreasing the prices or the cost of production. The subsidy is divided into three types: 1) Direct subsidies. 2) Incentives are given in a direct taxation (personal income or corporate taxation) in the form of tax credits or allowances. 3) Differentiation of the tax rates in indirect taxation (Kosonen and Nicodème, 2009).

Ultimately, an environmental tax operates as a pricing instrument, also called Pigouvian tax[2], it means that price contemplates the negative environmental effects of the production or consumption; as a consequence, it increases the price and influences on the consumer behavior. (Goulder and Parry, 2008; Kosonen and Nicodème, 2009).

Additionally, in some cases, the implementation of taxes on emissions becomes an almost impossible task to realize by the authorities. The reason, it is difficult to monitor the emissions of each polluter directly; as a result, there is the option of adjust taxes on inputs or goods associated with emissions or when a tax is levied on a 'proxy' for emissions (Goulder and Parry, 2008; Heine, Norregaard, and Parry, 2012; Metcalf, 2003). For example, Mendelsohn and Sipes (2001) studied the effectiveness of a gasoline tax, in Los Angeles and Connecticut, due to the difficult to control the emissions of mobiles sources and the fail of others environmental policies such as fuel efficiency targets, subsidies to the public transit and support for carpooling. However, this option could not be effective because these taxes do not focus on the specific externality; as a consequence, the reduction of emissions and as well as the gained welfare are smaller in comparison to the emission tax.

[2] A Pigouvian tax, established by Arthur Pigou in 1920, corrects the problems associated with negative externalities, in that way, the marginal private cost internalizes the damage marginal of the society; therefore, it ensures the social optimal level.

2.3. Superiority of the environmental taxes against others instruments

Until now, there is no agreement among experts in this field that establishes one instrument totally above the others. Additionally, there are dudes about which mechanism is better to enforce the environmental goals, and in a broader sense, with social objectives (Aidt, 1998); nevertheless, some attempts have been made. For example, Goulder and Parry (2008) establish four criteria that should be taken into account in the selection of the best environmental tool: economic efficiency, distribution of benefits and/or costs, ability to address uncertainties and political feasibility. On the other hand, Field (1994) proposed similar criteria for evaluating environmental policies: economic efficiency, fairness or equity (equal to the distribution of benefits and/costs), the incentives that policies offer to the society to seek for a better solution, enforceability and moral considerations, this last means "the innate feelings that people have about what is right and wrong undoubtedly affect the way they look at different environmental policies" (Field, 1994).

Some authors (Goulder and Parry, 2008; Uchiyama and Kohsaka, 2016) establish the Pigouvian tax as the best option to achieve the efficiency of the resources; as a result, during the last years, the environmental policies have changed their instruments, mainly the shift of normative regulations to incentive-based policies such as Pigovian taxes, subsidies and tradable carbon allowances (Kallbekken, Kroll and Cherry, 2011). For example, the European Union has encouraged the use of fiscal instrumentals, especially the implementation of taxes because they allow the efficiency in ecological and economic terms (Kosonen and Nicodème, 2009; Mendes and Oliveira, 2017; Metcalf, 2003). Also, according to Uchiyama and Kohsaka (2016), the forest environmental tax is a useful instrument for the sustainable management of the prefectures in Japan.

However, this economic efficiency is not always achieved. For example, at first place, the *tax-interaction effect* refers a loss of the social welfare due to the increase of the consumer price, accompanied by a reduction of real income and wages, and a decrease of the labor supply; therefore, the instrument would be more expensive (Goulder and Parry, 2008; Kosonen and Nicodème, 2009).

Additionally, Kallbekken, Kroll and Cherry (2011) mention that Pigouvian taxes are often regressive to the people with low-income level. The reason is that taxes are applied to goods with high levels of consumption or of basic necessity, such as energy or transport (Kosonen and Nicodème, 2009). Mendelsohn and Sipes (2001) found that higher income groups are less responsive to an increase in gasoline price, due to a tax, than lower income groups.

Moreover, people do not appreciate the difference between a Pigouvian tax, its objective is to reduce the activities that generate negative externalities to the environment, and a Ramsey tax, in which the goal is to increase the number of resources for the government; hence, the lack of support for the Pigouvian taxes is explained by the ignorance from the people who are not conscious about the environmental benefits derived by this kind of taxes (Kallbekken, Kroll and Cherry, 2011); therefore, polluters prefer a norm such as environmental instrument than a tax (Field, 1994).

As a consequence of the previous situation, there is a high level of tax aversion among people (Iskandar, Bhaduri and Wünscher, 2016; Kallbekken, Kroll and Cherry, 2011); therefore, the probability of tax evasion is high too. So, in terms of environmental taxes, these are related with the number of emissions; as a consequence, the tax evasion is presented when there is an underreporting the real number of emissions with the purpose of reducing the amount of payment (Iskandar, Bhaduri and Wünscher, 2016). Added to this, if the imperfect monitoring generates uncertainty about the emissions reports and the poor ability to evaluate them.

Also, it is important to consider structural inefficiencies related to the political and institutional environment; being the corruption the main problem, since it encourages and eases the tax evasion (Iskandar, Bhaduri and Wünscher, 2016). Hence, bribery has a direct impact on the compliance behavior because the firms offer a payment with the purpose of evading the consequences or the legal framework of the environmental policies. However, the tax compliance increases when the penalty fee is higher and/or the auditory has a big presence, but the tax evasion increase when the tax increases too (Iskandar, Bhaduri and Wünscher, 2016).

In spite of the negative effects to the economy obtained by the tax, it is important to compensate the loss efficiency using the emission tax revenues, in that way, the net benefits are higher (Goulder and Parry, 2008; Heine, Norregaard, and Parry, 2012; Kallbekken, Kroll and Cherry (2011; Kosonen and Nicodème, 2009; Metcalf, 2003; William, 2003). This case is named *revenue-recycling effect*, so the environmental tax revenues are used to reduce the distortions by themselves or by pre-existence taxes, such as compensate the poor people who are the most affected by this kind of policy, impulse the financing of innovation programs, improve the management of natural resources or invest in R&D with the purpose of reducing the pollutant emissions (Field, 1994; Kosonen and Nicodème, 2009). For example, Uchiyama and Kohsaka (2016) express that in Japan, the environmental tax revenue is destined to the forestry management.

Therefore, from this perspective is to go beyond of the Pigouvian sense, there is no discussion about what to do with the revenue obtained, so there is no revenue-recycling effect (Heine, Norregaard, and Parry, 2012). However, it is important to create awareness about how tax revenues are used, otherwise, the public support in favor of the taxes is reduced because people think that the revenue tax is wasted or used in a wrong way (Kallbekken, Kroll and Cherry, 2011).

On the other hand, people and policy-makers are skeptics about the effectiveness of only use a single environment policy, due to the lack of support from the public sector (in the case of taxes), market imperfections, the lack and the cost of the information and the asymmetric emissions of the polluters; therefore, it is necessary a combination of different environmental policies with the purpose of achieving efficiently the objectives (Cheng, Mu and Zhang, 2017; Kallbekken, Kroll and Cherry, 2011; Kosonen and Nicodème, 2009). Moreover, the successful of incentive-based policies will be affected by the interactions of "pre-existing distortions" (Goulder and Parry, 2008; Heine, Norregaard, and Parry, 2012; Metcalf, 2003; William, 2003); hence, the existence of previous environmental policies can affect the functioning of the Pigovian taxes.

2.4. Cost-Benefit Analysis (CBA)

As it was established in the previous paragraphs, the taxes bring with them a list of consequences, as positive as negative effects, in their attempt to achieve a better environmental quality; hence, it is vital to know the net benefits (i.e., the total benefits minus the total cost) that will generate the implementation of any environmental policy.

For that reason, the Cost-Benefit Analysis (CBA) allows the accumulation of costs and benefits of a project or policy over the time with the purpose of observing a possible welfare improvement, when the benefits exceed the costs (Birol, Karousakis and Koundouri; 2006). In that way, it is possible to contrast the economic benefits that generated the natural resources with the costs of maintaining and preserving them.

Additionally, this kind of information is useful for the policy-makers and institutions with the purpose of designing how much of the available budget is destined to the protection or improvement of the ecosystem, that is to say, take better decisions; and therefore, being conscious of the potential benefits from those actions (Alves et al., 2017; Chen, Nakama and Zhang, 2017; Hanley and Torres, 2016). Furthermore, the information obtained helps to increase the comprehension of the natural resources for the population, policy-makers, and visitors through the recognition of their real value (Alves et al., 2017; Birol, Karousakis and Koundouri, 2006).

In the European Union, there are examples of the previous situation, such as Clean Air for Europe (CAFE) program of the Directorate General for Environment uses the cost-benefit analysis with the purpose of verifying the effectiveness of new regulations. Also, in the United States, the Environmental Protection Agency (EPA) utilizes the same method (Ami et al., 2010).

2.5. Social damage function

So, with the purpose of estimating the CBA of the environmental policies, in this case, it will estimate the social damage function or (simply called damage function). According to Ami et al. (2010), the external cost or the damage cost of a pollutant is an ecological indicator used by the government to make a CBA, when it is discussed the implementation of an environmental policy.

For that reason, the calculation of the damage function associated with the pollution level demands a detailed process, in which it is important to determinate how a source of pollution "increases the exposure of all affected receptors […], followed by the use of exposure-response functions for each of the numerous possible impacts" (Ami et al., 2010).

In that sense, Barghouthi and Marie (2016) express the existence of many accounting approaches to measure the social cost of pollution:

A. Property value approach: "it relies on property value at non-polluted vacant areas relative to similar values of the property located at the polluted areas" (Barghouthi and Marie, 2016).
B. Wage differential approach: workers desire less polluted areas with low wages than polluted areas with high wages.
C. Specific damages approach: in this approach it is important to classify the damage, such as: 1) Damage measure in financial terms, such as increase of the costs associated with the maintenance and replacement of productive assets or the human productivity reduction. 2) Loss of life and human health problems. 3) A future damage on economic resources.

As a consequence, the social damage function is measure as the loss benefit given the pollution level, such as the mortality risk, the cost of the environmental degradation and the cost of dealing health problems (Barghouthi and Marie, 2016, Heine, Norregaard, and Parry, 2012).

2.6. Total Economic Value (TEV)

Given the objective of measuring the benefits from an environmental improvement or deteriorate, it is essential to consider the Total Economic Value (TEV), and it is defined "as the sum of the value of all services that natural capital generates" (Jianga et al., 2017). TEV is all the utility that generates the environmental resource, with the same unit of account, the most common is in monetary terms.

Many authors (Alves et al., 2017; Birol, Karousakis and Koundouri, 2006; Field, 1994; Loomis and Pate, 1995) establish that TEV of the natural resources and ecosystems is composed by two categories of value: The use value refers to the direct use value that contemplates the market value of the natural resources, such as good of consumption or as an input; an indirect use that represents the ecosystem services value, e.g., regulating services or recreational services. Also, it includes the optional value, it means the possibility of consuming the natural resources in the future.

On the other hand, non-use value: consider the value of goods and services when they are not consumed. It includes the option value, the value derived from the possibility of enjoying the resource in the future. Additionally, the non-value contemplates the altruism and existence values, e.g., the value derived from knowing that an ecosystem exists. Finally, the bequest value, the benefit that generates to conserve something for future generations.

Now, it is evident that a complete CBA must include the gained benefits of the environmental improvement due to environmental policies. However, many researchers have stipulated the big challenge to include completely the total economic value of the environmental resources or systems because the economic benefits generated thanks to the goods and services that are provided by those resources are not quantified completely (Alves et al., 2017; Birol, Karousakis and Koundouri, 2006; Jianga et al., 2017).

The main cause of this problem is the own essence of the natural resources. For example, in the case of coastal and marine services, Alves et al. (2017) express that the total services are not completely expressed in the market because the most of their services do not require a charge or a price to be consumed; therefore, the non-market values from these services represent an extra value for the society. So, the value of the seafood is priced in the market, but services such as recreational services are not valuated by the market.

In the same sense, the natural resources are cataloged as public goods; hence, there is no way to establish a market price Thus, the lack of information in terms of the real value of these kinds of goods does not allow showing the true scarcity. For that reason, it is evident the existence of pollution levels or extractions rates that overtake the optimal condition and it represents a market failure (Birol, Karousakis and Koundouri, 2006).

2.7. Abatement Cost Function

After all the above, with the purpose of complete the CBA, it is important to measure the cost that will appear due to the environmental control. In this scenario, the abatement cost is measured as the costs of tools and equipment that the firms need with the purpose of maintaining their emission levels within of the allowed levels (Barghouthi and Marie, 2016).

Before such scenario, the policy-makers are worried about the costs associated with the control of pollution by the firms and the environmental policies; thus, they do not put attention to the benefits gained from the regulations (Barghouthi and Marie, 2016) and there is resistance by these groups to establish environmental policies. However, there is a discussion of how the firms face environmental policies. In this case, there are two approaches about how the industries´ competitiveness responds to the environmental regulations: Pollution Haven Hypothesis (PHH) and the Porter Hypothesis (PH) (He, Zhou and Zhu, 2017).

The first approach explains that different environmental regulations between countries or regions provoke the transfers of the firms to places where the environmental policies are not rigorous or non-existent. Mendes and Oliveira (2017), and He, Zhou and Zhu (2017) mention the existence of strict environmental regulations induces the reallocation of firms from one region to another one; therefore, those actions weaken the economic development. For example, competitiveness at global and national level is affected by domestic taxes because environmental policies produce an increase in the costs; as a consequence, the most sensitive firms lose their market share due to disadvantageous situation against foreign and local firms with better conditions (Kosonen and Nicodème, 2009; Mendes and Oliveira, 2017). Nevertheless, in this context, it is important the use of subsidies, tax credits, financial and political support with the purpose of the permanence of the firms (He, Zhou and Zhu, 2017).

Conversely, in the PH approach, as the name implies, it follows the ideas of the economist Michael Porter during the early of the 90's, when the firms face these kinds of environmental regulations, the firms have the chance to innovate and develop techniques with the objective of using resources efficiently and green technologies, and then they are able to offset the costs (He, Zhou and Zhu, 2017; Kosonen and Nicodème, 2009; Mendes and Oliveira, 2017). For example, Kallbekken, Kroll and Cherry, (2011) express taxes help to cause incentives to innovate; since the market-based instrument establish a tax per emission or per unit of pollution, polluters try to develop new technologies with the purpose of reducing the number of emissions and decrease the marginal cost of pollution abatement.

In that scenario, there is a debate about which approach is experienced by the firms (Mendes and Oliveira, 2017). In some regions, with high levels of wealth and environmental awareness among interest groups, it is possible to establish better (efficient) environmental policies than places with less wealth and awareness, so it is developed laws to impulse only the economic growth (He, Zhou and Zhu, 2017).

3. Methodology and Model

Once that literature has been exposed, it will be illustrated the methodology. In the first instance, the main model observed in some authors (Barghouthi and Marie, 2016; Field, 1994; Metcalf, 2003) is presented in Figure 1, and it is graphed the Marginal Social Damage (MSD) and the Marginal Abatement Cost (MAC). The MSD shows that each time the number of pollutant emissions q increases, it is associated with a higher level of damage, so the vertical distance between q_1 and MSD is the Marginal Social Damage and each point of q represents a single Marginal Social Damage. On the other hand, the MAC shows the costs that a polluter faces when it has to reduce the number of emissions, analogously the vertical distance between q_0 and MAC is the Marginal Abatement Cost and each point of q is associated with a single Marginal Abatement Cost. The point q_0 represents the *threshold of pain*, the level of pollutant emissions that starts to have a negative impact on the society. Ultimately, the point q_1 represent the *uncontrolled pollution level* by the polluter. When the polluter is releasing the amount q_1, the Total Social Damage generated associated with the uncontrolled pollution level is equal to the area of the triangles *a*, *b* and *c*.

Having considered the MSD and MAC functions, it is important to consider which is the efficient level of emissions. This efficiency situation or the socially optimal level is defined as the level where the marginal social damage equals the marginal abatement cost (Barghouthi and Marie, 2016; Birol, Karousakis and Koundouri, 2006; Field, 1994; Goulder and Parry, 2008; Heine, Norregaard, and Parry, 2012), that means the emission level in which both costs exactly offset one another. In figure 1, $q*$ represents the efficient level; therefore, the Total Social Damage has been reduced from q_1 to $q*$ a value equal to the area *a* and the Total Abatement Cost is equal to area *b*. As a final result, there is a reduction of costs, in general terms, of the area *c* but also the costs are shared with the polluter.

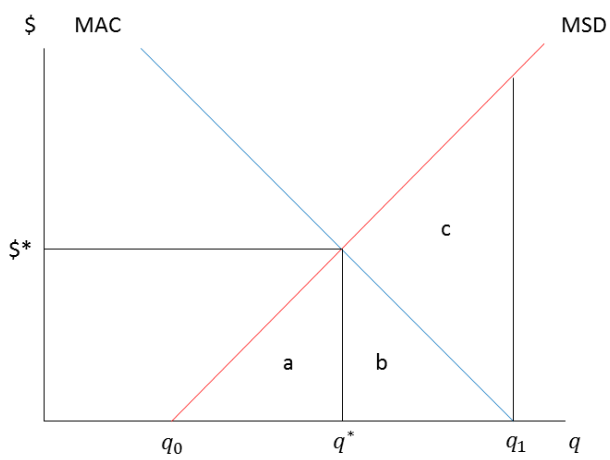


Figure 1: Linear model in equilibrium

Now, it is considered a non-linear case, so the functions MSD and MAC are represented in Figure 2. So the Total Social Damage and the Total Abatement Cost associated with the uncontrolled pollution level are measured by the areas under their respective curves and they are represented by:

$$\text{Total Social Damage} = \int_{q_0}^{q_1} \text{MSD(q)dq}$$

$$\text{Total Abatement Cost} = \int_{q_0}^{q_1} \text{MAC(q)dq}$$

Like the previous situation, the intersection of both functions represents the efficient pollutant emission, i.e., the level $q*$. Hence, the polluter deals with the Total Abatement Cost equal to:

$$Total\ Abatement\ Cost = \int_{q*}^{q_1} MAC(q)dq$$

And the Total Social Damage is reduced to the efficient level:

$$Total\ Social\ Damage = \int_{q_0}^{q*} MSD(q)dq$$

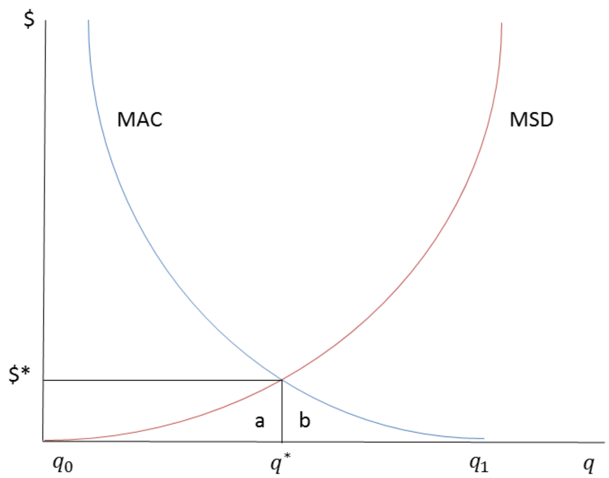


Figure 2: Non-linear model in equilibrium

With the model present above, the objective is to observe the effects of a normative regulation and an environmental tax, it is important how to measure the damage associated to the pollution or the overexploitation of natural resources. In first place, it is now evident that natural resources and ecosystems are classified as non-market good and services; hence, with the objective of obtaining information about costs and benefits gained due to variations of environmental quality, it is necessary to use non-market valuations; this kind of methods let to measure the value others components of natural resources and ecosystems; nevertheless, they represent a more complicated process (Alves et al., 2017).

Alves et al. (2017) and Delacámara (2008) divide the estimation methods into two groups. The first group named revealed preferences assumes that environmental preferences of the consumers are reflected by their consumer habits. An example of this approach is the Hedonist Pricing Model (HPM) proposed by Rosen in 1974; in this case, the components of environmental quality may be reflected in the market price. For example, the environmental preferences are derived from the market prices of goods and services, in that way is possible to uncover non-market components that are in the market, i.e., the price difference between similar goods is due to differences in environmental quality.

Another case of this approach is the Travel Cost Method (TCM) established by Hotelling, (1949); it is used to estimate the recreational value of the environmental resources. The main argument of this method is that all the costs (time, money, opportunity cost, etc.) that a person incurs to visit a specific place, represent the price of access to the site (Alves et al., 2017). Therefore, it is possible to estimate the willingness to pay of the people in function of the number of visits that realize in the same place with different travel costs, so the TCM follow the law of demand, i.e., when the number of visits reduces as the distance increases because travel costs increase.

In general, these methods are useful because they can show or capture the effects of environmental quality changes on variables such as income or wages; however, they do not contemplate values out of those variables (Hanemann, 1994); hence, revealed preferences methods fail to contemplate the non-use values of the environmental resources (Alves et al., 2017; Hanemann, 1994).

On the other hand, the stated preferences approach allows to obtain the willingness to pay for the environmental services when it is impossible to determine the personal valuation with the information from the market, and it is "expressed in terms of a stated choice in hypothetical scenarios presented to survey respondents" (Alves et al., 2017); thus, people are questioned about how much money they are willing to pay for extra units of environmental quality. The most representative method of this approach is the Contingent Valuation Method (CVM) stated by Ciriacy-Wantrup in 1947 (Hanemann, 1994; Ibarrarán, Islas and Mayett). In contrast to the revealed preferences, the CVM allows measuring both the non-use value and the use value of the goods and services (Chen, Nakama and Zhang, 2017; Delacámara, 2008; Hanemann, 1994; Ibarrarán, Islas and Mayett, 2003; Loomis and Plate, 2015).

One of the most important features of the CVM is the versatility to be applied is any natural resource, ecosystem or situation. For example, Chen, Nakama and Zhang (2017) use this method in the case of village forest landscape, value the wetlands (Birol, Karousakis and

Koundouri, 2006; Loomis and Plate, 2015) or coastal and marine ecosystems (Alves et al., 2017; Hanley and Torres, 2016), measure the air pollution (Ami et al., 2010) and even in the case of valuing an alternative service of collection and selection of solid waste (Ibarrarán, Islas and Mayett, 2003).

However, the process or the application of the CVM is complex because there are many factors to be considered; therefore, the results can vary (Delacámara, 2008). For example, how the survey is structured and the implementation, the use of mail surveys or personal interviews, open-ended questions or closed ended-questions, even the delimit target population (Hanemann, 1994). Also, the CVM suffers from criticism; for example, the estimations derived from this method depends on the amount of the information provided by the interviewers and the intention of the respondents to bring information to the survey (Loomis and Pate, 1995), that phenomenon is often called strategic behavioral, that means people do not express their true willingness to pay (Hanemann, 1994).

After exploring this theoretical view, it will be presented the effects of the environmental regulations, norms, and taxes, in the model and also it will present some considerations that could alter the effectiveness of the used instruments.

3.1. Direct regulatory instruments: Norms

First, it is considered the case where a norm is established. As it was expressed before, the norm is a public policy in which a mandate captures a socially desirable behavior, and in this context, with the goal of reaching an improvement of the environmental quality.

Figure 3 represents the main model, the marginal abatement cost of one source and the marginal social damage associated with the pollutant emissions q. Now, it is supposed q_1 as the uncontrolled emission level, a situation in which is beyond of the efficient level $q*$ and the Total Social Damage is $a+b+c$. With the purpose of achieving an efficient condition, the government or any authority in charge set an emission standard or norm at $q*$, this represents the maximum level of allowed emissions; as a result, the Total Social Damage is only a. and the Total Abatement Cost is b, this last cost is also called “the compliance costs of meeting the standard” (Field, 1994). If the polluter is not able to achieve the norm, it is subject to a penalty.

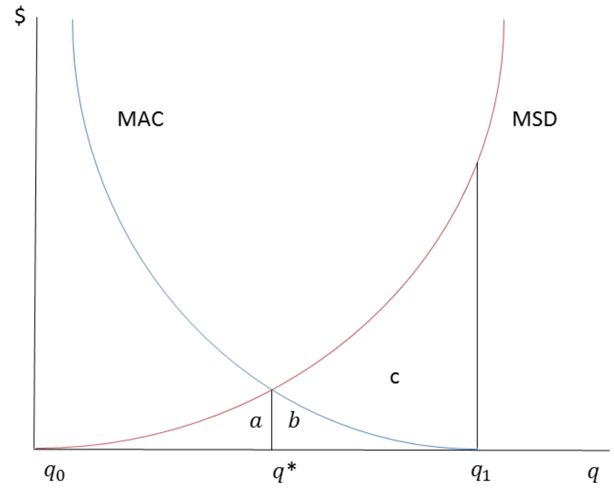


Figure 3: Effect of a norm as an environmental policy

3.2. Incentive-based instruments: Taxes

The second environmental policy is a tax, a pay for each pollutant emission. To observe how a tax per emission works, it is considered a similar scenario in Figure 4, the Total Social Damage associated with the uncontrolled emission level q_1 is a+b+c+d. However, the authority wants to establish a tax that allows an efficient result; therefore, if it knows the MSD and MAC curves, the authority sets the tax in the point where the functions intersect, the level $q*$, so the optimal tax is $t*$; as a consequence, the Total Social Damage is only a, but the polluter face two types of cost. On one hand, the polluter pays the Total Abatement Cost b; on the other hand, the tax payment, which it equals the number of emissions multiplied by the tax, that is a+e.

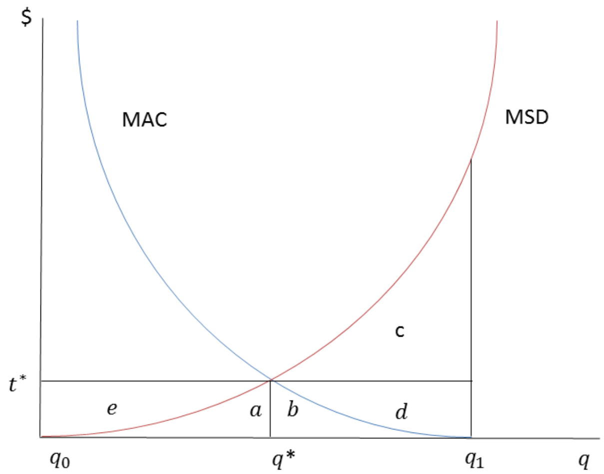


Figure 4: Effect of a tax as an environmental policy

The main question here is: how the polluter react to the environment tax? For example, if the tax is set at $80 per ton/month, Table 1 shows all the results related to the environmental tax. When the firm is emitting 10 tons/month, it would not face any abatement cost, but on the other hand it would face a tax payment equal to $800; however, the firm would wish to cut off its emissions to 9 tons because it would prefer to pay $15 in abatement costs than the tax. As a conclusion, according to this logic, the firm reduces its emissions until the point where the tax rate equal to the marginal abatement cost (Field, 1994). In this condition, the firm is minimizing its total costs, the sum of the Total Abatement Costs and the total tax payment. In this example, the firm reduces its emissions to 5 tons with a total cost equal $625.

Emissions (tons/month)	Marginal Abatement Cost	Total Abatement Cost	Total Tax Payment	Total Cost
10	0	0	800	800
9	15	15	720	735
8	30	45	640	685
7	45	90	560	650
6	60	150	480	630
5	75	225	400	625
4	90	315	320	635
3	105	420	240	660
2	120	540	160	700
1	135	675	80	755
0	150	825	0	825

Table 1: Emissions of a polluter and their associated costs

3.3. On the equivalence of tax and norms

After exposing how the environmental policies work, it is important to know which instrument could achieve a better result. According to Weitzman (1973), “no matter how one type of planning instrument is fixed (a tax or a norm), there is always a corresponding way to set the other which achieves the same result when implemented”; therefore, there would no difference between the direct regulatory and incentive-based instruments. Now, the previous statement will be illustrated in Figure 5. It is considered an initial situation where a firm is expelling pollutant emissions due to its economic activity and without any regulation its pollution level is q_1; as a result, the Total Social Damage is equal to $a+b+c+d$. In that context, the government is able to establish a maximum emission level, a norm, or an environmental tax, if the government chooses the norm and the limit is market at $q*$, the firm has to reduce its emission level until that point, so the Marginal Abatement Cost is equel to the Marginal Social Damage; as a result, the Total Social Damage is only a and the Total Abatement Cost is b.

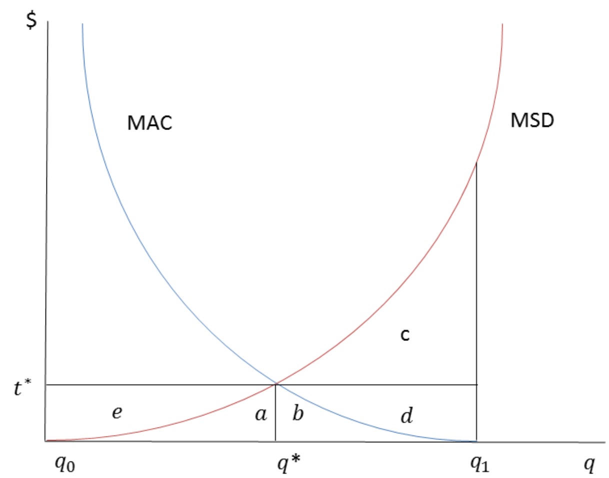


Figure 5: On the equivalence of tax and norms

However, instead of the norm, the government establishes the tax equal to t^*, in the initial emission level, the firm would have to pay $a+b+d+e$ and the Total Social Damage is $a+b+c+d$, but the costs that face the firm are high; thus, the firm decides to incur in abatement cost to reduce its emission level. As it was expressed before, the process of reducing its pollutant emissions finish when the value of the tax is equal to the abatement cost associated with the last pollutant emission (t^*=MAC).

In this new result, the Total Social Damage is “a” too, the Total Abatement Cost is b and the tax cost is $e+a$ and the total cost is $a+b+e$. The main result of both situations is that an emission tax t^* allows getting the same optimal emission level established with a norm. This view is the same if it is compared with the theory of commercial policy. Bhagwati (1969) mentions that:

> Tariffs and quotas are equivalent in the sense that an explicit tariff rate will produce an import level which, if set alternatively as a quota, will produce an implicit tariff equal to the explicit tariff (and, pairwise, that a quota will produce an implicit tariff which, if set alternatively as an explicit tariff, will generate the same level of imports).

So, it would not be unusual that an explicit emission tax will produce an implicit emission level which, if set alternatively as an emission level, will produce an implicit emission tax equal to the explicit emission tax, and vice-versa; hence, there is no superiority of one instrument over the other, a tax and a norm will achieve the same efficient result, at least in terms of an optimal emission level given the MSD and the MAC. However, Weitzman (1973) also expresses that this phenomenon of equivalence between both instruments is only achieved in situations of perfect information and certainty; therefore, if the authority does not know information about what the current level of emissions is, the damage associated with the pollutant emissions and the abatement costs that firms would face with any environmental regulation, it is not possible to establish this equivalence, unless it is by trial and error, but it would be expensive for the authority.

3.4. Imperfect information and norms

Now, under imperfect information, the result of any environmental regulation can vary; and therefore, the distributions of the costs. For example, in Figure 6, it is considered q_0* as the optimal emission level, in this point MSD is equal to MAC and the government decides to establish a norm; however, it does not have enough information such as uncontrolled pollution level, the threshold of pain or the MSD and MAC functions. In this scenario, the government establishes arbitrarily the level q_1* as the optimal level.

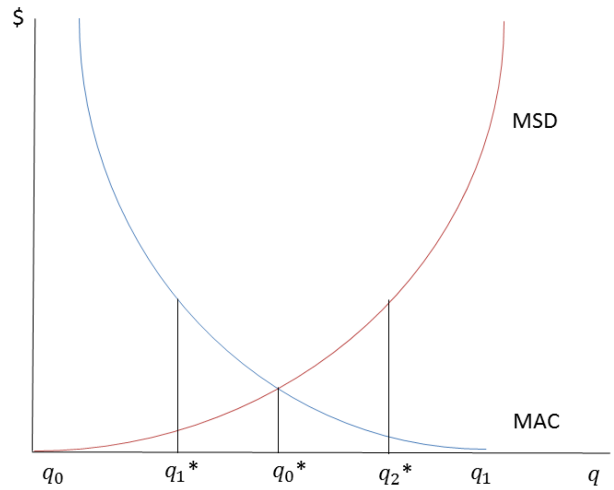


Figure 6: A norm under imperfect information

What is it the consequences of this new optimal level? When it is observed Figure 6 again, it is appreciated that Total Social Damage associated with q_1*has been reduced drastically. On the contrary, the Total Abatement Cost is high; hence, the polluter(s) faces with higher costs and it would not accept the norm. Now, it is considered a different case, where q_2* is the optimal emission level established by the authority. Figure 6 shows that Total Social Damage associated with q_2* is too high; on the other hand, the Total Abatement Cost that is low, so the polluter would be agreed with the norm, but those who receive effects of the pollution would not be satisfied.

In both scenarios, with imperfect information, a norm as an instrument of environmental regulation, it does not allow economic efficiency because q_1* and q_2* do not allow the intersection of MSD and MAC curves; therefore, the minimization of the costs is difficult to reach in this context.

Nevertheless, in the situation where the authority establishes unrealistic norms due to the lack information, Field (1994) expresses that unrealistic standards help to incentive the firms to invest in R&D (Research and Development) with the purpose of searching new technology, and it is called technology forcing. This phenomenon is illustrated in Figure 7, in the first place, q_0* represents the economically efficient point and the curves MSD and MAC intersect; however, due to the imperfect information establish arbitrarily the level q_1*. In this situation, the efficiency is not achieved and the Total Abatement Cost is *a*+*b*+*c*+*e* and the Total Social Damage is only *d*; therefore, the result would not accept for the polluter.

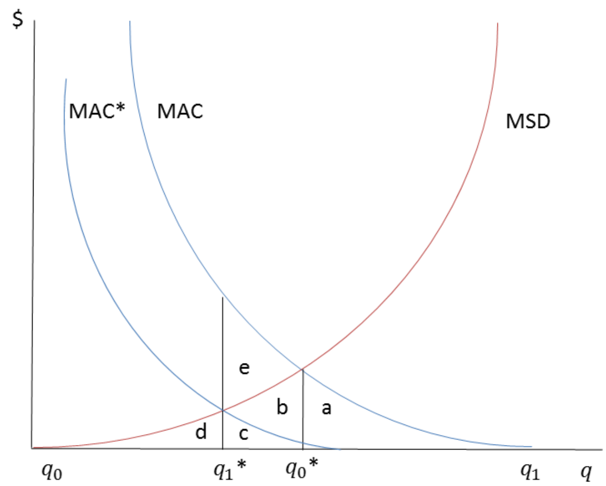


Figure 7: A polluter facing an unrealistic norm

However, with the purpose of achieving the environmental regulation, it is possible that the polluter is motivated to spend resources with the objective of developing new technologies, i.e. R&D, that allow reducing the emissions level. When it is reached, the MAC curve moves to the left to MAC*, in this new situation the Total Social Damage is still *d*, but the Total Abatement Cost has been reduced dramatically to *c*. As a conclusion, the unrealistic norm has the potential to reduce the Total Social Damage and Total Abatement Cost when the polluter is committed achieving the environmental regulation. Moreover, it is possible that investment on R&D generates better results, then the shift of the curve to the left is greater and it achieves a lower emission level established by the authority, with even fewer costs and damages.

In spite of the previous situation, this transition does not occur from overnight. It is obvious that the polluter needs time to observe the result of the R&D; hence, the authority could determine grace periods, this means a period of time in which the polluter is able to ignore the norm, but with the responsibility of working to accomplish the norm when the period is over. But, the polluter can take advantage of this: for example, the polluter can argue to the authority that the established norm is so restrictive and it requests a longer grace period. Due to the imperfect information, the authority trusts to the polluter and it expands the grace period; as a result, the polluter can abuse of the previous situation and the potential of technology forcing is not achieved.

3.4.1. Enforcement costs

Another important aspect to consider with direct regulation is the presence of enforcement costs; this means the costs that the authority in charge incurs when it is keeping an eye on the fulfillment of the environmental regulation. For example, if the law establishes that car producers must install a catalyst in the motor vehicles with the purpose of reducing CO_2emissions, the government has the responsibility of verifying that all firms are abiding the mandate. On the contrary, when a firm does not fulfill the law, it is worthy of a sanction. The previous situation influences significantly in the analysis of the model presented. Figure 8 presents how the enforcement costs distort the total costs and the optimal emission level established by a norm.

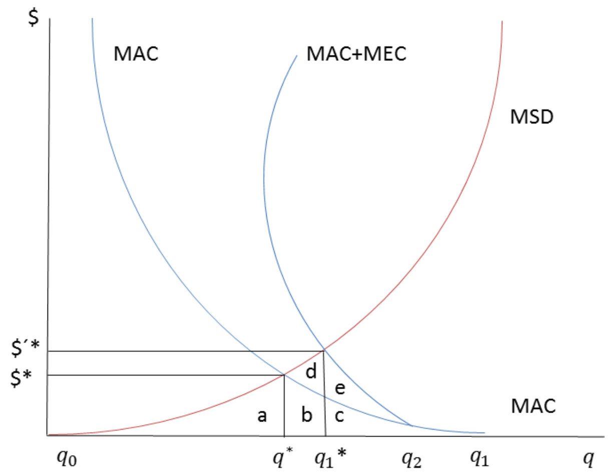


Figure 8: Enforcement costs

As has already been presented, when a norm stipulates a maximum emission level $q*$, the Total Social Damage is a and the Total Abatement Cost is b+c. In the first instance, it is possible to expect some degree of voluntary compliance, but from the level q_2, it is necessary the supervision of the authority and this translates into the use of economic resources and the creation of a supervisory entity. As a result, the new curve represents the marginal abatement cost plus the marginal enforcement cost (MAC+MEC). Hence, due to emission reduction is now relatively more expensive than before, the socially efficient level of emissions q_1*. In this new situation, the total cost of emission reduction is c (Total Abatement Cost) plus e (Total Enforcement Cost) and the Total Social Damage has increased to a+b+d. As a conclusion, the enforcement costs generates a condition of "extra-costs", that appear to be distributed, in the first instance, unfairly because the polluter spends less in order to reduce their emissions, the negative consequences of pollution increased and the authority incurs in an additional cost due to the supervision.

3.5. Imperfect information and taxes

After showing the consequences of the norms, as an instrument of environmental regulation under imperfect information, it will be exposed how the taxes work in the same situation.

For example, in Figure 9, if the authority establishes a tax t_0, the polluter reduces its emissions, fulfillment the condition where the tax per emission is equal to the marginal abatement cost of the last emission, so the new level is the point q_0*. However, with the t_0 the efficient level of emissions is not achieved because both curves, MSD and MAC, do not intersect.

But if the authority establishes a tax higher than the previous one,t_1, the authority will earn more resources and the polluter will face a higher cost associated to the tax payment with the emission level q_0*; therefore, the polluter choose to reduce their emissions because it is relatively cheaper to pay the increase of the Total Abatement Cost than the tax payment associated to the level q_0*. As a result, in Figure 9 shows that emissions are reduced until reach the point q_1* (always following the condition already described). Additionally, in this context, the efficient emission level is reached, so t_1 is the tax that allows the efficiency.

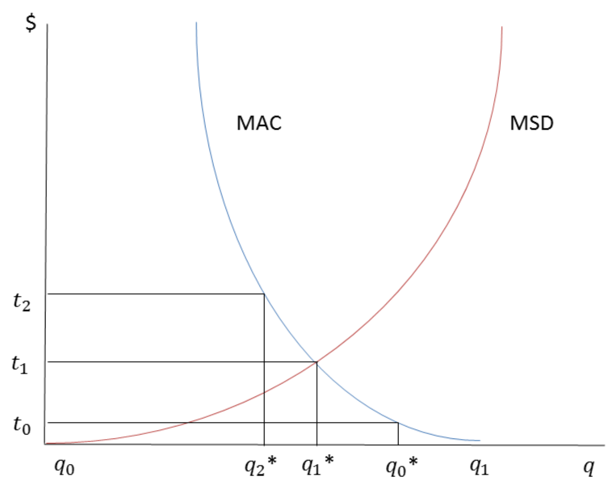


Figure 9: A tax under imperfect information

However, due to the imperfect information, the authority can establish even a higher tax than the previous scenarios. If it is set the tax t_2, in Figure 9, the authority will earn even more resources, but the polluter faces higher costs; hence, the polluter will prefer to reduce its emissions until the point q_2*. Unfortunately, in this case, the efficiency is not achieved.

As a consequence, when a tax is established and the authority does not know how the polluter reacts, it is hard to determine how much the pollution emissions will be reduced or which the optimal level of emissions will be; unlike a norm, in which this instrument is direct and it sets a specific target (Field, 1994). Nevertheless, Figure 10 explores how the polluter performances when the authority establishes a tax in a context of imperfect information:

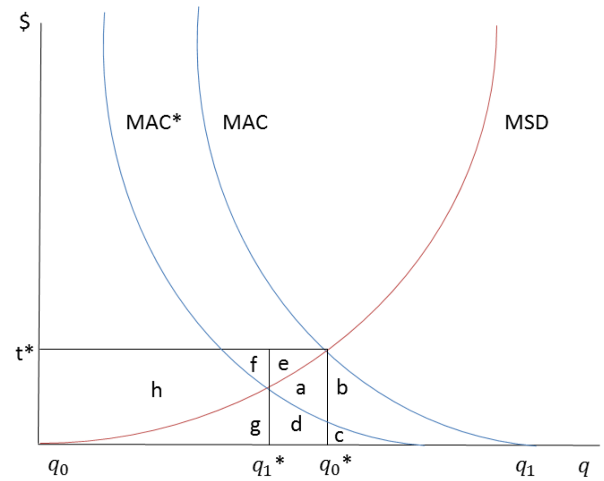


Figure 10: Polluter performances when the authority establishes a tax under imperfect information

1. First scenario: Due to the high costs for the polluter, the polluter acts voluntarily and decides to invest some resources in R&D with the purpose of reducing the pollutant emissions and their associated costs. Therefore, the MAC shifts to the left; this result represents a lower emission level q_1* and a decrease of the general costs, that is, the Total Abatement Cost is reduced to *c*+*d*, the Total Social Damage is *g* and the tax payment is only *h*+*f*+*g*.
2. Second scenario: The authority decides to give back the tax income to the polluter. So in the first period, when the tax is established, the authority recollects *a*+*d*+*e*+*f*+*g*+*h*, but, in the second period the authority awards the polluter with a lump-sum, this resource is financed with the tax payments, with the goal of reducing the pollutant emissions. If this initiative is successful, the MAC shifts to the left to MAC*, like the others situations, and it is assumed to get the same result, i.e., the Total Abatement Cost is reduced to *c*+*d*, the Total Social Damage is *g* and the tax payment is *h*+*f*+*g*. Additionally, there is no reason for the authority to stop the support in the third period and reduce even more the pollutant emissions; and therefore, decrease the costs associated.

It is important to express the possibility of both situations in the same context. The own initiative of the polluter to reduce the cost plus the wish of the authority to reduce the emissions and their damage associated will bring even a greater shift to the left of the MAC curve. Therefore, a source is motivated to exploit all the possible abatement channels until reduce their total costs as much as possible. In that sense, the incentive-based instruments, allow more flexibility, this means that any polluter can choose how to reduce its emissions (Kallbekken, Kroll and Cherry, 2011, Kosonen and Nicodème, 2009).

However, according to Field (1994), sometimes with a flat tax (the same tax rate for all the emission levels), "the total tax payments of firms would substantially exceed remaining damages"; hence, a way to resolve this is with a two-part emission tax. For example, in the same Figure 10, if the authority allows until the level q_1* free of taxes, the polluter has the initiative to invest in R&D and reduce its pollutant emissions; once the source reaches the level q_1*, it only will face the Total Abatement Cost (c+d) and the tax payment will disappear (h+f+g).

To sum up, there are two important conclusions associated with the taxes and imperfect information. 1) The polluter always tries to minimize its total cost even if the efficiency level is not achieved, given the tax rate established by the authority; satisfying the condition t*=MAC. 2) If the authority establishes a high tax, the polluter is incentivized to invest in R&D and reduce its emissions and total costs.

3.6. Many polluters

Until this point, it has been assumed the existence of a unique source or polluter, but: What happens in the existence of many polluters? How is the distribution of costs among the polluters? Is it possible to get an efficient solution?

In the first place, when the polluters are similar and face same abatement costs, there is homogeneity among polluters, in this case, all firms posse the same MAC curve. Controversy, if each polluter faces different abatement costs due to the technological differences, it is a context of heterogeneity among the polluters, this situation is illustrated in Figure 11, the firm A and firm B start in the same uncontrolled emission level. However, the abatement costs associated with each emission for firm A is higher than firm B because the first one, possess an older technology and this represents less efficiency to reduce its emissions; therefore, it is more expensive to reduce its emissions. And the end, the firm A will pay a higher Total Abatement Cost than firm B associated with the same emission level.

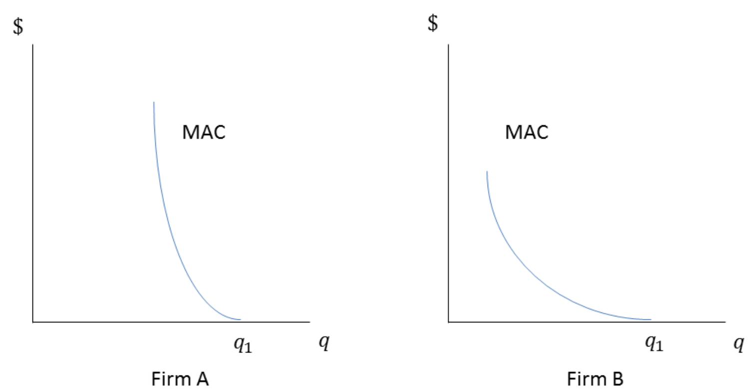


Figure 11: Two polluters with different MAC curve

In the second place, the differences among polluters also depend on the magnitude of their emissions on people. For example, there are the same polluters, the firm A and the firm B, who are expelling pollutant emissions that affect the environment of a community; however, the firm A is relatively closer to the community than firm B. Therefore, it is expected the impact of the firm A is relatively greater than the firm B; this is presented in Figure 12. It is observed that firm A, its MSD function grows faster with each pollutant emission; on the other hand, the MSD function associated with the firm B grows relatively slower. As a result, the Total Social Damage associated with the same emission level $q*$ for both polluters are different, and the firm A generates more damage than firm B. Additionally, it is possible to appreciate different pain thresholds among polluters; depending on the impact of the emissions to the environment. In this case, Figure 12 shows that firm A starts to affect with its emissions to the community in the level q_0, but the pain threshold of the firm B starts later than firm A, in the level q_1.

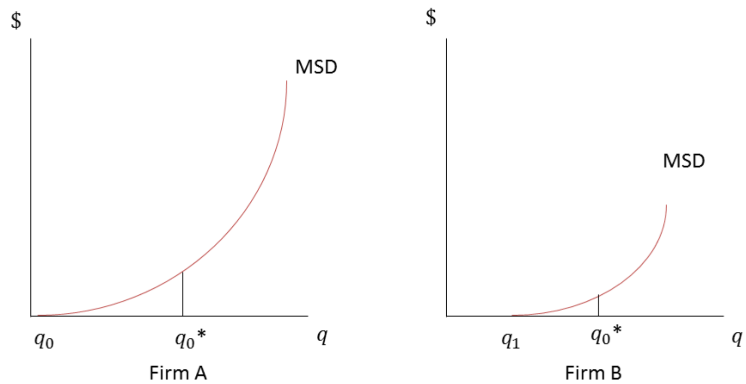


Figure 12: Two polluters generating different MSD curves

With the existence of many polluters, it is important to consider how this situation affects the effectiveness of the environmental regulations. First, it is considered a case where the authority wishes to establish a norm as an environmental regulation due to excess CO_2 in a city, and it is assumed two sources, firm A and B, with the same impact of their pollutant emissions to the environmental quality but with different abatement costs; ultimately, it is assumed a context of imperfect information. This last assumption plays an important role because if the authority is not conscious about the differences between both firms and it decides to establish the same limit of CO_2, the effectiveness of the norm could be lost for one of the firms.

Figure 13 illustrates the previous situation when the authority establishes q_1* as the maximum emission level. The firm A is able to minimize the Total Social Damage and the Total Abatement Cost because the norm allows the efficiency pollutant level. However, the firm B does not achieve the efficiency; therefore, the level established by the authority is not optimal for the firm B; therefore, the uniformity of standards or norm with different sources is not optimal.

However, if we consider the same scenario but in a context of perfect information, then the authority is conscious about the differences between firm A and B, then it is possible to establish different norms for different firms. Figure 13 also represents the previous situation, as it was expressed before, with the first norm the firm A acts efficiently with q_0*; however, when the authority emits a specific norm for the firm B, in which set a limit emission level equal to q_1*, this point allows to achieve an efficient condition. This case of different norms for different polluters can be expanded for an infinite number of polluters, as long as the authority knows enough information about the polluters; including their impact of the emissions on the society and the abatement costs. However, due to the difficult to establish diverse norms, it easiest establishes a norm for different zones or according to a radio, instead of different norms for different sources.

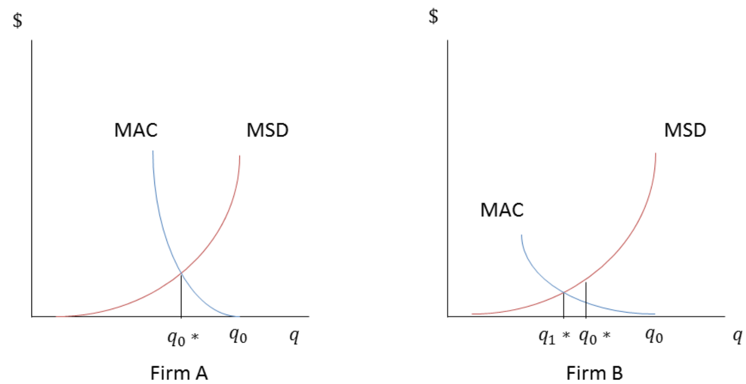


Figure 13: Different norms for different polluters

Let´s deepen more on the importance of establishing different norms due to the heterogeneity of the firms is the example of Figure 14. In this case, it is presented the marginal abatement costs of firm A and B, the MAC curve of the firm A increases more rapidly than firm B. The uncontrolled emission level is 10 tons/month at each polluter or a total of 20 tons/month. Then the authority wants to reduce half of the total emissions; hence, it is established a norm with the purpose of setting a maximum of 5 tons/month per source. A. In first instance, it appears to be fair because each polluter reduces its emissions in the same proportion; however, in economics terms, this norm is not the best solution. With the previous statement, it is important to consider the equi-marginal principle; Field (1994) explains this concept:

> If you have multiple sources to produce a given product or achieve a given goal, and you want to minimize the total cost of producing a given quantity of that output, distribute production in such a way as to equalize the marginal costs between the production sources.

So, at the level of 5 tons/month, the firm A faces a marginal abatement cost is $37.00 and firm B equal $11; thus, the Total Abatement Cost of firm A is $71.00 and for the firm B is $25.00, with a grand total of $96.00. But, when the equi-marginal principle is satisfied, the firm A cut its pollutant emissions to 6 tons/month and firm B to 4 tons/month, the marginal abatement cost for both are the same, $17.00. In this scenario, the grand total is now

$76.00, a reduction of the 20.83%; as a consequence, with a unique norm and heterogeneity firms, the costs are not distributed, in a way that it does not let to minimize the total costs.

	Marginal Abatement cost ($)	
Emission level (tons/month)	A	B
10	0	0
9	2	1
8	5	2
7	10	4
6	17	7
5	37	11
4	60	17
3	90	30
2	142	45
1	189	63
0	232	81

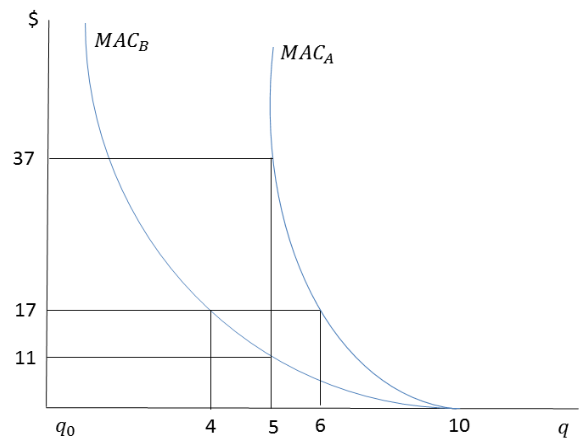


Figure 14: The Marginal Abatement Costs of many polluters

To sum, the direct regulatory instruments such as a norm, the polluters do not have the chance to exploit different pollution channels due to the heterogeneity of the firms and by the nature of this kind of imposition; however, if the firms are very similar, any direct regulatory instruments could be a good idea because the firms face almost equal costs (Goulder and Parry, 2008). As a consequence of the previous situation, the information about abatement costs is essential for the design of regulations and the cost-effectiveness analysis, with the purpose of ensuring the biggest net benefit (Barghouthi and Marie, 2016).Hence, when a norm is enacted, the efficiency is hard to achieve because due to the situation of imperfect information, and with many and different sources or (in terms of abatements costs and impact of their emissions to the environmental quality). These factors hinder the work of the authority to establish a norm or a set of norms.

Now, it will present the case of an environmental tax. It follows the same assumptions, authority wants to establish a tax as an environmental regulation due to excess CO_2 per emission in a city, there are two sources, firm A and firm B, with the same impact of their pollutant emissions to the environmental quality but with different abatement costs and it is assumed a context of imperfect information.

Figure 15 illustrates the previous situation when the authority establishes the tax rate t_0. With this, the firm A is able to minimize the Total Social Damage and the Total Abatement Cost because the norm allows the efficiency pollutant level. On the other hand, the firm B does not achieve it; thus, t_0 is not optimal for the firm B.

Nevertheless, in a context of perfect information, the authority is conscious about the differences between firm A and B, it will establish different taxes for different firms. Figure

15 also shows the previous case, with the first tax t_0, the firm A performances efficiently with q_0*, but the authority establishes a specific tax rate t_1 for the firm B. In this new context, the firm is able to achieve the efficiency, with an emission level equal to q_1*. The case of different taxes for different polluters can be expanded for an infinite number of polluters, as long as the authority knows enough information. However, due to the difficult to establish diverse taxes, it easiest establishes a tax for different zones or according to a radio, instead of different taxes for different polluters (the same situation like the norms).

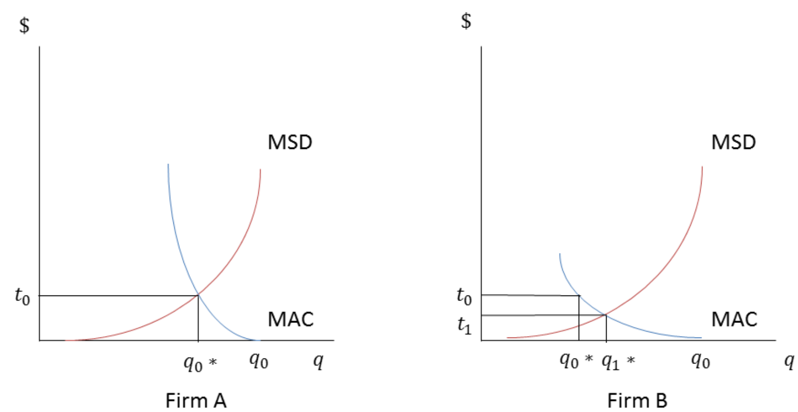


Figure 15: Different taxes for different polluters

Now, it will explore the relationship between the equi-marginal principle and the tax rate. This example is illustrated in Figure 16; there are two sources with different marginal abatement costs functions due to different production technologies, the MAC curve of firm A increases much rapidly than firm B with reductions in emissions. When the authority establishes the tax t*, both polluters reduce their emissions until their MAC curve equal the tax; therefore, "marginal abatement costs will automatically be equalized across all the sources" (Field, 1994). The polluter A reduces their emissions to q_1* and polluter B to q_2*, but the polluter B has reduced more their emissions than polluter A; hence, a tax will induce, for the firms with marginal abatement cost increase less rapidly, a greater reduction than firms with marginal abatement cost increase more rapidly. Additionally, the less MAC curve, it will be larger the emission reductions and smaller the tax payment.

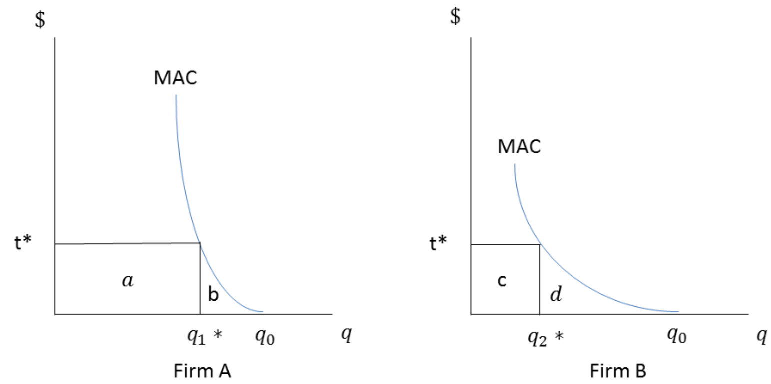


Figure 16: A case of two polluters with different MAC curves

An important characteristic of this instrument is that any emission tax releases an efficient result, "even though the administering agency knows nothing about the marginal abatement costs of any of the sources" (Field, 1994). This represents a huge advantage for the taxes; on the other, a norm requires the exactly marginal abatement costs for each polluter with the purpose of creating an efficient situation.

3.7. Example

After explaining the model, it be will be exposed a simple example; exposing most important aspects. The axis x measures the pollutant emissions to the water (tons/month), it is assumed one firm that pollutes the population of a city. Also, both functions, MSD and MAC, are considered as linear functions. The functions are the following:

$$Marginal\ Social\ Damage = -5 + \$1(q)$$

$$Marginal\ Abatament\ Cost = 10 - \$1(q)$$

These functions are represented in Figure 17. The MSD function expresses the threshold of pain, with the value of 5 tons/month. Additionally, $\$1(q)$ represents the damage associated with the increase of one pollutant emission, expressed in monetary terms. Ultimately, the MAC function shows the uncontrolled emission level of the polluter, 10 tons/month, and the abatement cost associated with the reduction of one unit of emission is $1 per emission.

With the situation of uncontrolled emission level, the marginal social damage associated with the last pollutant emission is $5; therefore, the Total Social Damage is $12.5 (equal to the area of a+b+c+d); however, when it is considered the MAC function, it is possible the determinate the efficient level, with a value of 7.5 tons/month. In this efficient context, the Total Social Damage has reduced to only $3.125 (the area a), but the polluter faces a Total Abatement Cost is $3.125 (the area b). As a result, in the first instance, the costs associated the pollutant emissions are shared with polluter, in this case, the costs are distributed in the same proportion between the polluter and people affected by the pollution, half and half. On the other hand, there is a saving equal to $6.25 (the area c and d disappear); hence, each one entity (polluter and society) only faces the 25% of the Total Social Damage associated to the initial level 10 tons/month.

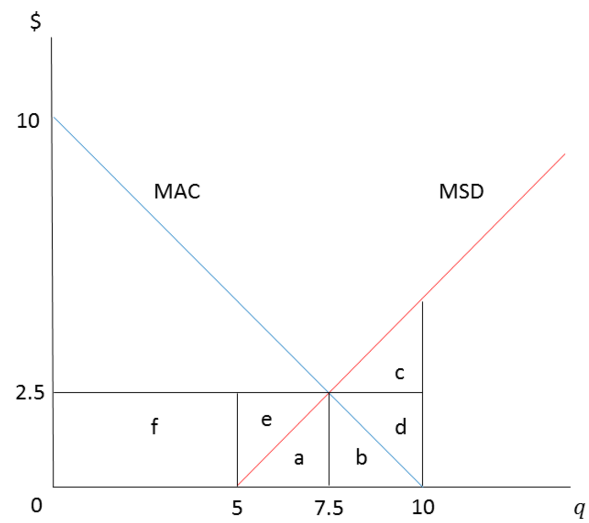


Figure 17: A numeric example of MAS and MAC curves

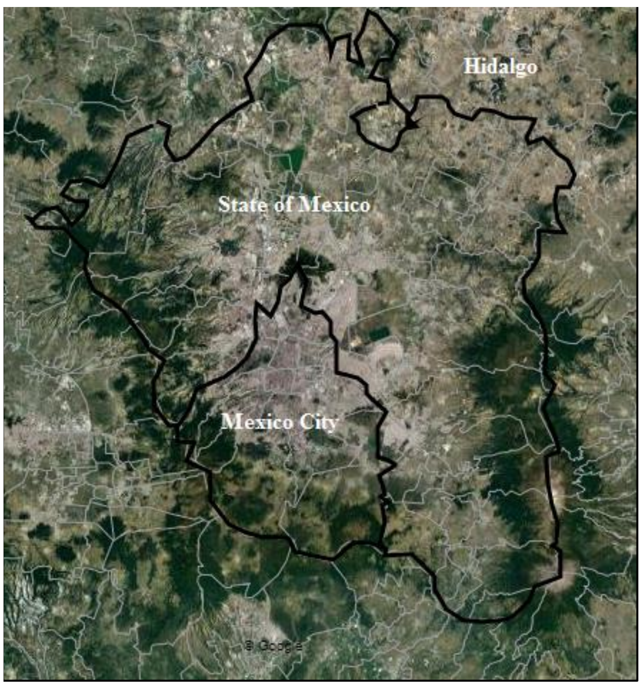
According to this example, the intervention of the authority with any environmental policy should ensure an efficient condition. Hence, if it is established a norm, it must specify a maximum emission level of 7.5 tons/month, then the costs are distributed in the same way, like the previous paragraph.

On the other side, if the authority decides to set a tax, it is important to remember, the polluter equals the given tax with its marginal abatement cost; therefore, the tax must, at the same time, be equal to the marginal damage social, with the purpose of achieving the intersection of both function, so the tax is equal to $2.5 per ton/month. In Figure 17, with this tax and the uncontrolled emission level, the polluter no faces any abatement cost, but the total tax payment is $25 (*a*+*b*+*d*+*e*+*f*). Due to this situation, the polluter prefers to reduce its emissions until 7.5 tons/month, in the efficient level, the Total Social Damage and the Total Abatement Cost are the same, $3.125; nevertheless, the total tax payment is now $18.75 (*a*+*e*+*f*). However, it seems unfair to tax all the pollutant emissions; hence, the authority starts to tax from the threshold pain, so the total tax payment is only $6.25 (*a*+*e*).

4. The Valley of Mexico Metropolitan Area (VMMA): atmospheric pollution problem

After showing the entire theoretical framework and a basal example, it will be presented a case using information from the *Instituto Nacional de Ecología y Cambio Climático* (INECC) related to the air pollution in the center region of Mexico. But first, it will be introduced a general panorama of the environmental quality; focusing on the Valley of Mexico Metropolitan Area.

The Valley of Mexico Metropolitan Area (VMMA) or the Greater Mexico City is formed by the Mexico City (16 municipalities), State of Mexico (59 municipalities) and Hidalgo (only one municipality). It has the highest urban concentration in the country and it occupies the fourth place as the most populated metropolis in Latin America (Pradilla, 2016). According to the last national census of the population applied in Mexico[3], the VMMA possess approximately 20 million persons, this translates to 17.91% of the total population of Mexico. In terms of economic performance, individually, the total value of the GDP in Mexico City was 2, 974 thousand of millions of pesos in 2016[4] (at constant prices of 2013); this represents the 17.47% of the national GDP in the same year. On the other hand, the State of Mexico earned 1,478 thousand millions of pesos equal to 8.68% of the national total and Hidalgo with 264 thousand millions of pesos equal to 1.55%. Additionally, in the VMMA, during 2014, it was estimated 2,410 shops and services, 1,935 industries and 5.8 thousand houses (Secretaría del Medio Ambiente del Gobierno de la Ciudad de México, 2016).



Map created in Mapa Digital de México V6.3.0-INEGI: http://gaia.inegi.org.mx

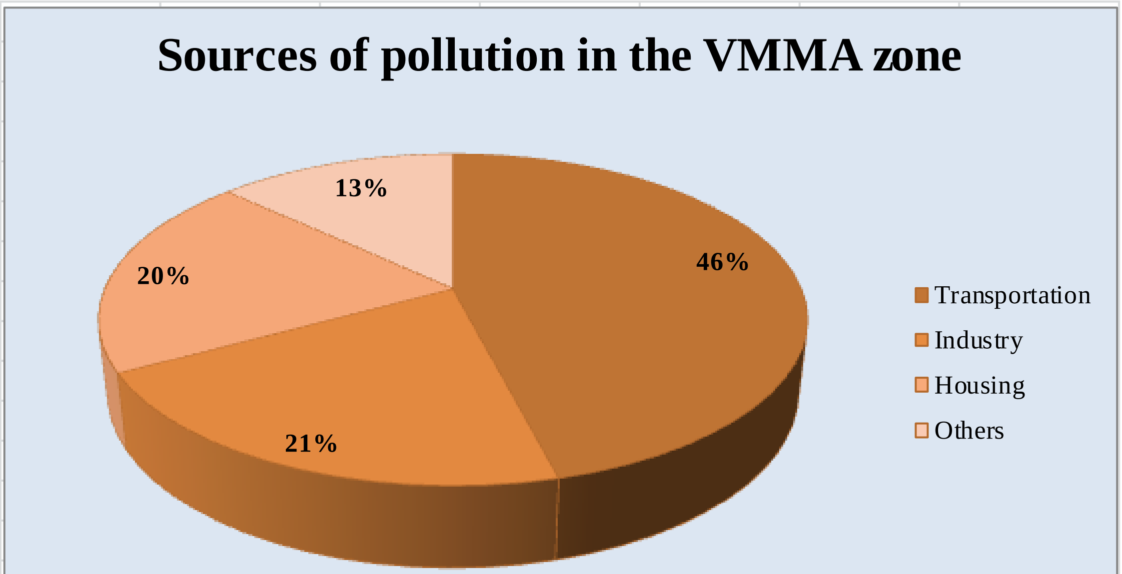
However, from an environmental perspective, the VMMA has developed serious environmental problems, especially a crisis of atmospheric pollution because it is

[3] Instituto Nacional de Estadística y Geografía. (s.f.). *Censo de Población y Vivienda 2010*. Recuperado el 16 de Abril de 2019, de Censos y Conteos de Población y Vivienda: http://www.beta.inegi.org.mx/proyectos/ccpv/2010/

[4] Instituto Nacional de Estadística y Geografía. (n.d.). *PIB - Entidad Federativa, anual*. Retrieved April 16, 2018, from PIB y Cuentas Nacionales: http://www.inegi.org.mx/est/contenidos/proyectos/cn/pibe/

considered one of the most zones with a serious atmospheric pollution problem around the world (Escalante and Ferrer, 2009). According to the World Health Organization, WHO (2018), the atmospheric or air pollution is the "contamination of the indoor or outdoor environment by any chemical, physical or biological agent that modifies the natural characteristics of the atmosphere". Since the XX century, in the decade of 50´s, the VMMA started to show symptoms of the general environmental deterioration, in the areas of water, soil, and air. But with the passage of time, the atmospheric pollution has become more notorious and its impact on the environment also has increased.

The causes or the sources of the pollution of the zone are various. Figure 18 illustrates the main polluters in the VMMA. It is possible to observe how approximately the 50% of the atmospheric pollution is caused by the transportation, including private and public vehicles. In the second place, the industrial activity generates the 21% of the pollutants, followed by the housing activities with the 20% and the rest due to other activities, such as the forest fires.



Own elaboration with information from Andrade, M., Rivera, C., & Sánchez, F. (2016). *Contaminación Atmosférica de la Zona Metropolitana del Valle de México y sus efectos en la salud.* Ciudad de México: Universidad Autónoma Metropolitana.

Figure 18: Sources of pollution in the VMMA Zone

Additional, there are some factors exacerbating this situation, such as the population growth, the increase of number and age of the vehicles, poor quality of fuels and the industrial activity (Andrade, Rivera and Sánchez, 2016; Comisión Ambiental Metropolitana, 2010; CESOP, 2017; Escalante and Ferrer, 2009; WHO, 2016). For instance, Table 2 illustrates the historical evolution of the population in the zone, it is evident the abrupt increase of people, the number of habitats has increased approximately ten times in 60 years. As a consequence, this fact shows the increment of exploiting the natural resources and the environmental deterioration.

Period	1940	1950	1960	1970	1980	1990	2000	2010
Population	1,957,499	3,340,38	5,461,675	9,094,472	12,895,607	15,563,795	18,396,677	20,116,842
Period	**1930-1940**	**1940-1950**	**1950-1960**	**1960-1970**	**1970-1980**	**1980-1990**	**1990-2000**	**2000-2010**
Growth rate	4.75%	5.49%	5.04%	5.23%	3.55%	1.69%	1.69%	0.90%

Own elaboration with information from *Zona Metropolitana del Valle de México: neoliberalismo y contradicciones urbanas* (2016)

Table 2: Population and population growth rate of the VMMA, 1940 to 2010

Furthermore, the own conditions of the Valley of Mexico, such as the weather and the topography, have provoked the slow dispersion of all the emissions; as a consequence, the pollutants concentrate for a longer period of time in the same place and the exposition to the human health also increases (Andrade, Rivera and Sánchez, 2016; Escalante and Ferrer, 2009).

It is alarming the actual condition about the transportation sector, not only because they are the main cause of atmospheric pollution, but because their use in the VMMA has increased. According to some authors (Comisión Ambiental Metropolitana, 2010; Escalante and Ferrer, 2009), the main cause of the atmospheric or air pollution of the VMMA is the excessive use of the vehicles with combustion engines, being the private vehicles the most responsible of the current situation of environmental degradation. Figure 19 presents the types of vehicles in the VMMA during 2014, and it is possible to appreciate that 80% of the vehicles in the zone were for private use; on the other hand, only the 7% were public and the rest freight vehicles.

Combined with the previous issue, there is also an excessive use of the motorized vehicles; Table 3 shows the registered cars in circulation in the VMMA. It is notorious the explosive increase since 1990 the VMMA only contemplates 2.63 million of cars in circulation and in 2016 there are approximately 11 million, so in only 26 years the number of vehicles has risen four times more, especially in the last ten years. For that reason, some authors have concluded that (Comisión Ambiental Metropolitana, 2010, Escalante and Ferrer, 2009) transportation sector must gain more importance and relevance in the construction of solutions or the establishment public of politics with the purpose of reducing the atmospheric pollution; focusing on the development of an efficient and sustainable public transport.

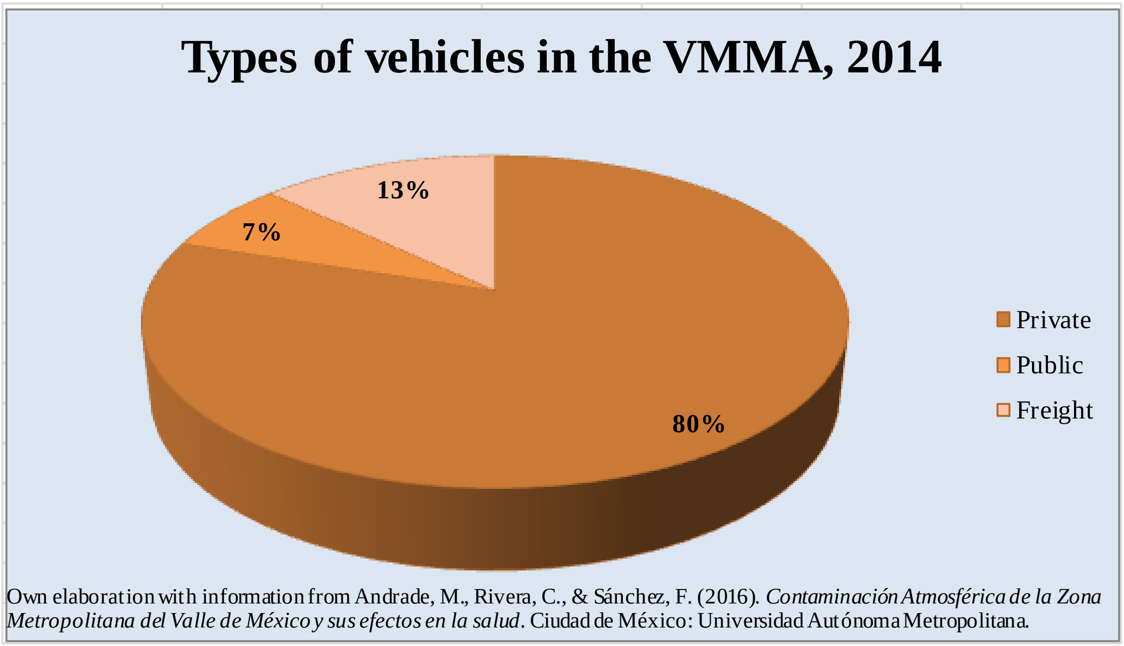


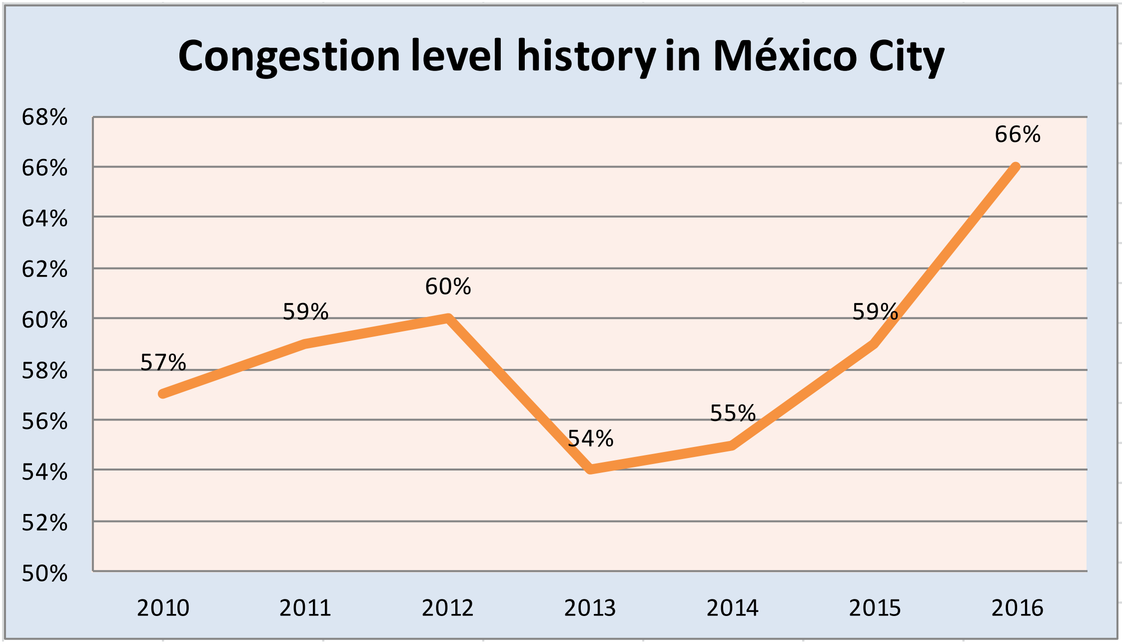
Figure 19: Types of vehicles in the VMMA, 2014

Period	**1990**	**1995**	**2000**	**2005**	**2010**	**2015**	**2016**
Vehicles	2,643,668	2,493,232	3,387,357	3,557,535	6,627,047	10,079,863	11,103,099
Period	**1985-1990**	**1990-1995**	**1995-2000**	**2000-2005**	**2005-2010**	**2010-2015**	**2015-2016**
Growth rate	13.92%	-5.69%	35.86%	5.02%	86.28%	52.10%	10.15%

Own elaboration with information from INEGI. (n.d.). Vehículos de motor registrados en circulación. Retrieved March 2018, 2018, from Registros Administrativos: http://www.inegi.org.mx/est/lista_cubos/consulta.aspx?p=adm&c=8

Table 3: Registered cars in circulation in the VMMA

In the same context, due to the increase of cars in the VMMA, the vehicular congestion also has increased; as a consequence, it provokes a greater atmospheric pollution because of the emission of pollutants increases. For example, according to the TomTom Traffic Index, only the Mexico City occupies the first place as the most congested city in the world during 2016, with a 66% extra travel time, this represents an increase of 7% with respect to the previous year and it implies almost an extra hour (specifically 59 extra minutes) to travel for any trip on average, Figure 20 exposes the congestion level history in Mexico City and its upward tendency. Moreover, in the same year, the morning peak in the Mexico City reached an increase of 96% in travel time compared to an uncongested situation, while the evening peak got an extra travel time of 101%; therefore, the environmental damage is exacerbated in the VMMA.



Own elaboration with information from TomTom International BV. (n.d.). TomTom Traffic Index: Mexico City. Retrieved Macrh 20, 2018, from https://www.tomtom.com/en_gb/trafficindex/city/mexico-city

Figure 20: Congestion level history in Mexico City

In the same sense, it is important to consider the energy consumption of fossil fuels of the zone. As it is exemplified, in 2014, the VMMA consumed by direct consumption approximately 543 Petajoules[5] of petroleum; being the principal energetic in the zone and it represents the 78.63% of the total energy consumption of the area; on the other hand, the rest of the energetics such as turbosina, woods and electric power only represent the 21.37% of the total consumption. This information is present in Table 4. Moreover, the petroleum consumption per capita was 800 liters of fuel in the same period of time (Secretaría del Medio Ambiente del Gobierno de la Ciudad de México, 2016).

Also, in this sense, the transportation sector was the one who consumed more petroleum in the VMMA during 2014, with the 58% of the total. Then, the industry in overall consumed 26% of the same energetic, and finally, the 13% and 3% of petroleum consumption are related to housing labors and shops and services sector, respectively. Figure 21 reveals this information.

[5] 1 Petajoule = 1 x 10^{15} joules, and 1 joule = 0.2388 calories

Energy Consumption in the VMMA, 2014	
Energetics	**Petajoules (PJ)**
Petroleum	543
Turbosina	22.5
Wood	0.6
Electric power	124.5
Total	690.6

Own elaboration with information from Secretaría del Medio Ambiente del Gobierno de la Ciudad de México. (2016). Inventario de Emisiones de la CDMX 2014: contaminantes criterio, tóxicos y de efecto invernadero. Ciudad de México: SEDEMA.

Table 4: Energy Consumption in the VMMA, 2014

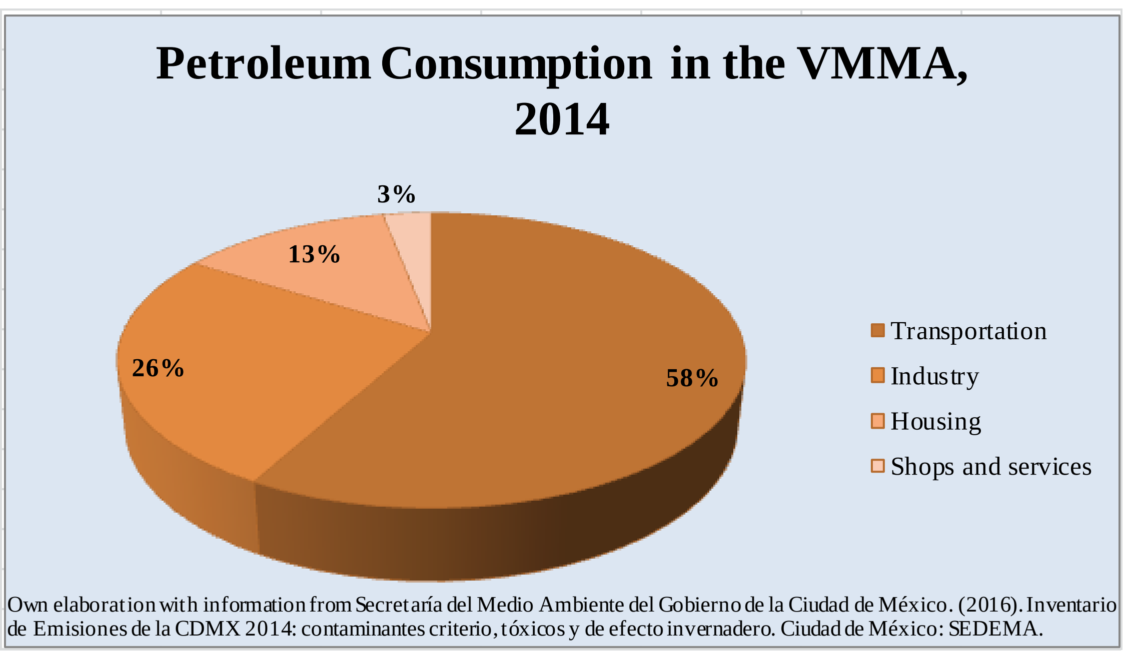


Figure 21: Petroleum Consumption in the VMMA, 2014

4.1. Actions against the atmospheric pollution in the Valley of Mexico Metropolitan Area

As it was illustrated before, the VMMA has been plagued by the atmospheric pollution; therefore, the government and the authorities in charge have made efforts with the purpose of enhancing the environmental quality. The first attempt to improve the air quality of the VMMA was in 1979, the program called *Programa coordinado para mejorar la calidad del aire en el Valle de México 1979-1982*; representing the initial step of environmental management of the air in the VMMA (Granados et al., 2006). However, in the late of the 80´s and early of 90's the atmospheric pollution got worse in the region (Andrade, Rivera and Sánchez, 2016; Granados et al., 2006, Comisión Ambiental Metropolitana, 2010).

For that reason, in the next years the authorities in charge put in action many actions to counter the environmental damage (Comisión Ambiental Metropolitana, 2011), such as "*21 Acciones para reducir la Contaminación del Aire*" and "*100 Medidas Necesarias*" in 1986 and 1987, respectively, with the intention of improving the quality of the fuels. One year later, two new programs were introduced: "*Programa de Contingencias Ambientales*" and "*Programa de un Día sin Auto*" (and then it was turned into"*Programa Hoy No Circula*" in 1989 and it still in force). Due to this panorama, during the decade of the 90's onwards, the new efforts to reduce the atmospheric pollution started to gain a formal character, Table 5 shows the programs established from 1990 till the date in the VMMA:

Program	Year	Descrption
Programa Integral Contra la Contaminación Atmosférica (PICCA)	1990-1994	It was the first attempt to reduce the atmospheric contamination in the VMMA that included the federal and local participation. It created many strategies with the purpose of: improve the quality of fuels, reduce the emissions from vehicles, control of industrial emissions and the reforestation of the zone
Programa para Mejorar la Calidad del Aire del Valle de México (PROAIRE)	1995-2000	The main objective was to protect the health of the people in VMMA, with the reduction of the atmospheric pollution, mainly through a cultural change
	2002-2010	It follows the same objectives of its predecessor. Moreover, it also considers to increase the monitoring of the pollutants in the zone and acquisition of data
	2011-2020	With this new program, its main purpose is to incorporate the new scientific findings in the ecology management of the VMMA and improve the air quality

Own elaboration with information from PROAIRE 2011-2020 and La calidad del aire en la Zona Metropolitana del Valle de México: 20 años de monitoreo (2006)

Table 5: Programs to manage the atmospheric pollution established from 1990 till the date in the Valley of Mexico Metropolitan Area

In addition to these programs, in the VMMA, standards or norms have also been established with the purpose of setting maximum or permissible limits to the main of air pollutants and avoiding the negative impact of those emissions; and therefore, to protect and guarantee the welfare of the population in short and long rung. These permissible limits are named *Normas Oficiales Mexicanas de Salud Ambiental* (known as NOM); with the particular feature that state governments are the responsible ones for the fulfillment of the NOM (Secretaría del Medio Ambiente de la Ciudad de México, 2017). Table 6 presents the NOM in force.

However, Escalante and Ferrer (2009) express that spite of the done efforts, the implementation of various programs and large quantities of money, the atmospheric pollution problem in the VMMA persists, even in the last years has worsened. For example, the most recent cases were the environmental contingencies[6] during 2016; being the ozone (O_3) the biggest responsible. As a consequence, this causes high costs for the human health and quality of life, with a decrease of competitiveness of the area (IMCO, 2016).

Besides, the NOM also are not respected (Andrade, Rivera and Sánchez, 2016; Escalante and Ferrer, 2009). According to Escalante and Ferrer (2009), the pollutants emissions of ozone and particles smaller than 10 micrometers exceed their maximum limits in 59% and 9% in all the days of one year, respectively; therefore, the environmental degradation has increased in significant levels in the VMMA.

Pollutant	Mexican Official Norm	Specifications	Last actualization
Ozone	NOM-020-SSA1-2014	95 ppb hourly average 70 ppb 8-hour moving average	August 19, 2014
Carbon Monoxide	NOM-021-SSA1-1993	11 ppm 8-hour moving average	December 23, 1994
Sulfur Dioxide	NOM-022-SSA1-2010	110 ppb average of 24 hours 220 ppb 8-hour moving average, second maximum 25 ppb annual average	September 8, 2010
Nitrogen dioxide	NOM-023-SSA1-1994	210 ppb hourly average	December 23, 1994
Particles smaller than 10 micrometers	NOM-025-SSA1-2014	75 µg/m3 average of 24 hours 40 µg/m3 annual average	August 20, 2014
Particles smaller than 2.5 micrometers	NOM-025-SSA1-2014	45 µg/m3 average of 24 hours 12 µg/m3 annual average	August 20, 2014
Lead	NOM-026-SSA1-1993	1.5 µg/m3 quarterly average	December 23, 1994

Own elaboration with information from Secretaría del Medio Ambiente de la Ciudad de México. (2017). Calidad del aire en la Ciudad de México, informe 2016. Ciudad de México: Dirección General de Gestión de la Calidad del Aire, Dirección de Monitoreo Atmosférico.

Table 6: List of Official Mexican Environmental Health Regulations in force until the date

[6] An environmental contingency is defined as "the eventual and transitory situation declared by the competent authorities, when the concentration of pollutants in the atmosphere reaches levels harmful to the health of the general population" (Mexico City government, 2006).

4.2. The costs of the atmospheric pollution

There are no doubts about the relationship between the air or atmospheric pollution and the deterioration of human quality. PROAIRE 2011-2020 (SEMARNAT, Secretaría de Salud, Secretaría del Medio Ambiente del Gobierno del Distrito Federal, 2012) expresses a huge amount of evidence that shows how the prolonged and chronic exposition of air pollutants is directly related to the mortality and morbidity of the persons: respiratory and cardiovascular diseases, chronic obstructive pulmonary disease, strokes, they also affect the neurological and reproductive systems and the development of some types of cancer such as lung cancer (Escalante and Ferrer, 2009; Munguía and Pérez, 2003; SEMARNAT, Secretaría de Salud, Secretaría del Medio Ambiente del Gobierno del Distrito Federal, 2012; WHO, 2016). Now, it will present some statistics from WHO that shows the human cost of atmospheric pollution:

- Approximately 3 million of deaths a year are directly related to the exposition of outdoor pollution. Indeed, in 2012, 6.5 million of deaths or the 11.6% of the total deaths worldwide were caused by the outdoor and indoor pollution (WHO, 2016). In the same publication, the WHO expresses that "nearly 90% of air-pollution-related deaths occur in low- and middle-income countries" (2016).
- In the same year, in 2012, the atmospheric pollution is approximately related to the 72% of premature deaths, due to the development of strokes and ischaemic heart disease, 14% of deaths caused by lung chronic obstructive diseases and pulmonary diseases, and other 14% of deaths are provoked by lung cancer (WHO, 2016).
- Also, 1.7 millions of child deaths per year are linked to the low-quality environment, and 570,000 of those deceases are caused by respiratory infections, due to the atmospheric pollution and second-hand smoke (2017). Besides, when the infants are exposed to this unhealthy situation, children and pre-schoolers are at risk to develop pneumonia, chronic respiratory diseases, heart disease and cancer in their lifelong (WHO, 2017).

Now, in the specific case of the VMMA, many authors (Andrade, Rivera and Sánchez, 2016; Comisión Ambiental Metropolitana, 2010; Escalante and Ferrer, 2009; Munguía and Pérez, 2003) have claimed that ozone (O_3) and particles smaller than 10 micrometers (PM_{10}) are the pollutants with greater presence in the VMMA (including $PM_{2.5}$); as a result, they are the emissions with more harmful effects on the human health of the zone and they are the also the main responsible for the atmospheric pollution in the region.

Currently, there are some studies that have calculated the environmental cost in the VMMA. For example, in 2015, according to IMCO (Instituto Mexicano para la Competitividad), it was estimated a total annual cost of $1,669 million of pesos related to the atmospheric pollution in the VMMA. Additionally, all the extra costs associated with the traffic congestion equal to $33,000 million of pesos (2016).

5. The case of the Valley of Mexico Metropolitan Area: a numeric example

INNEC measures the atmospheric pollution impact on the population of the center region of Mexico (it includes Mexico City, State of Mexico, Puebla, Tlaxcala, Hidalgo, Morelos and Querétaro), associated to the most important pollutant emissions of the zone, in terms of premature deaths. The information used in this research is from the *Sistemas de Monitoreo de Calidad del Aire* (SMCA). The way used to measure the impact of pollution on human health in the region is through calculating the premature deaths associated with the air pollution. Therefore, the researcher simulates scenarios with different levels of reduction of the emissions; principally considering the established limits of the NOM and the standards of the WHO. Table 7 shows a comparison between both norms with respect to these emissions:

Maximum values of emissions, according to the type of pollutant and standard				
Polluter	**Exposure metric**	**Maximum limits**		
		NOM	**WHO**	**Units**
PM_{10}	Annual average	40	20	µg/m³
$PM_{2.5}$	Annual average	12	10	µg/m³
O_3	Mobile average	70	50	ppb

Own elaboration with information from: Instituto Nacional de Ecología y Cambio Climático. (2017). Estimación de impactos en la salud por contaminación atmosférica en la región centro del país y alternativas de gestión. Mexico City: Coordinación General de Contaminación y Salud Ambiental.

Table 7: Maximum values of emissions according to the NOM and WHO

Furthermore, and in the same sense, the INECC valuates this mortality using the "Value of a Statistical Life" (VSL) method, with of purpose of obtaining a monetary value, which it bases on calculates the willingness to pay (WTP) of people to marginal variations of reducing the probability of a premature death, also the VSL is defined as the value to avoid the death of an unidentified person within a society and who belongs to it. (INECC, 2017) The paper contemplates different approaches and information to measure the VSL; however, in this case, it will use a value of $1.6 million of pesos (at 2014 prices) per human life; the reason, it was calculated from a local contingent valuation study realized in Mexico[7].

Considering the previous statements, the INECC shows estimations about avoided premature deaths and their associated monetary cost with the fulfillment of the NOM and WHO norms of the pollutants. The estimated results for the case of the VMMA (Mexico City, State of Mexico and Hidalgo) are expressed in the following Table 8:

[7] The second estimator is based on a VLS from USA, adjusted with the characteristics of Mexico equal to 13.85 million of pesos at 2014 prices. For more information, check the paper.

	Avoidable premature deaths and costs (in millions of pesos at 2014 prices) by scenario of the reduction of PM_{10}, $PM_{2.5}$ and O_3 in the entities of the VMMA						
Entities	Guidelines	PM_{10} Avoidable deaths	Costs ($)	$PM_{2.5}$ Avoidable deaths	Costs ($)	O_3 Avoidable deaths	Costs ($)
México City	NOM	1,270	$2,032.00	4,038	$6,460.80	191	$305.60
	WHO	5,945	$9,512.00	4,709	$7,534.40	755	$1,208.00
State of México	NOM	1,067	$1,707.20	2,978	$4,764.80	68	$108.80
	WHO	4,382	$7,011.20	3,420	$5,472.00	330	$528.00
Hidalgo	NOM	0	$0.00	284	$454.40	0	$0.00
	WHO	36	$57.60	293	$468.80	2	$3.20

Own elaboration with information from: Instituto Nacional de Ecología y Cambio Climático. (2017). Estimación de impactos en la salud por contaminación atmosférica en la región centro del país y alternativas de gestión. Mexico City: Coordinación General de Contaminación y Salud Ambiental.

Table 8: Information obtained from the INECC

It is possible to appreciate two important facts: First, there is a significant variation of the avoidable mortality and their associated average costs between the guidelines of the NOM and WHO; being relatively less restrictive the first one. This fact is principally evident in the case of PM_{10}. Second, the low estimates in the state of Hidalgo. The reasons are various: it only considers two monitoring stations (located in Tizayuca and Ajacuba), the lack of information provided from the monitoring stations and the representativeness of the state for the VMMA is very low.

From the perspective of the NOM, if the VMMA would have fulfilled the norm of the PM_{10} in 2014, a total of 2,337 deaths would have been avoided; this represents $3,739 million of pesos. For the case of the $PM_{2.5}$, a total of 7,300 deaths would have been avoided, which represents a loss of $11,680 million of pesos. Finally, the fulfillment of the O_3 would have avoided 259 of deceases and this is equal to $414.4 million of pesos. On the other hand, in the same year, if the VMMA would have fulfilled the WHO norms, 10,363 deceases would have been evaded for the case of PM_{10}, this translates into $16,580.8 million of pesos, 13,475 deaths complying the limit of $PM_{2.5}$, equal to $13,475 million of pesos, and for the O_3 a total of 1,087 deaths that represents $1,739.2 million of pesos.

Once the main information from the INECC has been presented, the construction of the main model continues. First of all, it is important to choose a pollutant, in this instance, this paper will use the PM_{10} emissions, and just as a mere example. Also, all the information related to the state of Hidalgo does not account due to the lack of representativeness. Moreover, it is vital to consider the followings assumptions for the establishment of the model in the VMMA:

- The VMMA is considered as a whole; therefore, their emissions are measured as the annual average concentration of PM_{10} of Mexico City and the State of Mexico. In the same work, the INECC calculates the concentrations of that polluter for the

Mexico City and the State of Mexico equal to 44 ug/$m^3$and 45.7 ug/m^3, respectively; as a consequence, the average of the region is 44.85 ug/m^3.

- Due to lack of information to determinate a specific pain threshold, the permissible limit set by the WHO will play that role, equal to 20 ug/m^3. This means that emissions under this level do not cause damage and hence there is no cost.
- The minimum desirable situation for the people in the VMMA is the level of 40 ug/m^3 annual average ofPM_{10}, that is, they wish that at least the Mexican norm has been fulfilled.
- Both functions, MDS and MAC, are considered lineal functions for simplicity.

Now, it is possible to graph the information of the PM_{10} for the case of the VMMA and make some estimation to prove the effectiveness of taxes. The calculated total damage is 10,327 of premature deaths and it is equal to $16,523.2 million of pesos, that is, the area *a+b*. This is just the sum of the costs of Mexico City and the State of Mexico according to the parameter of the WHO. Consequently, the marginal social damage associated with the current level of 44.85 ug/m^3 is approximately $1,329.85 million of pesos (if the formed area is considered as a figure triangular). Then, the MSD function estimated is:

$$MSD = -1{,}070.28 + 53.5145(PM_{10})$$

Also, in this case, the MAC function is given; hence, it crosses the MSD function at the point of 44.85 ug/m^3, and it is the initial point of balance. Figure 22 is graphed both functions. As it was established before, the VMMA has overtaken the limits of PM_{10}emissions; thus, a tax will be imposed with the purpose of achieving the NOM, so the question: *what is the magnitude of the tax to accomplish to accomplish this goal?* Well, it is possible to calculate the value of a tax that allows reaching the emission level of 40 ug/m^3 annual average of PM_{10}. The results show a tax equal to 12.125% to get the desirable situation (See appendix). As a result, if the authorities are able to impose this tax in the VMMA, the total social damage associated with these emissions will be reduced, on average, by a total of $5,820.2 million of pesos, and this represents a reduction of 3,637 premature deaths in the zone too.

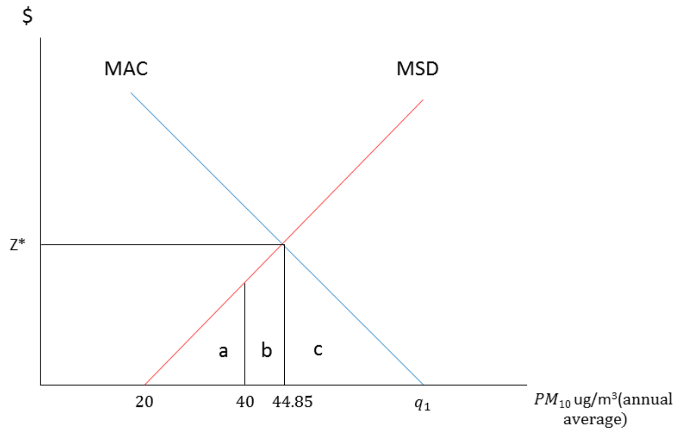


Figure 22: Graphic representation of the case of the VMMA

Nevertheless, it is important to remember some issues already expressed in the theoretical framework for a better treatment of the problem. First, it could be convenient do not ensure the VMMA as a whole. It would be better dividing the zone and consider many polluters in the region. The criterion(s) to do this division can be: locate the places with more concentration of polluters, according to the concentrations of emissions in the air, or the amount of the population susceptible to atmospheric pollution damage[8].

To explore the situation of many polluters in the VMMA, for simplicity, the zone is divided into their respective entities, State of Mexico and Mexico City. Therefore, all the polluters in the State of Mexico will pay a tax according to the pollutant level of the place, and polluters from Mexico City will do the same. The method to calculate an optimal tax for the State of Mexico and Mexico City is the same used in the general scenario. Hence, it keeps the same assumptions for both: MSD and MAC functions are linear, the pain threshold is 20 ug/m^3 and the minimum desirable condition is a maximum level of 40 ug/m^3.

As it was mentioned before, the INNEC calculated the annual concentration of PM_{10} of Mexico City (44 ug/m^3) and the State of Mexico (45.7 ug/m^3) in 2014; as a consequence, with the objective to reach the level of 40 ug/m^3 for both places, it is necessary to establish different taxes. To find the optimal taxes, it is important to estimate, in first place, the MSD functions of both places, following the same procedure exposed in the appendix, the functions are:

$$MSD_{MC} = -660.557 + 33.0278(PM_{10})$$

$$MSD_{SM} = -424.606 + 21.2303(PM_{10})$$

[8] With this, the authorities could establish physical limits within the zone according to common characteristics, in which it could create a different environmental normativity for each one of them.

Where MSD_{MC} is the Marginal Social Damage of Mexico City and MSD_{MC} is the Marginal Social Damage of State of Mexico. Now, with the MSD functions it is possible to estimate the taxes to accomplish the emission level of 40 ug/m^3 for both areas:

$$t_{MC}^{*} = 10\%$$

$$t_{SM}^{*} = 14.25\%$$

As a result, to achieve the level of 40 ug/m^3 in the VMMA, it would be necessary to set two different taxes, in according with two different zones and polluters. This result has a great meaning in the design of environmental policies because it expresses that the achievement of a desirable level emission in one single region, it is important to establish different taxes for the different polluters.

To illustrate this fact, let´s considered the situation of heterogeneous polluters in the VMMA because the polluters generate distinct impacts on the health and those differences are represented in the MSD functions of MSD_{MC} and MSD_{SM}; however; the pertinent authorities ignore this issue, and they proceed to impose a unique tax for the whole area equal to 12.125% on the PM_{10} emissions. How do the polluters react? The polluters who face MSD_{MC} will end with an annual concentration of 39.24 ug/m^3; on the other hand, the polluters with MSD_{SM} will have 40.76 ug/m^3. Thus, if we get an average of the VMMA, the annual concentration would be 40 ug/m^3, the same result if we impose different taxes. Nevertheless, someone could consider the distribution of the emissions is unfair, in spite of the fact that taxation is equal in the whole region, since in some areas of the VMMA the concentrations of PM_{10} are relatively higher than others, so the negative impact on that specific part society also will be higher, but this phenomenon is compensated due to the other zones with a reduction of the pollutant emissions beyond of the desirable level.

Another important issue is the response of polluters when there are different taxes. If polluters do not face associated costs of moving from one place to another, it is evident that polluters would prefer to be in the zone with the lowest tax, in this case, Mexico City possesses the lowest tax equal to 10%. Hence, the polluters move to Mexico City, and its environment would get worse, in contrast, in the State of Mexico the PM_{10} emissions would disappear completely. But it is possible that on average, the concentrations in the VMMA still the same, that is, 40 ug/m^3 in the entire zone[9].

Consequently, it is acclaimed two important points when it is considered heterogeneous polluters and the establishment of a tax as an environmental political tool: 1) The distribution of the costs: set a single tax is supported by the polluters because they pay the same amount, but the community will experience different levels of pollution and some do

[9] To achieve this result, the emissions in Mexico City would have to increase until reach a level of 80 ug/m^3. With zero emission in the State of Mexico, the average of the VMMA would be 40 ug/m^3

not ensure the minimum desirable level; thus, the society do not support the establishment of only one tax. On the other hand, set different taxes is not supported by the polluters because some of them will pay taxes relatively higher than others, but ensuring the same level of pollution for all the society. 2) The mobility of the polluters: the lower the costs the polluter faces to move from one point to another, a greater capacity to move to the place with the lowest tax.

6. Conclusions

In conclusion, this document sustains that the use of economic instruments, as the implementation of a tax, offers a better alternative than normative instruments in the context of environmental regulation. Also, it proposes one mechanism to calculate the value of a tax that ensures the optimal pollution level given the functions of Marginal Social Damage and Marginal Abatement Cost.

Because of the lack of information and the heterogeneity of the polluters that faces the authority, an environmental tax allows that each polluter take the best decision in which how to distribute its cost; considering its marginal abatement costs. Therefore, the polluter could choose the scenario that permits the minimization of its total costs. Even though a norm seems to be fair because it limits the pollutant emissions of all the sources in the same quantity, the polluters are not able to adapt the best choice; as a consequence, the fairness is reduced at the same time as the efficiency.

Additionally, a tax also offers more incentives for the sources to invest in R&D with the purpose of reducing their emissions. When a tax is established, the polluter deals with two types of costs associated with their emissions, the total tax payment, and the Total Abatement Cost; as a consequence, the polluters are motivated to exploit new and different channels to decrease the emissions. Also, the authority collects resources associated with the tax, this represents an opportunity to pay back the polluters and invest in R&D, allocate these resources among the affected or a combination of both.

On the other hand, when the norm is sufficiently restrictive for the source, in this case, it is possible that the phenomenon of “technology forcing" appears; however, the polluters can take advantage of this restrictive scenario because they will demand grace periods, and in this way, the polluters are able to indefinitely prolong these periods with the excuse of the norm is hard to achieve, then the technology forcing disappears. Additionally, the authority also faces the enforcement costs due to the surveillance and compliance with the norm. In spite of these differences, a tax could be an excellent complement for the norms, if we believe on the equivalence of both instruments, because it helps to reach the desirable level or the optimal level of pollution.

With respect to the specific case of the Valley of Mexico Metropolitan Area, the environmental quality of the zone could improve significantly with the use of a tax, and it does not only work with the atmospheric pollution, also it covers the problems related to the water, deforestation, and so on. Also, in this example, it is possible to observe how the distribution of costs could be in a context of heterogeneous polluters. The authority has to put a lot of attention in this issue because the obtained result will depend on the chosen criterions to take the decision; nevertheless, this case underlines the heterogeneity of the MSD functions, this translates into different impacts generated by different polluters meanwhile the MAC function was fixed and equal for all the polluters, so the heterogeneity of the polluters can be also explored in the MAC function, that is, technological differences to reduce their pollutant emissions. Likewise, the government has to be conscious about the capacity of polluters to move to places with a relatively lax environmental policy.

Ultimately, it is important to insist to the Mexican authorities a greater involvement in the design and analysis of the environmental policies; hence, it is necessary to increase the amount of investigations, as well as the creation and proliferation of information and measurements related to these kinds of topics. In this way, it is possible to improve the welfare of the society.

7. Appendix

It has been mentioned a crucial assumption, the Marginal Social Damage function and the Marginal Abatement Cost functions are considered as linear functions. That is:

$$y = a + mx$$

Where y is the dependent variable, x is the independent variable, a is the intersection and m is the slope of the function.

Also, it was calculated a total social damage equal to $16,523.2 million of pesos related to the PM_{10} level of 44.85 ug/m^3 of the VMMA. Moreover, the explication of the theoretical model establishes that total social damage is calculated as the area under the curve of the Marginal Social Damage function until the point of the actual emission level; therefore, it shapes the figure of a rectangle triangle, with an area equal to the value of the total social damage.

With the finality to estimate the Marginal Social Damage function, it is estimated the base and the height of the rectangle triangle. The base of the triangle is just the distance between the current emission level (44.85) and the threshold of pain (20), so the horizontal leg is equal to 24.85 ug/m^3. The height is calculated in the following way:

$$Area\ of\ a\ triangle = \frac{1}{2} x(base)(height)$$

$$Area\ of\ a\ triangle = 16{,}523.2 = \frac{1}{2} x(24.85)(height)$$

$$Height = \frac{(16{,}523.2)(2)}{24.85} = 1{,}329.84$$

Taking advantage of the previous assumptions it is possible to calculate the marginal social damage related to 44.85 ug/m^3, that is, $1,329.64 million of pesos. Now, with this information, it is able to calculate the slope of the MSD function from two points:

$$m = \frac{y_1 - y_0}{x_1 - x_0} = \frac{1{,}329.84 - 0}{44.85 - 20} = 53.5145$$

Then, the interception of the MSD function is:

$$y = a + mx$$

$$0 = a + 53.5145(20)$$

$$a = -1{,}070.28$$

So, the estimated MSD function is:

$$MSD = -1{,}070.28 + 53.5145(PM_{10})$$

Now, with the purpose of measuring the tax, it is used the following expression:

$$\frac{MSD + 1{,}07028}{53.5145} = PM_{10}(1 + t)$$

It measures how the emissions changes when the tax varies. Therefore, if it is set a level of 40 ug/m^3, the optimal tax is:

$$\frac{1{,}329.84 + 1{,}07028}{53.5145} = 40(1 + t)$$

$$t^{*} = 12.125\%$$

As a conclusion, in this scenario, the authority could establish a tax on the PM_{10} emissions in the VMMA to reduce those emissions until the level of 40 ug/m^3.

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