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A Review of the Economist's Approach to Pollution and Its Control

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Abstract

Pollution, being a social and environmental problem, has been a subject of inquiry by environmental economists. Environmental economists see pollution as an externality problem or a market failure, and have therefore investigated factors affecting pollution and its control. Consequently, they advocate the use economic instruments to control pollution. However, despite the widely acclaimed potency or effectiveness of economic instruments in the literature, their real-world application has not caught on, the situation which could be caused by the shortcomings associated with the application of economic instruments. This paper, therefore, critically reviews economic approach to pollution and its solutions, with a view to providing ways the associated shortcomings or problems could be overcome. The paper also conceptualizes and classifies pollution as well as externalities into different taxonomies. Examining the taxonomies will prove useful in designing policy measures to combat various types of pollution, for each type requires a unique policy measure. Failure to recognize the distinctions among the different types of pollution may lead to counterproductive policies. One of the factors found to be responsible for the weak application of the instruments in the real world is implementation costs. An option recommended for policymakers is to minimize those costs associated with implementing economic instruments by designing pollutant-specific policies, while other tractable problems should be tackled as recommended in this paper.

Keywords: Pollution; Externalities; Economic Instruments; Coase Theorem; Materials Balance

Introduction

Different fields of study have perceived the term pollution differently, and hence have provided different solutions to it. Among the diverse approaches to solving pollution problem, the economist's approach seems to be the most promising, effective and efficient, both theoretically and empirically. Evidence galore exists in countries which have implemented some of the economic instruments and have witnessed significant reductions in the level of pollution. For example, the effectiveness of deposit-refund system-the economic instrument for controlling litter pollution-has been validated empirically. Two independent studies, one in 1979 and the other in 1980 both conducted on the United States, found that, as a result of the imposition of deposit/refund on containers, container-related litter dropped by 56% in 1979 and 69-77% in 1980 (USEPA, 2001) [1]. After the introduction of deposit-refund instrument, Michigan recorded a significant reduction in the amount of beverage-related litter by 85% in 1979 (Porter, 1983) [2]. Hawaii launched its deposit-refund system in 2005 and achieved a 60% reduction in beverage containers as a percentage of total litter between 2005 and 2008 (Abell Foundation, 2012) [3]. Due to the implementation of the instrument in Alberta, in 2010 recycling and redemption rates of beverage containers were approximately 97% and 91%, respectively (Reid, 2011) [4]. Oregon reduced litter by about 85 percent just two years after implementing deposit-refund mechanism.

Furthermore, at one time, success story of deposit-refund mechanism in relation to reduction of litter was also told of Hungary, which recorded between 70 and 80% reduction; Estonia, 90%; Finland, 92% and 94%; Germany, 98%; Norway, 82% and 92%; Sweden; 86 percent; and Netherlands, between 95 and 99% reduction (Thomas & Callan, 2010; Astrup & Hedh, 2011) [5,6]. Fletcher, *et al*. reported evidence of the efficacy of deposit-refund instrument in Sweden, Denmark and Germany, where they found that due the implementation of deposit-refund instrument, Sweden increased its recycling rates of plastic packaging from 17% to 30% between 2003 and 2005 and then 44% in 2006 [7]. In the same period, however, the authors found that the recycling rates for polyethylene terephthalate plastics were between 77% and 82% under the system. According to them, the return rate for 33cl glass bottles stood at 99% and 90% for 50cl glass bottles. In Denmark, return rates in 2007 were 84% for cans, 93% for plastic bottles, and 91% for glass bottles, and in Germany, the return rates were 95 to 99% in 2005.

Despite these successes and others recorded of the efficacy of the economic instruments in general, policy makers seem not to favour the economist's approach. This paper, therefore, critically reviews the economic approach to pollution and its solutions.

The term pollution refers to damage done to the environment-land, air or water-that makes it unsuitable for human, plant, and animal lives. The World Health Organization defines pollution as "[the alterations of the environment] in composition or condition directly or indirectly as a result of activities of man so that it becomes less suitable for some or all of the uses for which the environment would be suitable in its natural state" [8]. This definition implies that pollution involves both qualitative and quantitative changes in the physical, chemical, and biological properties of the environment that results from intentional or unintentional discharges of waste materials. To World Health Organization, "pollution occurs when environmental changes create or are likely to create nuisances or hazards to public health, safety or welfare…or other legitimate uses of environmental components…"

Economists see pollution as a negative externality. To them, pollution is a consequence of an absence of prices for certain scarce environmental resources, such as clean air and water [9]. It is an output that occurs outside of normal market transactions [1]. Pollution is any by-product of production or consumption that harms or violates the property rights of others [10]. Occurrence of pollution distorts the classical market outcome.

A person engaged in a polluting activity is called a polluter. However, the word polluter has diverse meanings. Generally speaking, a polluter can be seen as a person or a firm whose production or consumption activities generate by-product that harms or violates the property rights of others. A polluter could also be defined to include not only anyone engaged in polluting activities but also anyone who is engaged in such activities as resource use which contribute to environmental degradation [10]. This definition is rather broad in that it includes natural resource use as pollution. It sees a polluter as not only anyone who is harming others, but also anyone who is using his own property and resources in a way that is not approved by government officials or environmentalists Thus, a polluter is anyone who directly or indirectly contributes to environmental degradation and/or who creates conditions leading to such degradation.

The object of this paper is to provide a critical review of the economic approach to pollution. Section 2 discusses the taxonomies of pollution. While Section 3 presents pollution as an externality problem, Section 4 presents the neoclassical theory of externalities. The economist's solutions to externalities and concluding remarks are contained in Sections 5 and 6, respectively.

Taxonomies of Pollution

Pollution has been variously classified in the literature. Examining the taxonomies of pollution will prove useful in designing policy measures to the various types of pollution, for each type requires a unique policy measure. According to Tietenberg and Lewis, the failure to recognize the distinctions among the different types of pollution may lead to counterproductive policy [5]. This paper therefore classifies pollution as follows:

Natural and Anthropogenic Pollution

Thomas and Callan define natural pollution as one arising from non-artificial processes in nature. Examples are particles from volcanic eruptions, salt spray from the oceans, and pollen. Anthropogenic pollution results from human activity. It is human-induced and includes all residuals associated with consumption and production [5]. Examples include litter, waste, gases from combustion, and chemical waste from certain manufacturing processes. Of the two types of pollution, anthropogenic pollution is of greater concern to environment economists.

Land, Water, Air, and Noise Pollution

Air pollution is the addition of harmful substances to the atmosphere which results in damage to human health and the environment. Such substances are noxious gases like carbon dioxide (CO_2), methane, and carbon monoxide (CO). Water pollution is the contamination of water sources, which makes the water unfit or unsuitable for both human consumption and animal life. It ranges from simple addition of dissolved or suspended solids to discharge of the insidious and persistent toxic pollutants such as pesticides, non-biodegradable water-sachets, heavy metals, and chemical compounds.

Land pollution is the degradation of the land or the misuse of the soil probably by poor agricultural practices, industrial waste dumping and indiscriminate disposal of urban wastes. It includes litter and pollution of the soil. Noise pollution refers to unwanted, undesirable sound or noise such as that produced by milling or grinding machines, airplanes, traffic or industrial machinery. Possible effects of noise pollution include loss of hearing, productivity loss, sleep loss, stress, and distraction.

Point-Source and Nonpoint-Source Pollution

Distinction based on the identifiability of the source of pollution is also usually made in the literature. On this basis, pollution is classified into point-source and nonpoint-source pollution. Point-source pollution refers to pollution that comes from specific, localized and identifiable sources, such as sewages, pipelines or industrial smoke-stacks. Point sources discharge pollutions from specific locations, such as factories, sewage treatment plants, and oil tankers. Non-point source pollution refers to pollution that comes from dispersed, diffuse or unconfined sources, such as contaminated water runoff from urban areas or automobile emiss [5,12]. Under this classification, pollution is also categorized based on the mobility of the source of pollution: stationary pollution and mobile pollution. While stationary pollution refers to fixed-site pollution, mobile pollution refers to nonstationary or nonfixed-site pollution [5]. Examples of mobile pollution include exhaust from a moving vehicle.

Stock Pollution and Fund Pollution

Stock pollution refers to pollution for which the environment has little or no absorptive capacity [11]. It is caused by materials that either do not decompose or decompose slowly in the environment [12]. Examples of these nonbiodegrabale materials or pollutants are plastic sachets, bottles, metals, glasses, etc. The damage caused by this type of pollution increases and persists as the pollution accumulates. By its nature, stock pollution creates interdependence between the present and the future, since the damage imposed in the future depends on current actions [11].

Fund pollution refers to pollution for which the environment has some absorptive capacity [11]. It is caused by degradable materials, such as sewage, paper, and other organic materials, that rapidly decompose through natural process. This type of pollution becomes a problem only when added to the environment faster than the pollutants decompose [12]. That is, fund pollution does not accumulate as long as the emission rate does not exceed the absorptive capacity of the environment and as a result, the link between present pollution and future damage is broken-current pollution causes current damage, and future pollution causes future damage so that future damage is independent of current pollution [11].

Local, Regional, and Global Pollution

This classification is based on the zone of influence of pollution. On this basis, pollution can be local, regional or global, depending on how far-reaching the effect from the polluting source. Local pollution refers to environmental damage that does not extend beyond the polluting source and is typically confined to a single community [5]. Smog is an example of local air pollution. Local effects, especially of smog, can be aggravated by local topography. Smog contains ozone, which is harmful in the lower atmosphere and beneficial in the stratosphere. While ozone in the lower atmosphere kills vegetation and irritates lung tissue, ozone in the stratosphere helps protects the earth from ultraviolet rays of the sun. Another example of local pollution is litter or solid waste.

Regional pollution is one whose damage whose damage is felt at greater distances from the source of pollution, usually in another community, city, state, or nation. Its damage extends well beyond the polluting source. Acidic deposition (acid rain), precipitation, and some surface water pollution are typical examples of regional pollution. Global or International pollution occurs when the damage of pollution affects the entire planet. For instance, there is tendency for air pollution to extend beyond a region to cause global effect since it is air borne. Thus, there is possibility of cross-border effects of air pollution. International effects take place in the stratosphere. Pollutants, such as oxides of carbon, sulphur or nitrogen, are borne by air across borders, from the source to the receptor countries.

International pollution is difficult to control partly because international cooperation is needed to achieve effective solutions [5]. Classic examples of effects of global pollution include global warming and ozone depletion. The global warming will have different effects in different regions or countries. These categories are not mutually exclusive in that it is possible for a pollutant to be in more than one category. For instance, sulfur dioxide and nitrogen oxides are both local and regional pollution [11]. In addition, the effects of pollution may be immediate (primary) or delayed (secondary or intertemporal). Primary effects of pollution occur immediately after contamination occurs, such as the death of marine plants and wildlife after an oil spill at sea. Secondary effects may be delayed or may persist in the environment into the future, perhaps going unnoticed for many years.

Pollution as an Externality Problem

Pollution is a classic example of what economists describe as an externality. An externality is said to occur when production or consumption behaviour of an economic agent favourably or adversely affects the welfare of another economic agent without adequate reflection of the effects in the market price of the good or service. An externality is "an unintended or incidental by-product of some otherwise legitimate activity" [13]. The externality effects, which may be costs or benefits, are borne by a party other than the parties that are directly involved in the market transaction. The term externality first appeared in Marshall as external economies/diseconomies-the economies/diseconomies external to the firm but internal to the industry [14]. However, little attention was given to the concept until it was developed and extended by Pigou, who suggested the first interventionist policy [13,15]. Later on, the term was further extended and given various alternative names such as spillover effects, neighbourhood effects, external effects, side effects and secondary effects.

To properly situate pollution in the right context, it is deemed necessary to classify externalities following the taxonomies given in this section. Classified below is a wide range of externalities noted and discussed in the literature.

Classification Based on Type of Effects

Based on the type of effects, externalities have been classified into positive and negative externalities. A positive externality is a beneficial externality in which an economic agent gains or profits free of charge from the production or consumption of a good by another economic agent. Positive externalities yield benefits, rather than imposing costs, to the affected party. An example is when a landlord puts on a light at night in front of his building. He is not the only that benefits from the light, his neighbours and nightly passers-by also do.

Negative externalities, on the other hand, are those externalities that impose costs or inflict damage on other party or the society as a whole. They are also called pollution externalities or external diseconomies. According to Coase, negative externalities are those actions of firms or individuals that have harmful effects on others [16]. They are thus referred to as public "bads". They adversely affect the third party who might not be part to the market transactions. Thus a negative externality arises when a producer or consumer loses or suffers from the production or consumption of good by another producer or consumer. A classic example of negative externalities is pollution (air, land or water pollution). A smoke-emitting factory situated in a residential area generates pollution in terms of smoke and engine-noise, which can damage the health of the inhabitants in the area; so can the smoke produced from burning water sachets.

A negative externality costs the producer nothing, but is costly to society. A company that pollutes loses no money in doing so, but society must pay to take care of the problem caused by the pollution. Positive externalities are probably more common, yet they do not get much attention because they generally do not pose serious problems that must be addressed through public policy.

Classification Based on the Source of Externality

The two principal agents of externalities are producers and consumers. Externalities are produced by either consumers or producers. Given this, the two primary sources of externalities are production and consumption. Production externalities are simply the externalities resulting from production activities. Externalities generated by oil production activities in the Niger-Delta region and that of smoke-emitting factory are typical example of production externalities. Consumption externalities usually arise mainly from the disposal of waste generated from the consumption of a good. A negative consumption externality is said to arise when the consumption and disposal of a good or service by one consumer confers a disadvantage on, or adversely affects, the welfare of others in the society [17].

Classification Based on Price Reflection

Based on this criterion, externalities are classified into technological and pecuniary externalities. Technological externalities, or real externalities as sometimes called, are those that do not reflect the social costs or benefits of a product in its price. They, therefore, cause divergence between private and social costs and benefits-a source of market failure. Negative technological externalities tend to undervalue the prices of commodities, and hence cause overproduction and over consumption, and ultimately inefficient allocation of resources.

Pecuniary externalities, on the other hand, are not true externalities. This is because their effects are captured in market prices and do not affect the market's ability to allocate resources efficiently, and hence they do not cause market failure. According to Tietenberg and Lewis, pecuniary externalities arise when the external effect is transmitted through altered prices [11]. Thus, real or technological externalities become pecuniary externalities after the external effects have been internalized. The fact that the behaviour of some people affects the welfare of others does not necessarily cause market failure; markets are efficient as long as the effects are transmitted via market prices [18].

Take, for example, the case of someone buying up acres of land in a town. His action will cause the prices of lands to rise, thereby making other people who want to buy the lands worse off. This is pecuniary externality because the effect is transmitted through prices, and is considered part of the normal functioning of the market. Thus pecuniary externalities do not produce market failure because the resulting prices and rents reflect scarcity of land. The rise in the price of a product that results from increased demand for the product is an accurate reflection of societal preferences, and the price helps to assure that the right mix of products is produced [19].

Classification Based on the Perceptibility of Effects

Under this classification, externalities can be obvious or hidden. An externality is said to be obvious when its effects are conspicuous or clearly perceptible; otherwise, it is hidden. Hidden externalities have insidious effects. The extent to which an externality may be obvious or hidden depends on the awareness level of its effects, the state of scientific advancement, the opportunities for communication, and category-small or large, poor or rich—of agents affected [20]. The category of agents affected determines the level of importance or the priority that will be accorded to the externality problem. The externalities affecting the rich are likely to be more pronounced than those affecting the poor, and they are likely to take precedence over the latter.

Spacio-Temporal Classification

Robinson and Ryan classify externalities on spacio-temporal basis. According to the authors, spatial externalities occur when an externality-generating activity takes place at one location but its effects are felt at another location. Spatial externalities are caused by regional and global pollution. A temporal externality occurs when there is a long-time lag between when an externality-generating activity takes place and when its effects are felt or become apparent. It may be due to local, regional or global pollution. The environment may not suffer noticeable damage immediately, but over a longer time, the damage or effects become profound and irreversible. Temporal externality problems could be caused by the tyranny of small decisions [21].

Other Classifications

Based on the mapping of the number of agents involved in the two parties, Stewart and Ghani (1991), quoted in Egwaikhide and Aregbeyen, and provided a crosscutting classification of externalities as follows:

- One-one: one agent affects the welfare of one other agent.
- One-few: one agent affects few other agents.
- One-many individually: one agent affects each of many other agents.
- One-many collectively: one agent affects the welfare of each many other agents, when the effects are added up, for example, radia tion effects of nuclear power stations.

- Many individually-many individually: many agents affect many agents individually; it is the same as one-one but multiplied by number of agents.
- Many individually-many collectively: individual agents affect many agents collectively. It is the same as one-many collectively, but multiplied by number of agents.
- Many collectively-many individually: many agents collectively affect many individual agents, for example, ozone destruction and farming desertification.
- Many collectively-many collectively: many agents collectively affect many other agents collectively, for instance, car pollution and pollution from water sachets.

Despite their diversity in the literature, externalities have certain common characteristics. First, externalities are incidental, or unintentional, in nature-that is, they are not deliberately produced or absorbed-they are unintended by-products of apparently legitimate economic activity. Externalities, negative or positive, are not under the control of the persons or firms that experience them. Secondly, they can be produced by firms as well as consumers. Thirdly, externalities can be positive or negative and can be public goods or public bads. Fourthly, externalities can be reciprocal as well as unidirectional in nature. Finally, they appear to increase with economic growth. Economic growth precipitates environmental degradation. In other words, increases in industrial activities cause environmental pollution. Ever-increasing output generates an ever-increasing stock of pollution [20].

Economic Theories on Pollution[1]

Pollution, being a social and environmental problem, has been a subject of inquiry by environmental economists. Economists see pollution as an externality problem or a market failure. They have investigated why pollution exists and how it can be curtailed? This section, therefore, reviews the economic theories relating to pollution.

The Neoclassical Theory of Externalities

The neoclassical theory of externalities describes the economist's approach to pollution and its control. Economists, notably, Alfred Marshall, Arthur Cecil Pigou and Ronald Coase, see pollution as an instance of negative environmental externalities and thus as a source of a market failure [13-16]. To them, pollution is a negative environmental externality with negative impacts that reach far beyond the community of origin. Externality theory describes that external effects, which may be positive or negative, are (1) not taken into account when the commodity is being priced, (2) borne by a party other than the parties that are directly involved in the market transaction, and (3) ultimately result in a market failure—the inefficient allocation of resources by the market [13,15,18,19,22]. This inability of the market to allocate resources efficiently usually results in an environmental problem which could persist if the failure is not corrected.

Neoclassical economists, notably A.C. Pigou, recognised these inefficiencies associated with externalities as a form of market failure and recommended government intervention to correct for the effects of externalities [15]. Neoclassical microeconomic theory identifies four basic sources of market failures-market imperfection (non-competitive behaviour), externalities, public goods, and imperfect (or asymmetric) information-which differ according to the type of assumption of perfect market violated. Each source results from the failure of each of the assumptions basic to the perfectly competitive model and points to a potential role for government in the economy [22]. If any of the assumptions of perfect market is violated, market forces cannot operate freely and the result will be a market failure, a typical source of which is externality, which in turn may result in an environmental problem [5].

According to the neoclassical theory of externality, what causes a negative externality, such as pollution, is the divergence between the private and social costs of producing a good that generates the externality [13,15]. For an economy to achieve an efficient outcome of decisions, all costs-both private and external costs—must be weighted. However, the price of a commodity that generates pollution does not reflect the true costs of the commodity. It only reflects the private costs to the firm or the consumer; it does not reflect the external or environmental costs to the society of producing the pollution-generating product. The producers consider only the private cost of production without taking into account the external cost their production activity has on the society. This is because market does not always force consideration of all the costs while pricing a product. Hence, the price of the product will be very low. The lower the price, the more the commodity will be consumed and thus the more the externality will be generated.

This failure to internalize, or take account of, the external costs result in the divergence between private and social costs, which sends wrong price or profit signal to the economic agents and thus leads to misallocation of resources. Pollution, for example, disrupts the smooth functioning of the market system. When pollution externalities exist, markets do not produce socially optimal outcomes because the information conveyed by the price of the pollution-generating is fundamentally inaccurate, thereby leading to an inefficient allocation of resources [18,22]. The price mechanism allocates resources efficiently via prices and profits, the signals that determine the allocation, but if the prices do not reflect the full social costs, there is bound to be inefficient allocation of resources [5,18,22].

The neoclassical theory of externality provides an insight into why we observe increasing damage to our physical environment. The theory explains from a market perspective the persistence of environmental problems and the need for government to intervene

[1]This section draws from Biala (2019)

where such problems exist. It considers environmental degradation as a consequence of market failure. The environment acts as a sink into which wastes are eventually discarded; and because this waste absorptive capacity of the environment is provided free of charge, excessive wastes are discharged into the environment, thereby creating externality or imposing social cost on other users of the environment who are not part of the transactions that led to the waste generated [23]. This is particularly true because anything that is free is virtually always abused. Thus, the market failure resulting from externalities arise because the waste assimilative function performed by the environment is not priced or exchanged in the market and is, therefore, often not valued and accounted for in economic activities. If this function of the environment is priced, their use would have been different from what it is today. It is this present-day treatment of this environmental function that results in a market failure.

For a mathematical exposition of the theory of externalities, consider a situation involving production externalities between two firms, Firm 1 and Firm 2, where Firm 1 produces some amount of x_1 and also produces a certain amount of pollution, e , hich adversely affects Firm 2's production possibilities[2] .

Suppose that firm i's cost function is given by

$$C_i = f(x_i,\ e)$$

where x_i is the amount of output produced by firm i. We assume that pollution and output are not necessarily produced in a one-to-one ratio. Firm 2's cost of production depends on the amount of pollution produced by Firm 1. Since pollution is a negative externality, it is assumed to increase the cost of producing x_2, that is,

$$\frac{\partial c_2(\mathrm{x}_2,\ \mathrm{e})}{\partial_e} > 0,$$

and decrease the cost of producing x_1, that is,

$$\frac{\partial c_2(\mathrm{x}_2,\ \mathrm{e})}{\partial_e} < 0$$

because it is discharged by Firm 1 at zero disposal cost.

Incorporating pollution into the two firms' profit maximization yields the following profit maximization problems:

$$\max_{x_1,\ e}\ \mathrm{p}_1 x_1 - c_1(x_1, e) \quad \text{(Firm 1's profit maximization problem)}$$

$$\max_{x_2}\ \mathrm{p}_2 x_2 - c_2(x_2, e) \quad \text{(Firm 2's profit maximization problem)}$$

While Firm 1 chooses the amount of pollution that it generates, but Firm 2 must take the level of pollution as given, because it has no control over its production. In the absence of any mechanism to control pollution, the first-order conditions for Firm 1's profit maximization will be

$$p_1 = \frac{\partial c_2(x'_2}{}$$

$$0 = \frac{\partial c_1(\mathrm{x}_2^*,\ \mathrm{e}^1)}{\partial e}$$

and that of Firm 2 will be

$$p_2 = \frac{\partial c_2(\mathrm{x}_2^*,\ \mathrm{e}^1)}{\partial e}$$

These conditions state that, the price of each good as well as the price of pollution should equal its marginal cost at profit-maximizing point. In the case of the profit maximization of Firm 1, pollution has a zero price, implying that Firm 1 should produce pollution until the cost of an additional unit of pollution is zero.

The externality here is that Firm 1 produces pollution e and output x_1 but considers only the cost of producing x_1 and ignores the cost of producing pollution it imposes on Firm 2 while making its profit-maximizing calculation. In other words, Firm 1 considers only

[2]The mathematical exposition presented here draws from Varian (2010)

the private cost; it ignores the external cost, which is also part of the social cost of producing x_1. This leads to a lower cost of production. As a result, x_1 will be underpriced and Firm 1 will produce too much output and too much pollution from the societal point of view. If the impact of pollution is considered, the cost of production and thus the price of x_1 will rise, and less output and less pollution will be produced.

Now suppose that the two firms merge into one firm that produces both , x_1 and x_2 , and possibly pollution. Then there is no externality because the seeming externality has now been internalized. After all, an externality arises when one firm's actions affect another firm's production possibilities. Since there is only one firm producing x_1 and x_2 from two divisions, then it will take the interactions between the two divisions into account while choosing its overall profit-maximizing output. Prior to the merger, each firm had the right to produce whatever amount of x_1 or x_2 or pollution that it wanted, irrespective of what the other firm did. After the merger, the merged firm has the right to control the production of both x_1 and x_2 .

The profit maximization problem of merged firm's becomes with the following first-order optimality conditions:´

$$\mathrm{p}_1 = \frac{\partial c_1(\mathrm{x}_1', \mathrm{e}')}{\partial x_1}$$

$$\mathrm{p}_2 = \frac{\partial c_2(\mathrm{x}_2', \mathrm{e}')}{\partial x_2}$$

$$0 = \frac{\partial c_2(\mathrm{x}_2', \mathrm{e}')}{\partial e} + \frac{\partial c_2(\mathrm{x}_2', \mathrm{e}')}{\partial e}$$

The last condition shows that the merged firm will take into account the effect of pollution on the marginal costs of both firms. When the division that produces decides how much pollution to produce x_1, it considers the effect of this action on the profits of the division that produces x_2 . In other words, the division producing takes into account the social cost of its output.

Now a pertinent question here is, what does this unitization or internalization imply about the amount of pollution produced? When Firm 1 acted independently, the amount of pollution was determined by the condition

$$\frac{\partial c(x_1^*, \mathrm{e}^*)}{\partial e} = 0$$

That is, it produced pollution until the marginal cost of pollution was zero. In the merged firm, the amount of pollution is determined by the condition

$$\frac{\partial c_1(\mathrm{x}_1', \mathrm{e}')}{\partial e} + \frac{\partial c_2(\mathrm{x}_2', \mathrm{e}')}{\partial e} = 0$$

That is, the merged firm produces pollution until the sum of the marginal cost of producing an extra unit of pollution to each division is zero. This condition can be rearranged as

$$-\frac{\partial c_1(\mathrm{x}_1', \mathrm{e}')}{\partial e} = \frac{\partial c_2(\mathrm{x}_2', \mathrm{e}')}{\partial e} > 0$$

Hence, the merged firm will want to produce less pollution than the independent Firm 1, since marginal cost to x_1 division is now positive, unlike when it was negative. When the true external cost of the externality (i.e., pollution) involved in the production of x_1 is taken into consideration, the level of pollution generated will be reduced.

When Firm 1 considers minimizing its private costs (the cost it imposes on itself) of producing , it produces where marginal cost of extra pollution equals zero; but the optimal level of pollution requires minimizing the social costs (private cost plus external cost) of the pollution. At the Pareto-efficient level of pollution, the sum of the two firms' marginal costs of pollution must be equal to zero. For graphical illustration of this argument [24].

The foregoing requires that the two firms be merged. However, merger is not always a feasible option. Therefore, different interpretations are given to the Pareto optimality conditions derived above. Each of these interpretations (discussed in Section 5) suggests a mechanism to correct the inefficiency associated with the production externality.

Materials-Balance Theory

Ayres and Kneese and later Kneese, Ayres and D'Arge introduced the materials balance approach, also known as the Ayres-Kneese model, to establish a balance between the resources that we draw from nature and the return of such resources to nature[3] . The model, which represents an approach to solving the problem of externalities based on the conservation of natural resources, explains the relationship between the natural environment and economic activity. It provides an alternative method of resource and residuals management. It is a coherent source-reduction framework in which an economic analysis of resource use and its implications for the environment can be placed. According to this approach, limited capacity of the environment to quickly absorb the impacts of economic activity-that is, the residuals-is the cause of externalities. If pollution were absorbed as soon as it is discharged, externalities would not arise. Therefore, externalities should be reduced at source [25,26].

The materials balance approach recommends targeting environmental policy on extractions and not on emissions, because the mitigation of emissions does not necessarily reduce extraction and both activities-extractions and emissions-violate nature. Thus, it is necessary to reduce the throughput of materials into the economy in order to reduce residuals that run from the economy back into the environment [27]. Emissions follow the extractions, but not vice versa. Sub-targets for this policy are rising resource productivity at all stages of production and a reduction of resource use in consumption. By taxing extractions instead of emissions (e.g., by imposing a materials levy instead of emission charges), the costs spread over all stages of production so that prices of all products rise due to the direct and indirect materials which form parts of the product. This will induce material-saving technical progress on all stages of production and create new less materials-intensive products for final consumption [27].

This approach, sometimes described as the management of common-property resources approach, views the social costs of disposal to the environment as being dependent in part on the extent of emissions relative to the assimilative capacity of the environment. It considers externalities as an inherent and normal part of economic process, since they appear in many locations and are not independent from one another. It thus recognizes the pervasiveness of externalities and pollution problems. The explicit recognition of externalities as pervasive in the economy is an important contribution of this approach.

The Ayres-Kneese model was suggested to replace conventional neoclassical production theory. Unlike the neoclassical model, which includes descriptions of consumption and production externalities as exceptional, Ayres-Kneese model describes externalities as an inherent and normal part of production and consumption process. The Ayres-Kneese model is based on the laws of thermodynamics. The first law of thermodynamics—also known as the law of conservation of matter and energy-states that matter and energy can neither be created nor destroyed but can only be converted from one form to another or be disposed of somewhere within the system. This implies that nature is composed of a constant amount of matter and energy. It explains the fact that economic production and consumption activities always generate some pollution and wastes and, in our attempt to solve pollution problems, we are only converting one form of pollution problem into various other forms without actually solving it.

The first law implies that when materials are discharged as residuals, though their forms are altered, their mass remains unchanged, and their altered forms cause significant damage to the environment. Application of the first law to materials balance model means that in the long run, the flow of resources drawn from nature into production and consumption must equal the flow of residuals that run from these activities back to the environment. In other words, when raw materials are used in economic activity, they are only converted into wastes-other forms of matter and energy-but nothing is lost in the process [5]. Therefore, no activity creates matter: the activity of nature is not the creation but the transformation of matter, which instructs us that natural resources are finite [28,30]. The law also implies that economic growth-increased production and consumption levels—cannot occur without additional extraction of resources from nature and increase in the quantity of wastes or pollutants. This means that externalities are pervasive and tend to grow in importance as the economy itself grows.

Since matter and energy cannot be destroyed, the first law of thermodynamics seems to suggest that the materials flow can go on forever. Therefore, the second law of thermodynamics, popularly known as the entropy law, reminds us that nature's capacity to convert matter and energy is limited because entropy increases while converting one form of energy to another. The second law says that entropy-the amount of energy unavailable for work-increases. It states that each time useful energy is converted from one state to another; there is always less useful energy available in the second state than there was in the first state [29]. In every energy conversion, some useful energy is converted to useless energy; some energy is always lost or becomes unusable, and the rest, once used, is no longer available for further work. Thus the total amount of usefully concentrated matter and energy in a closed system must decline overtime. This implies that conversion cannot go on forever, because no conversion from one form of energy to another is completely efficient and that the consumption of energy is an irreversible process [11].

Since the transformation of material and energy is an irreversible transformation of useful materials into wastes, all useful energy will ultimately become waste and there will be no energy to convert again. Thus, the second law implies that in the absence of new energy inputs, any closed system must eventually use up its available energy. If a system is closed so that it does not exchange matter or energy with any other system, its entropy increases with every physical action or transformation that occurs within the system. Therefore, wastes, being entropy, can never decrease in the universe.

[3]Though it was first introduced by Ayres and Kneese (1969), its complete development is found in Kneese, Ayres, and D'Arge (1970)

When applied to the materials balance model, the second law implies that the overall entropy of economic activity (conversion process) must increase overtime. Economic activity increases entropy and decreases the availability of useful matter and energy. It converts low entropy materials into high entropy materials (i.e., wastes and pollutants). According to the second law, as long as there are production and consumption activities, entropy will always increase. According to the law, economic process dissipates the overall available energy for life, and since energy is necessary for life, life ceases when useful energy flows cease. Thus, the second law is a metaphor for inevitable decline or eventual end [30].

In the long run, all resources become wastes or pollutants that are returned to nature. Some wastes arise in the short run (e.g., wastes created during production) and others arise in the long run because resources are first transformed into commodities and do not enter the residual flow until the goods are used up [5]. We cannot get rid of anything: recycled and reused products will eventually become wastes in the long run. The amount of a residual can be reduced only if its by-product (the wanted good) or resource use in the production of the good is reduced too. When wastes exceed the absorptive capacity of the environment, they reduce the services that the environment provides and therefore become pollutant. The residuals from production and consumption processes usually remain, become pollutants and render disservices like killing flora and fauna, reducing public health, and environmental degradation.

The model can be summarized by the following schema adapted from Eugine (2004):

In the production sector: $R \xrightarrow[\text{transforms to}]{} Y + W_1$

In the consumption Sector: $Y \xrightarrow[\text{transforms to}]{} W_2$

Putting (2) in (1), the schema yields,

In the economy: $R \xrightarrow[\text{transforms to}]{} W_1 + W_2$

where R stands for raw materials drawn from nature, Y for quantity of output produced from production process, W1 for wastes (first-stage entropy) resulting from production process, and W_2 for waste (second-stage entropy) resulting from consumption process. The production process uses R units of raw materials from the environment to produce Y units of output, and while doing so, generates W1 amount of waste. The consumption process consumes all the Y units of output produced in the production process, and generates W2 amount of wastes from the process. This demonstrates that the mass of waste products discarded to the environment is approximately equal to the mass of resources drawn from the environment, and that externalities associated with the residuals resulting from consumption and production activities are a normal, and indeed, inevitable part of these processes. That is, residuals are a necessary outcome of all production and consumption activities. Hence, residuals can be reduced only by reducing resource use.

There are three implications of the laws of thermodynamics as applied to the materials balance model [5,29]. First, pollution is an inevitable by-product of any transformation of matter and energy, including the human economy. Every resource drawn into economic activity ultimately ends up as a residual, which has the potential to damage the environment, owing to the limited waste-assimilative capacity of the environment. Secondly, nature's ability to convert resources to other forms of matter and energy is limited. That is, resource flow cannot go on forever. In the absence of new resources, all available natural resources in the system will eventually be converted to wastes, and there will be nothing to convert again. Recycling can help but it is energy intensive and imperfect, so it cannot fully compensate. Recycling and waste management can re-convert high entropy (non-useful) matter into low entropy (useful) forms, and will thereby help slow down the entropy production process. However, all resources including the recycled products will ultimately be converted to wastes. Consequently, the fundamental process on which economic activity depends is finite [5]. The third implication is that, to reduce waste (entropy), we must reduce resource extraction or conversion. The materials balance model, therefore, emphasizes recycling and less residual-generating production process as solution to environmental problems.

Ayres and Kneese contend that Pareto optimality is shattered when the environment lacks the waste absorptive capacity, or has limited assimilative capacity, because the market system "cannot be free of uncompensated technological externalities unless all inputs are fully converted into outputs, with no unwanted material residuals along the way, and all final outputs are utterly destroyed in the process of consumption". Neither of these conditions can hold in an actual economy. Thus economic activity always affects the environment either directly or indirectly. The importance of the model for environmental management is that it demonstrates that waste generation is pervasive to the economy. In turn, if the capacity of the environment to assimilate and degrade the waste into harmless form is limited, then externalities arising from waste will also be pervasive. This is in marked contrast to the neoclassical view that externalities are occasional deviations from market perfection.

The basic lessons from the materials-balance model are summarized from Ayres and Kneese (1969) as follows:

- Technological externalities are not freakish anomalies in the processes of production and consumption but an inherent and normal part of them.

- As the level of output increases, externalities become progressively pronounced, and the assimilative capacity of the environment becomes exhausted. When wastes exceed the absorptive capacity, they degrade the environment.
- Isolated and ad-hoc taxes and other restrictions are not sufficient for optimum control of pollution or waste.
- If a balance can be reached between acceptable levels of materials flows, there will be an increase in output and improvement in environmental quality.

However, an Achilles heel of this model is that it only emphasizes source reduction as a solution to externality problems but does not specify a particular method or instrument by which externalities should be reduced at source [25].

Economic Solutions to Pollution

How can the inefficiency-market failure-resulting from externalities be remedied? Finding an appropriate solution to an environmental problem stems from an understanding of how and why the market fails [25]. In the case of negative externalities, the market fails because of the divergence between private costs and social costs. Therefore, solutions to externality problems often require internalization of external costs in production and consumption decisions. This is achieved through the polluter-pays-principle: polluters should be made responsible to bear the full external costs of their externality-generating activities. If the externality-generating firms or individuals pay for, or take into account, the negative externalities they create, costs (private and social) of production or consumption will be higher and so will the prices. Less output will be produced and consumed because of the higher prices. Externalities are a problem only if they are not taken into account by decisions makers.

Several measures of internalizing external costs have been suggested in the literature. Pigou advocates the use of taxes and subsidies (now known as Pigouvian taxes and subsidies) to close the gap between private and social costs arising from externalities [15]. That is, government should impose a tax equal to the marginal external cost of the pollution generated by the product. Imposing a tax on pollution would equate net marginal private costs with net marginal social costs, and thus assures that market transactions lead to Pareto optimal outcomes [31]. When pollution is priced (i.e., taxed), the result will be a more optimal allocation of resources than when it is not priced.

Later on, a number of other internalization measures evolved, among which are deposit-refund systems, marketable disposal permits, virgin materials taxes, recycling subsidies, command and control (CAC) measures and suasive (information-based) instruments. All these measures, except CAC and suasive instruments, belong to a family of instruments called market-based instruments. Market-based instruments, or economic incentives more broadly, are instruments that use financial means or otherwise to motivate polluters to reduce pollution (that is, to change their behaviour indirectly). They are regulations that encourage pro-environmental behaviour through market signals rather than through direct instructions regarding pollution control levels or methods [32]. Any instrument that aims to induce a change in behaviour of economic agents by internalizing environmental cost through a change in the incentive structure that these agents face qualifies as an economic instrument. Economic instruments harness the forces of the market to solve environmental problems by changing the prices that individuals and businesses face. These economic instruments, as well as the traditional command-and-control mechanism, are reviewed as follows.

Direct Regulation

Although direct regulation is not an economic instrument, it is worthwhile to discuss it as a precursor to economic instruments. Direct regulation, also known as command-and-control (CAC) mechanism, is often used by the government to mandate certain actions and penalize noncompliance. It is the most common noneconomic interventionist approach in the environmental policies of most industrialized countries. Under direct regulation, the government sets rigid standards for emission and instructs the polluters to reduce pollution by a certain amount or else face the legal sanctions. The CAC instruments include outright ban, recycled content standards, licenses, permits, and land-use control. Government may lay down maximum allowable pollution level or outright ban on the production of a commodity that generates pollution.

There are three means through which direct regulation operates: source-specific emission limits (or disposal standards), output specifications (or performance standards), and technology requirements [1]. The first alternative applies emission limits to specific sources as a means of achieving environmental standards. The total amount of pollutants that are released could be limited by setting emission standards for individual polluters, such that total emissions just equal the sum of the individual contributions from each source. The second alternative requires that a firm's output meet certain conditions by specifying certain characteristics of outputs that are meant for product market. Examples include fuel efficiency requirements for automobiles, product specifications for gasoline, and regulations regarding the ability of products to be recycled and the recycled material content of consumer products. The third alternative specifies the techniques or equipment that polluters must use to control pollution. It may require that polluting firms install certain equipment that implies a particular technique of production.

Pollution control through regulation is bedeviled by some problems. First, the major constraint of a traditional regulatory system is the cumbersomeness and high administrative cost of enforcing the set standards when many polluters are involved. The cost of discovering and maintaining an optimal amount of the pollution may be prohibitive. The U.S., for instance, spent about $90 billion as annual compliance expenditures as at 1990, and $102 billion in 1992[4] [33]. The CAC approach involves the setting up of rigid

[4] Rutledge and Vogan, 1994 cited in Palmer, *et al*, 1995

rigid input and product standards and bans without sufficient consideration for the costs involved [34]. In addition, it is often hard for government to fix the correct level of regulation to ensure efficiency.

Furthermore, regulation might be inefficient when there is more than one firm. The literature has shown that CAC measures are inefficient because different firms with different marginal abatement costs are required to take similar abatement measures. Since the costs of pollution reduction or compliance are likely to defer from firm to firm, a one-size-fits-all regulation that mandates all firms to cut back their pollution by equal amounts leads to some firms producing too much and others too little [31]. CAC measures force all polluters to adopt the same measures and practices for pollution control and thus to accept identical shares of the pollution control burden regardless of their relative costs and impacts. Another problem with direct regulation is that it tends to be too lax or too tight. The optimal level of pollution would be where the economic benefit arising from a reduction of pollution equals the economic cost imposed by the regulation, a situation that is very difficult, if not impossible, with too lax or too tight regulatory control.

Charge Mechanisms

Charge mechanisms are the economic measures of internalizing negative externalities, which work through the polluter-pays principle. Charges are based on the quantity and quality of the discharged pollutants or the damage caused. The classic remedy to externality problems under charge mechanisms was first suggested by A. C. Pigou. Pigou advocates a tax, now called the Pigouvian tax, on each unit of a polluter's externality-generating output in an amount just equal to the marginal social cost or damage it inflicts at the efficient level of output. Until recently, the Pigouvian tax remains the standard solution most favoured by economists [15]. It is one of several ways in which government can intervene when individuals acting on their own cannot attain an efficient solution. The tax raises the prices of output and reduces both the amounts of output produced and consumed, thereby eliminating the suboptimal overproduction and overconsumption brought about by externalities.

Suppose we impose a Pigouvian tax of t naira per unit of pollution generated by Firm 1 in Section 4. Then its profit-maximization problem will be

$$\max_{x_1, e} p_1 x_1 - c_1(x_1, e) - te$$

and its first-order profit-maximization condition will be

$$-\frac{\partial c_1(x_2, e)}{\partial e} - t = 0$$

Comparing these conditions to equation (2), we see that setting

$$\mathrm{t} = \frac{\partial c_2(\mathrm{x}_2', \mathrm{e}')}{\partial e} = MEC$$

will make these conditions the same as the conditions characterizing Pareto efficient level of pollution.

The tax, in effect, forces the polluters to take into account the social costs of their activities and induce them to produce the efficient level of output. Such costs should reflect damages to the environment and the administrative costs incurred by the regulators. Otherwise, the mechanism will not be economically efficient. However, it should be noted that the revenue generated from the tax is not necessarily meant for the compensation of the victim of the externality. The Pigouvian tax possesses an important asymmetry in a market sense: it is a charge to the polluter, but not a payment to the victim because compensation to the victim from the generated revenue is not necessary to achieve efficiency [18]

Cropper and Oates note that: Compensation of victims is not permissible (except through lump-sum transfer). Where victims have the opportunity to engage in defensive (or ‘averting’) activities to mitigate the effects of the pollution from which they suffer, compensation cannot be allowed. For if victims are compensated for the damage they suffer, they will no longer have the incentive to undertake efficient levels of defensive measures (e.g., to locate away from polluting factories or employ various sorts of cleansing devices).

The issue of compensation of victims from pollution bears a resemblance with the moral hazard problem in insurance [9]. It should also be noted that taxes on externality-producing activities are not designed to eliminate externalities, they are simply meant to force the polluters to consider the full costs of their activities. “Even if it is assumed that a tax correctly measures all the damage done, the decision maker may find it advantageous to continue causing the damage [22].

While the Pigouvian tax generates revenue to the government, it also allows the market mechanism to decide how resources should best be allocated. However, it is confronted with the following practical problems:

- Measuring damage is difficult, if not impossible. For instance, the monetary value of damage to health and loss of life is very difficult to estimate. Hence, finding the correct optimal tax rate is extremely hard.
- It is also difficult to reduce damage to an efficient level. If we knew the optimal level, we could just tell the polluter to produceexactly that amount and not have to mess with the tax
- The Pigouvian tax overlooks a particular contingency that can result in "over-correction".
- The costs of collecting the necessary information and supervision are prohibitively high

Due to these problems, numerous variants of charge mechanisms have evolved. These variants include emission/pollution charges, product charges, advance disposal fees (ADF), user charges, tax differentiation, and virgin materials charges. While user-fees, also known as user charges, are paid for the disposal of waste or pollutants, product taxes or charges are added to the prices of products that create pollution either through their manufacture, consumption or disposal. Since raising pure emission charges is not always feasible in municipal solid waste management, an alternative is to charge the product that generates waste or levy user charges for the collection and treatment of the waste.

User charges are payments for the cost of collective services. They are primarily used as a financing device by local authorities for the collection and treatment of solid waste and sewage water. Although user-fees, product charges and taxes (or emission charges) are similar, a distinction is usually made between them. Taxes are purely revenue raising instruments, while fees and charges are cost-offsetting instruments used by the government to finance costs of collective collection and treatment services. Examples of user fees are pay-as-you-throw (PAYT) system such as per-bag fees, unit-based scheme, volume-based pricing and weight-based pricing on solid waste disposal. Fees and charges require that the polluter pay a fee or a charge for each unit of pollution. They are incentives for the polluter to reduce pollution because they represent an explicit cost to the polluting activity.

Emission charges are levied directly on the quantity of pollution. If, however, it is difficult to measure or monitor the quantity of pollution, a charge, called a product charge, is levied on the product that causes the pollution. Product charges can be levied on products as they are manufactured, consumed or disposed of. One disadvantage of fees is that they do not guarantee the amount by which a polluter would reduce pollution. Fees and charges are widely collected at all levels of government. Despite they tend to be set at rates too low to have a significant impact on pollution, fees and charges can generate substantial revenues for the government. However, if they were set at rates equal to the marginal damage being caused by the pollution, or at a level that would force changes in business or personal behaviour, they would be controversial.

Subsidies

Subsidies are the mirror image of emission charges. Rather than imposing charges on agents for their emissions or disposal, the subsidy approach offers cash payments to polluters for reducing emissions or waste disposal. Polluters who release emissions forgo the cash payment. Subsidy systems provide incentives to polluters to control all units of pollution whose marginal control cost is less than the subsidy. Subsidies can be used in two ways to control externalities. First, subsidies can be used to correct positive externalities. Activities that generate external social benefits may be subsidized at the margin to give the decision makers an incentive to consider them. Ignoring social benefits, just as ignoring social costs, can lead to inefficiency in the allocation of resources. Hence, governments should subsidize those who generate positive externalities, in the amount that others benefit [18].

Second, subsidies can also be used to correct negative externality, whereby polluters are subsidized or rewarded for every unit of emissions that they reduce below some threshold. The government can pay the polluter not to pollute or may subsidize control devices or research on substitutes/alternatives (e.g., alternative automobile fuels) and/or give grants, low-interest loans, tax holidays or tax-exempt production, tax credit for investment in pollution-control devices. This works much like the Pigouvian tax because a subsidy for not polluting is simply another means of raising the polluters' effective production costs [18]. The subsidy compensates for each unit of output that the polluter does not produce. Thus, the polluter forgoes production and accepts the subsidy. A subsidy per unit of emissions reduced can have the same incentive for abatement activity as a tax of the same magnitude per unit of emissions discharged. For example, a subsidy of ₦20 per pound of emissions reduced creates the same opportunity as a tax of ₦20 per pound of emissions discharged. Therefore, the regulator can use either the stick or the carrot to encourage emissions reduction [9].

However, there are important asymmetries between subsidies and taxes. Cropper and Oates point out that subsidies and taxes have quite different implications for the profitability of production in a polluting industry in that subsidies increase profits, while taxes decrease them [9]. They add that the two policy instruments thus have quite different implications for the long-run, entry-exit decisions of firms. The subsidy approach will shift the industry supply curve to the right and results in a larger number of firms and higher industry output, while the Pigouvian tax will shift the supply curve to the left with a consequent contraction in the size of the industry. It is even conceivable that the subsidy approach could result in an increase in the total amount of pollution. In sum, they conclude that unit subsidies are not a fully satisfactory alternative to Pigouvian taxes.

However, subsidy systems have some drawbacks. While subsidies provide incentives to existing firms and other sources to reduce their pollution, new entrants may be attracted by the higher profits earned as a result of subsidies. In some extreme situations, this could have the perverse effect of increasing total pollution [35]. Another drawback of a subsidy is that without a product charge or a user fee, a polluter has no incentive to generate less waste. Recycling subsidies also create burden to finance the budget and that taxpayers lose because they pay the cost of recycling.

Deposit-Refund Systems

Since pollution, especially land pollution is in many cases caused by littering, economists have suggested deposit-refund system as another instrument for controlling pollution. A deposit-refund system (DRS) is a market-based method of controlling litter in which the buyers or consumers of a litter-generating product pay a surcharge, which is later refunded to them when they return the used packaging of the product, or its residue, to a point of purchase or a designated collection site. A DRS is a way of fully internalizing the externalities of littering [36]. It combines a tax on the purchase of a product with a subsidy or a rebate for returning the used product or packaging to a designated collection centre. A DRS is a Pigouvian tax paid upon purchase but refunded on item not dumped, so the result can be equivalent to a tax on dumping or littering [37].

The deposits levied on the polluting product represent a charge designed to cover the costs of waste disposal in the event that the used packaging or leftovers are not returned for recycling or safe disposal. But when they are returned to the designated collection points, the supplier gives either a total (or partial) refund of the initial deposit, depending on the cost of recovery or recycling of the material. The funds represent an effective subsidy to waste-recovery effort [38]. As long as consumers bear the cost of disposal, they have the additional incentive to return their used recyclable products to collection centres. By doing so, they avoid disposal costs and reap financial reward for supplying a product someone wants. Scavenging and returning used water-sachets provides a significant source of income for people, especially the homeless.

The per-unit deposit raises the price paid at the time of purchase, but for every container returned to the designated site, the recycler (the person that turns in the container for recycling) is paid the deposit amount. The container can be returned by anyone and need not be returned by the original purchaser. Someone else, especially the scavengers, can collect the containers and return them for cash. This leeway, known as hustling, no doubt contributes to the role played by DRSs in supplementing the income of the poor, and thereby decreases crime rates [39]. Just like other economic instruments, the deposit-refund scheme is based on the polluter-pays-principles (PPP) and on the principle that incentives should be provided to encourage waste recovery, reclamation, and recycling. DRS can be voluntary (market-initiated) or mandatory (government-imposed) [36]. While the market-initiated DRSs are developed by the private sector, mandatory or government-imposed DRSs are created by legislations.

The DRSs are an effective way of reducing litter, removing the cost of disposal from generated taxation and placing the costs on manufacturers, distributors and consumers. The objectives of DRS are to encourage proper disposal of waste products, to make used packaging available for reuse and recycling in order to curb litter-related pollution, and to divert recyclable items. Deposit-refund scheme is usually adopted for products whose packaging materials are recyclable, costly to incinerate, generating large volume of waste, and occupying large space in landfills. It is also adopted for products whose discrete packaging contains toxic substances, the control of which poses special problems to waste handlers and the improper disposal of which poses serious health hazards [1,38].

A DRS is called for when there is a potential for illegal dumping of pollutants. A DRS is more effective in controlling litter because other charge mechanisms such as the Pigouvian tax encourage illegal waste disposal by individuals who try to avoid paying the tax or fee [40]. A DRS, on the other hand, encourages proper disposal of waste by returning waste to a designated place. Several studies have argued that the DRS is the best option in the presence of illegal disposal and that it can achieve the social optimum in this setting, efficiently controlling both legal and illegal waste disposal [40,42]. Tietenberg and Lewis claim that DRS is more cost effective than any other measure [11].

Despite the plethora of research extolling the virtues of DRS in theory, its real-world application has not caught on. USEPA posits that one factor that limits the widespread of DRSs is transaction costs: collecting and refunding deposits on the sale of individual products tends to be expensive. That is, additional costs are involved in collecting and returning used products [1]. Nonetheless, Numata attributes the gap between the theory and practice to the negative impacts of the introduction of the system on suppliers of DRS products [43]. These negative effects include (1) decrease in sales due to price increase brought about by adding deposits to prices, (2) huge initial costs of establishing the collection system, and (3) increase in collecting cost.

Considering these effects, Numata suggests two measures for mitigating the negative impacts on suppliers: (1) letting the suppliers keep unredeemed deposits as profits, and (2) paying handling commissions from a government to suppliers in proportion to the volume collected [43]. Another shortcoming of this mechanism is that, it engenders interjurisdictional emissions leakage from regions where the DRS is not implemented. The regions or states with DRSs may incur the extra expense of illegal returns or fraudulent redemption from non-DRS regions [5,44].

Marketable Pollution Permits

A marketable disposal permit is a combination of CAC and market-based approaches. The marketable disposal permit is the approach, first proposed by, in which a regulatory authority sets maximum limits on the total allowable emissions, and then allocates this total amount among the polluters by issuing permits that authorize the polluters to emit a stipulated amount of pollutant over a specified period of time [45,46]. A marketable pollution permits give the regulator (the environmental authority) direct control over the quantity of emission. If a goal for waste reduction has been set, the regulatory authorities can permit agents to trade any reductions exceeding that target. A firm with high marginal costs of waste reductions may thus comply with the regulation by acquiring credits from another firm that has an amount of waste reduction that exceed the regulation. Some economists prefer to use the term creating a market for this type of measure. This is because the government creates a market for a product, such as clean air or water, that otherwise would not have emerged for a product by selling permits (to pollute) to producers of pollution-generating products [18]. If the permits or the rights to pollute exist for polluters, these rights can be bought and sold to reflect the value of externalities created. Creating markets is deemed necessary because of the belief that it is the lack of markets for externalities that causes the problems [47].

Thus a missing market-the market for the pollutant-is another interpretation given to the problem pointed out in Section 4. The externality problem occurs because Firm 1 faces a zero price for its output, even though the victims (e.g., Firm 2) would be willing to pay to have that output level reduced. From a social point of view, the output of pollution should have a negative price, since pollution is a "bad". Thus, a more practical alternative to Pigouvian taxes is to introduce a market for the externality. Providing a market for Firm 2 to express its demand for pollution or a reduction of pollution will provide a mechanism for optimal production [48].

Following Schotter, suppose that Firm 1 must buy the right to produce amount x_1 from Firm 2 at price q; that is, Firm 1 pays amount qx_1 to Firm 2 to produce its output. In this case, the profit maximization problems are

$$\max_{x_1} \pi = p_1 x_1 - c_1(\mathrm{x}_1) - \mathrm{qx}_1$$

$$\max_{x_2} \pi_2 = p_2 x_2 - c_2(\mathrm{x}_2) - e(\mathrm{x}_1) + \mathrm{qx}_2$$

Here, Firm 1 chooses output x_1, taking into account the cost qx_1 that it incurs by paying for the right to produce the externality,while Firm 2 chooses outputs x_2 and x_1 it is willing to accept at price q. Ultimately, q is determined by market equilibrium.

The first-order optimality conditions are as follows:

$$p_1 - q = c'(\mathrm{x}_1^*)$$

$$p_2 = c_2'(\mathrm{x}_2^*)$$

$$q = e'(\mathrm{x}_1^*)$$

Under this mechanism, there are three methods of distributing permits: auction, free distribution/endowment, and sale at a fixed price. Under auction system, government will announce the auction of permits to spew certain level of pollutants such as sulphur dioxides in to the environment. Firms then bid for the right to pollute the environment, and the highest bidder gets the permits. A market clearing effluent fee is charged so that amount of pollution is equal to the level set by the government. For instance, suppose the government desires to control emissions of SO_2 into the atmosphere. It issues permits to spew the pollutant, the total of which equals the maximum amount SO_2 it desires to see emitted over a period of time. The principle here is that a polluter will continue to treat waste or pollution until the marginal cost of treatment is less than, or equal to, the cost of buying a permit. Through trading, low-cost polluters will sell some of their permits and abate more than they would under the traditional CAC approach, while high-cost polluters will buy permits and abate less. This results in the same amount of pollution reduction that would be achieved through the CAC approach, but it is achieved at lower cost.

Allocation of permits can alternatively be done by selling the permits to polluters at a fixed price. The polluters can then trade the permits based on their individual levels of pollution and abatement costs. The scheme also works when the government allocates the permits free of charge to individual polluting firms that are then free to sell them to other polluting firms. This involves giving the permits away pro rata the existing emissions known as grandfathering. The free allocation may be based on: (1) current levels of emissions existing prior to attempts to control them; (2) output of goods that produce the pollutants in production; (3) emissions allowed under current standards; (4) the projected equilibrium that would results from a perfectly competitive and efficient market in permits[5] . The permits are then tradable for money between polluters. Polluters who succeed in reducing their pollutants levels below their permit levels can sell their permits to other polluters who are exceeding their limits.

[5] See: Rosen (1999) and Hahn and Noll (1982) cited by Stavins (1993).

The difference between the auction and the free distribution options is that with the former, the money goes to the government, while with the latter approach, the money goes to the polluters that are lucky enough to be assigned the pollution rights. This implies that, even though the efficiency effects are the same, the distributional consequences are radically different [18]. However, auctioning marketable permits can result in important efficiency gains relative to simply giving these permits to existing sources, so-called grandfathering [1].

Cropper and Oates note the symmetry between tradable permits and taxes [9]. They assert that in a world of perfect knowledge, tradable permits are, in principle, a fully equivalent alternative to unit taxes. This symmetry between the price (tax) and quantity (pollution permits) approaches is critically dependent upon the assumption of perfect knowledge. They cite, for example, that in a setting of imperfect information concerning the marginal benefit and cost functions, the outcomes under the two approaches can differ in important ways. Weitzman explored this asymmetry between price and quantity instruments and produced a theorem with important policy implications [49]. The theorem establishes the conditions under which the expected welfare gain under a unit tax exceeds, is equal to, or falls short of that under a system of marketable permits. In short, the theorem states that in the presence of uncertainty concerning the costs of pollution control, the preferred policy instrument depends on the relative steepness of the marginal benefit and cost curves.

Property-Rights/Bargaining Approach

The proposition of the neoclassical economists that externalities require government intervention via taxation to achieve efficient market outcomes was intensely debated after Pigou [15]. Some economists, notably Coase, argue that market mechanism itself can correct for externalities and achieve efficient outcomes, and that affected parties can resolve externality problems through mutual negotiation and bargaining among themselves [16]. This proposition that inefficiencies from externalities can be overcome through bargaining was first put forward by Ronald Coase in 1960 [16].

In the quest for the best solution to externalities, Coase postulates that the government need not intervene in every case of externality, that the private sector can indeed deal with all externalities, and that many externality problems result from the fact that property rights to certain resources are ill-defined or not defined at all [16]. This approach sees the absence of property rights to certain resources as the remote cause of externalities, and the divergence between private and social cost-the neoclassical approach-as the immediate cause. If property rights to all resources were well defined, the divergence of costs would not even arise. It is the absence of property rights that causes the divergence of costs, which in turn causes negative externalities.

Clean air, for instance, is a resource on which property rights are not defined-a resource not owned by any one. The polluter can, therefore, use the clean air as a method of waste disposal of his noxious gaseous emissions without compensating the affected party who is deprived of clean air. This causes an externality-divergence of private cost from social cost-because there is no clearly defined owner to demand compensation for the external cost[6]. But if the victim has a well-defined right to clean air and is therefore compensated by the polluter, the external cost is thus internalized, and the private cost will be equal to the social cost.

According to Coase, an alternative to neoclassical solution of charges through government intervention is for the polluters and the victims to come to a bargaining solution whereby the latter is compensated. He explains that extending property rights is a way of internalizing externalities. Coase argues that if properly rights are fully assigned and if people can negotiate at low cost with one another, they would arrive at efficient solutions to externalities without the need for explicit government intervention in the form of regulation and/or taxation. That is, if there is an externality and property rights are well defined, the private market would find a way to take the society to efficient level of externality.

To Coase, it makes sense for the government to create conditions that allow a market to come into existence but then stay out of the market. Since the absence of well-defined property rights is considered the root cause of externalities, Coase suggests that government should clearly establish and enforce property rights on a resource and put the resource into private hands. He posits that if property rights are clearly defined and enforceable, the involved parties would adopt policies to internalize the externality, and a negotiated solution, through voluntary costless bargaining would be brought about by the parties themselves without government interventions [51,52].

The Coase's conclusion that once a costless negotiation/bargaining is feasible, the efficient solution would be achieved irrespective of who is assigned the property rights-either the polluter or the victim-as long as one party is assigned those rights, is what is referred to as Coase theorem. The implication of Coase theorem is that externalities need not lead to inefficiency because individuals have an incentive to make mutually beneficial deals-deals that can lead them to take externalities into account when making decisions. However, for Coase theorem to work, certain conditions must be satisfied. Based on these conditions, the applicability of the Coase theorem has been challenged by many economists. These conditions, which constitute its peculiar practical problems, are as follows:

- The property rights to the resource at issue must be clearly defined and understood. However, there are certain resources, such as clean air, to which property rights cannot be assigned.

[6] This situation is what Kula (1992) refers to as public externality: the use of natural resources without payment or compensation.

- There must be low bargaining transactions costs (i.e., no impediments to bargaining). The theorem requires that the costs of bargaining should not deter the parties from finding their way to the efficient solution. That is, the parties involved must be willing and able to discuss the externality issues openly and with little or no cost.
- Only a few people are involved. Serious problem can develop when one of the parties to the externality bargain is a large group of people. The whole universe may be involved in the case of the air pollution or global warming.
- Sources of pollution are traceable. That is, the source of pollution or the damage done to the affected party is traceable to a particular polluter or an externality-producing activity and that the victim can legally prevent the damage.
- There is no information asymmetry or uncertainty. The polluters and the victims are fully and equally informed about the risks and harms that may occur. No one party knows more than the other about the transactions.

Concluding Remarks

This paper has reviewed economic approach to pollution and its solutions, and has classified pollution as well as externalities into different taxonomies. Examining the taxonomies will prove useful in designing policy measures to the various types of pollution, for each type requires a unique policy measure. Failure to recognize the distinctions among the different types of pollution could lead to counterproductive policy.

The list of the instruments discussed here for correcting pollution externalities is by no means exhaustive. There are other instruments in the literature; this review discusses only the most relevant ones. Among other economic instruments for correcting externalities are materials levies and penalty. A materials levy is imposed on raw materials used to manufacture the waste-generating end product. It gives incentives to recycling in that it raises the prices of raw materials vis-a-vis recycled material [50]. The materials levies induce a reduction in the amount of packaging per product, and thus have a source-reduction impact on the amounts of waste generated. Penalty is imposed on illegally disposed waste that has been detected.

Despite the plethora of research extolling the virtues of economic approaches to pollution and its control, their real-world application has not caught on. One of the factors responsible for this is the implementation costs and difficulty. However, the cost of implementing the direct regulation is more prohibitive than that of the economic instruments. Since there is no such thing as a free lunch, every measure of pollution control must involve a cost. Therefore an option for policymakers is to minimize those costs associated with implementing economic instruments by designing pollutant-specific policies.

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