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ENVIRONMENTAL RISK SHARING

Alexander Wagner

Many environmental risks are idiosyncratic. That is they affect individuals differently. This paper applies standard insurance theory to examine the feasibility of a new type of security that allows efficient sharing of those risks. Under the proposed scheme, individuals who enjoy high environmental quality make payments to those who have suffered environmental or health risks on a particular day. In situations where uncertainty is high, risk-averse individuals will be willing to participate in such a daily risk sharing arrangement. The workings of the scheme are illustrated in the context of health impacts due to SO_2 pollution in an industrial city or region and with an application to international risk sharing. The paper also discusses the practical requirements for successfully setting up such a system.

Alexander Wagner is a student of the Kennedy School of Government and Department of Economics, Political Economy and Government Program, Harvard University. He is a Research Fellow at the Energieinstitut University of Linz, Austria.

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I. INTRODUCTION AND OVERVIEW

This paper proposes a new type of asset that leads to efficient sharing of idiosyncratic, as opposed to aggregate, environmental and health risks and thus promotes welfare improvements. The asset applies two straightforward insights of economic policy analysis: a) the notion that public goods can and should be made private in some instances; b) the theory of risk sharing, which explains how policy can achieve efficient allocations in the presence of uncertainty. The paper focuses on the impact of environmental quality variations. Thus, it adds to the literature on environmental policy which typically considers environmental quality levels and asks which average levels are efficient and how they can be obtained in a cost-effective way. The next section discusses an application of the proposal within a city or a region. Then, the paper turns to an application of environmental risk sharing across nations. While the same principles are at work, the time horizons will likely differ markedly, which makes it useful to distinguish the cases. The conclusions present a summary and thoughts on the practical implementation of these new securities, including the required institutional arrangements.

II. A MICRO APPLICATION OF SHARING ENVIRONMENTAL RISKS

To set the stage for the analytical discussion that follows, consider the case of an industrial city called Ecotopia.[1] Ecotopia is meant to be representative of a class of economic areas – in particular, cities and regions – where the proposal makes sense. While no comprehensive list of quantitative criteria that an economic area must fulfill in order to be a candidate for environmental risk sharing is useful (or possible), the reader will find a summary of relevant features below. For now, however, it is best to begin by way of example. Ecotopia's relevant geographical characteristics are as follows. In the western part of the city there is an active industrial park. For concreteness, the paper will focus on one of the many pollutants that enter the air in significant amounts as a byproduct of production in several of the industrial firms: sulfur dioxide (SO_2). What is important in the context of this paper is that it is not always the

[1] The author's inquiry into this subject was motivated by the case of Linz, an industrial city in Austria. Unfortunately, sufficient data are not available to show a quantitative application of the idea proposed in this paper. Therefore, the argument is here presented for a more generic case, which readers can adapt to special cases they may know better.

immediate area around the industry that is hurt most by emissions. Instead, depending on the prevailing wind each day, one of two regions on opposite sides of the location of the plants, A (to the east) and B (to the west), are affected.[2]

The characteristics of health impacts of SO_2 exposure are important for the feasibility and usefulness of the risk sharing mechanism proposed in this paper. The fact that there are negative effects of SO_2 exposure even within the standards typical for developed countries today is well-known.[3] What is particularly important for the proposal of this paper is that humans are susceptible to the effects of SO_2 even at short durations (Koenig and Mar 2000). For example, Horstman and Folinsbee (1986) demonstrated that SO_2 exposure for 2.5 minutes produced a significant decrement in pulmonary function tests. Large changes in pulmonary function were seen after only 10 minutes of moderate exercise during SO_2 exposure. In addition, the increase in airway resistance after 10 minutes of exposure to 1 ppm SO_2 during exercise was not significantly increased when the exposure was extended to 30 minutes. Balmes et al. (1987) reported bronchoconstriction in asthmatics after 1 minute of 1.0 ppm during hyperpnea. Results from epidemiologic studies on SO_2 exposure have been consistent with findings from controlled laboratory studies.[4] Overall, these findings imply that people should care considerably about short-duration variations in SO_2 exposure.

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[2] Given the location of the industrial park, it would be natural to imagine that A belongs to the same city as the industrial park, while B does not, although there certainly are industrial cities with the heavy industry placed close to the center. Other regions are of course also affected, but for the purposes of this illustration let us focus on these two areas.

[3] SO_2 exposure causes bronchoconstriction, decrements in respiratory function, airway inflammation, and mucus secretion (which makes it easier for bacteria to penetrate the body.) SO_2 is also a precursor of secondary sulfates such as sulfuric acid, which is a stronger irritant than SO_2, and plays a major role in the adverse respiratory effects of air pollution. The quantitative effects of SO_2 alone are very difficult to determine because SO_2 is often associated with particulate matter and other pollutants. The following, however, appear to be findings that are accepted as the consensus among experts (Koenig and Mar 2000). Both controlled laboratory studies and epidemiology studies have shown significant negative effects of SO_2, in the form of reductions in lung function at concentrations as low as 0.1 to 0.25 ppm, low birth weight in the range of 22-30 ppb, and even mortality with very small increases in ambient SO_2 in the range of 10-22 ppb. People with asthma are particularly sensitive to the effects of SO_2. This is particularly relevant, since as of 2000, over 18 million people (or 6.5% of the U.S. population) were estimated to have asthma. Although death resulting from asthma is rare, hospitalization from asthma occurs regularly. It has been estimated that asthma is responsible for 27 million patient visits, 134,000 hospital admissions, 6 million lost work days, and 90 million days of restricted activity (Koenig and Mar 2000). Asthma is the most common chronic illness of childhood and the primary cause for school absences. Pulmonary function is dramatically decreased in asthmatics exposed to SO_2 (Koenig 1997; Koenig et al. 1981).

[4] Several studies, using time series analysis, have shown that exposure to ambient concentrations of SO_2 are associated with mortality and morbidity. For example, hospital admissions for cardiovascular and respiratory illness have been associated with just a 4 ppb increase in SO_2 in Hong Kong (Wong et al. 1999). Similar effects were found in a study by Ballester et al. (1996) in Spain. Though it is difficult to separate the effects of particulate matter and

The monetary valuation of all these adverse effects, many of which take the form of increased risks which also have an impact on utility, is of course difficult. To determine the efficient quantity of emissions (which is typically non-zero because of the enormous costs that would arise by completely eliminating emissions of this substance), economists have expended considerable effort to quantify the individual and social damages precisely. (See the survey by Viscusi (1993) who reviews existing work on the value of life and health and Mrozek and Taylor (2002) who provide a meta-analysis of studies on the value of morbidity.) Here, let us assume that Ecotopia's government has been fortunate enough to be able to determine exactly what the socially optimal amount of total emissions in the whole city is per day, and let us assume that this amount is constant and still sufficiently high as to cause relevant adverse health effects.

Summarizing, the salient features of the environmental problem of Ecotopia – and in fact any area where the proposal would in principle make sense – are as follows: at least two distinct groups are affected by SO_2 (or some other pollutant) asymmetrically depending on the direction of wind. In Ectopia, the residents of area A are better off when the prevalent winds blow west, and the residents of area B are better off when they blow east. (A larger number of groups being differentially affected is of course also possible, but might pose a practical obstacle because of a collective action problem. The conclusion addresses this issue.) The total area-wide emissions are given and known when they occur; in fact, for simplicity they are assumed to be fixed at the socially optimal aggregate level.[5] But even though aggregate emissions are at their efficient level, the daily variations cause significant distress for the individuals in the population. As a result, residents live under a veil of ignorance as to environmental quality on any given day. This is especially relevant since the damage function of SO_2 exposure always increases at the margin.

It appears likely that these features characterize many cities or regions worldwide. Because the impacts of environmental damages will be correlated with the general level of emissions, the stakes are higher for all individuals in cities or regions with substantial emissions, such as those with large industrial areas or those only now replacing high-polluting Soviet-era power generation facilities. Although the focus so far has been on cities and regions of limited

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SO_2 in epidemiologic studies, SO_2 has sometimes been shown to be responsible for adverse health effects, when PM had no effect (Derriennec et al. 1989).

[5] Thus, monitoring activities like in O'Rourke and Macey (2003) are neither required nor would they play a special role.

size, note also that except for the high frequency of damages, i.e., the daily variations, all of the same characteristics just listed could in fact also be fulfilled by a whole country or a number of countries together. Because in these cases, the most relevant environmental damage variation will usually be of much lower frequency (for instance yearly) and because of the especially difficult implementation problems in practice, this case is relegated to the analysis section of the paper. The problem of idiosyncratic environmental risk is an important one and goes beyond the two issues traditionally at the center of environmental policy: finding the socially efficient point and the cost-effective allocation of emission control responsibility. We are now ready to consider a simple way in which the population of the two areas A and B could achieve higher welfare for the same path of emissions.

III. ENVIRONMENTAL RISK SHARING

Inhabitants of areas A and B value clean air and consumption of a private good, as is the standard assumption in economics. Thus, utility is given by the following equation.

$$U = U\ (consumption,\ environmental\ quality)$$

We assume that U is a well-behaved utility function with diminishing marginal benefits. In other words, individuals desire more of consumption and of environmental quality. However, we give them more of either good, the utility they derive from an additional unit of that good decreases. Both consumption and environmental quality are normal goods. Heterogenous preferences of individuals do not alter the logic presented here. Therefore, suppose A and B are each populated by one representative consumer. Also, the focus continues to be on one sole pollutant, the mirror image of which is environmental quality.

Now think of the world as consisting of a series of periods, in each of which two states can happen for each individual. Either she realizes high environmental quality or low environmental quality; in other words, environmental quality risk is idiosyncratic. This result arises because even though SO_2 is distributed uniformly in principle across all places around the chemical industry, day-to-day changes in winds will make it a non-uniformly mixed pollutant.[6] It is thus not known—neither day to day, nor year to year — which group will be better off. The setup can be generalized to allow for many (indeed a continuum of) states.

Additionally, we must assume that people are risk-averse with respect to both their private good consumption and environmental quality. Risk-aversion means that averages of consumption and environmental quality are preferred to alternating high and low consumption and environmental quality. The fundamental source of this property (and indeed, its mathematical definition) can be found in the increasing marginal damages of SO_2 exposure, as discussed in detail earlier. For private good consumption, risk-aversion also results from the assumption of diminishing marginal utility.

Given this setup, imagine creating a security that pools the risks. A and B agree to participate in the risk sharing (refer to note 8). Then, whenever A's environmental quality is worse than B's, B would pay her.[7] B would lose money, but he would have enjoyed better environmental quality and less health risk. A could use the money to purchase outside improvements of his utility, perhaps to directly avert that day's health risk. The same would be true conversely. Through this sharing of risk, the two would achieve greater expected discounted utility over their horizon, which could be modeled as either finite or infinite.[8] It is important to bear in mind that the daily veil of ignorance inhibits adverse selection problems. The properties of SO_2 emissions, together with the geographical features of cities or regions like Ecotopia, thus generate the need for an insurance market with relatively high-frequency settlement.

In practice, all asset holders would be registered with the financial administration of the program. It makes sense to establish the national health organization (or another organization that already has the relevant medical records of the individuals) as the clearinghouse in order to avoid adverse selection effects. Every day, the government gathers data on SO_2 emissions,

[6] We could of course also model individuals to care about minute-to-minute or second-to-second variations. That extreme may not be appropriate, but it is not out of the question either, since, as mentioned earlier, increased risks arise even at very small and short-duration peaks in concentrations.

[7] The precise amount for the efficient outcome depends on whether we assume identical or heterogenous preferences; in the general case, relative marginal utilities determine the theoretical optimum.

[8] There is nothing magical about the security. The idea of sharing risks in such a way is of course precisely the concept underlying insurance. Insurers are indeed offering insurance for big (environmental and related) risks like hurricanes and other catastrophes. Futures for such insurances are also traded on the CBOT. Chichilnisky and Heal (1998) have considered these catastrophe futures and hurricane bonds as ways of combining the risk pooling capacity of insurance with the diversification and hedging potential of securities markets. They conclude that they are an optimal instrument for managing catastrophic risks.

which are used to determine asset transfer vectors. Those who suffered a day of high SO_2 concentrations, for example, would receive transfers from those having enjoyed a particularly healthy day. The system need not perfectly measure the monetary equivalent of the environmental damages to start working immediately. Depending on the degree of risk-aversion and other parameters of the utility function, participants may require a smaller or larger probability of "being hit" to agree to be part of the program. In the extreme case, when one state becomes virtually certain, there is little incentive to share risks across states.[9] The result that the pervasiveness of uncertainty puts a limit on the acceptability of the system is quite intuitive.

IV. APPLICATION ON THE MACRO LEVEL

The application discussed so far was relevant for the micro level in two respects: high-frequency asset settlements, and geographically constrained relevance of the program. This section briefly discusses an application that goes to the other extreme, resulting in much longer time periods (years as opposed to days) and much broader geographical relevance (possibly the whole world). This environmental risk sharing on the macro level draws on and is related to recent work by Shiller (1993). He called for the creation of so-called macro-markets, insurance markets for nations to hedge against macroeconomic fluctuations. He shows that considerable welfare gains could be achieved through such macro risk sharing. Indeed the idea of insuring the greatest economic risks of all seems worth pursuing.

While clearly these markets seem to be somewhat down the road, it should be noted that since in many instances emissions fluctuate procyclically with output, the creation of insurance markets for economic macro risks could go hand in hand with the creation of a market for environmental risks. For geographically localized pollutants, individuals will be worse off when a country is booming because economic output, and hence pollutant output, will increase.[10] Countries experiencing a boom should therefore be willing to make payments to countries experiencing a recession. The logic for resultant expected welfare gains for every participating

[9] In the concrete case of the example that motivated this paper, the industrial city of Linz, Austria, for example, the areas A and B represent the so-called *Franckviertel* and *Steyregg*. Many-year averages provided by Rudolf Sommer (Upper Austrian Government) indicate that on a given day there is 60% chance of the wind blowing in the Franckviertel's direction, a 30% chance of the wind blowing in Steyregg's direction, and a 10% chance that neither of the two is affected.

[10] This ignores effects that may occur through technological change, which may itself be faster in a boom. A more completely specified model would be able to take this into account.

country is exactly the same as in the micro-application detailed earlier. No country should rationally expect to always be in a boom (or a recession). Thus, a veil of ignorance exists. As long as damages are increasing on the margin as emissions increase, these conditions suffice to create the potential for welfare gains through risk sharing. As for the practical implementation, there are two opposing forces to consider. On the one hand, an agreement for creation of this market should be easier to achieve than for the micro-application discussed earlier because of the significantly greater welfare gains at stake. On the other hand, international agreements typically involve multiple dimensions and negotiations along a wide variety of issues, which may prevent or at least significantly delay this type of created market.

V. CONCLUDING REMARKS

Using the well-known theory of risk sharing through insurance mechanisms, this paper has presented a simple yet powerful tool of welfare-improving environmental policy. Most of today's discussion in environmental policy focuses on instruments that improve allocative efficiency and/or cost-effectiveness. These goals are no doubt important. However, in their emphasis on levels of emissions, they neglect the important dimension of idiosyncratic environmental risk (i.e., distributional effects of the volatility of environmental quality). When individuals are risk-averse, significant welfare gains are possible with the following scheme: Individuals who enjoy high environmental quality make payments to those who have suffered environmental or health risks on a particular day. When uncertainty is high enough, that is, individuals are behind a veil of ignorance, every rational individual will be willing to participate in such a risk sharing arrangement.

The next step in pursuing the proposal made in this paper is a more quantitative assessment of the possible welfare gains in particular cases. This will be difficult, but hopefully not impossible, given the advances economists have made in understanding the valuation of lotteries under risk-aversion on the one hand and levels of environmental quality on the other hand.

Several implementation issues need to be addressed to make the proposal successful. First, like other market-based instruments, this proposal would have to jump through a political hoop common to market-based environmental policies, the fact that environmental damages can be valued monetarily. Fortunately, it appears that this notion has made its way into the minds of politicians and citizens alike, as evidenced, for example, by the recent increased use of tradable permit systems in the US and Europe (For Surveys see Stavins (2002) and Schneider and Wagner (2003)).

A second crucial issue is the effective monitoring of ambient emissions environmental quality. Many cities have installed measurement stations in different parts of a city or region to measure many different environmental quality indicators. These factors do not quantify actual health impacts or risks, but they serve as a best-available proxy for daily bronchiopulmonary medical examinations. For some substances this will work well; for others, like NO_x, this is somewhat problematic since they enter the air in very small amounts and at different altitudes. For such cases, estimations are necessary. From a cost-saving viewpoint and to avoid adverse selection, it would be desirable to locate the administration of the program, that is, the clearinghouse and broker of the new assets, in the same national health organization or other organization that is responsible for the monitoring of emissions.

Third, one needs to exclude manipulation. In a perfect system that accurately reflects the actual personal impacts of changes in environmental quality, there is no danger of people actually massing together in “hot spots” of bad environmental quality because they do have to pay in terms of lost utility. This reinforces the importance of effective measurement and monitoring.

Fourth, a tradeoff is likely to exist regarding the size of the area covered by the scheme. On the one hand, since the total possible welfare gains increase in proportion to the number of individuals involved (at least in many relevant circumstances), a larger economic area makes the scheme more attractive. On the other hand, by a simple collective action argument, it is possible, and indeed often inevitable, that a more diverse group of people will find it difficult to agree on a scheme, even if improves the overall welfare. Together, these considerations suggest that the most appropriate context to start an environmental risk sharing scheme probably is the context of a medium-sized city.

Like in many areas where economists suggest new policies that are welfare-improving but face nontrivial implementation issues (the least of which not being their novelty), the responsible policymakers will have to decide whether they risk implementing an environmental risk sharing scheme. The question that remains is: Who will be the first to take the risk? Or rather: Who will share the risk?

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