

Assessing the Costs of Air Pollution from Unconventional Oil and Natural Gas Activities



A Conservation Economics Institute Report

by

Joe Kerkvliet, Ph.D. and Pete Morton, Ph.D.



Cover photo and inside cover photo credit: WildEarth Guardians

January 2020

Both authors are Senior Economists at the Conservation Economics Institute www.conservationecon.org. Kerkvliet is also Professor Emeritus, Economics, Oregon State University. Report prepared for Earthworks www.earthworks.org.

Report Point of Contact: pete@conservationecon.org

Conservation Economics Institute is a 501(c)3 nonprofit organization that provides independent research on economic means to simultaneously provide for biodiversity, ecological health, and community welfare.

TABLE OF CONTENTS

EXECUTIVE SUMMARY

I. INTRODUCTION

II. ECONOMIC EFFICIENCY AND AIR POLLUTION

A. Market and Non-Market Resources and Property Rights

B. Efficient Use of a Non-Market Resource

C. Implementing the Economically Efficient Use of the Atmosphere

III. ESTIMATING MARGINAL AIR POLLUTION ABATEMENT COSTS

IV. ESTIMATING MARGINAL AIR POLLUTION DAMAGE COSTS

A. Health-Related Costs of Air Pollution

a. Air Pollution from Unconventional Oil and Natural Gas Activity (UCONGA)

b. Steps for Estimating Marginal Damage Costs

c. BenMAP Model

d. Evaluation of BenMAP Model

B. Stated Preference Methods (SP)

a. Contingent Valuation

b. Choice Experiments

c. Applying SP Methods to UCONGA

C. Hedonic Method

a. Hedonic Studies of UCONGA

b. Colorado Studies

c. Texas and Oklahoma Studies

d. Marcellus Shale Studies

e. Lessons Learned

D. Benefit Transfer Method

a. Unit Value Benefit Transfer

b. Benefit Function Transfer

c. Pros and Cons

V. CONCLUSION

VI. REFERENCES

VII. APPENDIX A. Pain and Suffering is a Non-Market Cost of Air Pollution

EXECUTIVE SUMMARY

This report has three purposes. First, we explain and illustrate the case for a user or impact fee in promoting the efficient use of a non-market resource such as the atmosphere. The user fee discussed is in the form of an impact fee on the air pollution produced by unconventional oil and natural gas activities (UCONGA). The impact fee should reflect the monetized damages caused by air pollution to human health and other sources of human well-being.

The second purpose is to review the tools developed and applied by medical researchers, policy analysts, engineers, and economists to provide the information necessary to design efficient user fees. We examine marginal pollution abatement costs (MAC) before reviewing the tools designed to estimate marginal damage costs (MDC) of air pollution. The tools reviewed are: a) BenMAP, a flexible tool developed by the U.S. Environmental Protection Agency to estimate marginal damages from air pollution based on changes in human health; b) hedonic methods to estimate the effect of UCONGA based on changes in real estate prices; c) stated preference methods using surveys to measure people's preferences and willingness to pay; and d) benefit transfer methods that "transfer" the empirical results from studies completed using the other 3 tools to an unstudied application.

The third purpose is to provide guidance to policy analysts and policy makers on the advantages and disadvantages of each tool, or perhaps combinations of tools, for purposes of designing efficient impact fees, as well as communicating the costs and benefits to stakeholders and the public.

Our highest ranked method is to estimate the marginal damages from air pollution based in changes in human health. BenMAP (USEPA 2018) is widely used and provides flexible modelling of changes in levels and locations of air pollutants. It then translates these changes into changes in health endpoints and monetizes these endpoint changes into damage estimates.

The second rank goes to benefit transfer (BT) methods. BT uses pre-existing air-pollution damage estimates and applies them to new sites and conditions. BT methods could be applied to the hedonic property value studies, stated preference studies on willingness to pay, as well as taking BenMAP estimates of health-related damages from a study of representative Colorado counties and transferring the resulting damage estimates to other counties.

The third rank goes to stated preference methods (SP). These survey-based methods are flexible and may be designed to address an array of potential damages; not just health, but noise, congestion, and social disruption. Properly done SP studies require expensive professional design, vetting, and analysis following established best practices.

We assign the lowest rank to hedonic studies of property values. Ordinarily, carefully-done hedonic studies are highly credible because estimated damages are based on actual market data. However, the hedonic studies reviewed here do not account for mineral rights and/or household water source, two factors which are likely to strongly influence the results. If, however, Colorado authorities decided mineral rights and water source data should be collected for other policy purposes (e.g. permitting or economic impact studies), hedonic studies using these data may rank much higher.

I. INTRODUCTION

Nobody likes pollution. But pollution is an unavoidable part of everyday activities nearly all of us take part in and the products nearly all of us use. The fossil fuels used to heat our homes, power our appliances, and move our vehicles are produced by a series of very polluting activities: oil and natural gas drilling, production, refining, distribution, and final use. An increasingly important part of the oil and gas industry is the production of unconventional oil and gas using hydraulic fracturing and directional drilling, also known as fracking. The term fracking is often mistakenly applied to several activities including exploration, unconventional well drilling, well completions, production, processing, storing, transporting, and final use. In this report, we will refer to all of these activities except for final use as 'unconventional oil and natural gas activities', UCONGA. While the fuels produced by UCONGA are similar to oil and gas produced by conventional methods, the processes themselves are more polluting. For example, as a percentage of total production, UCONGA-produced natural gas results in one third to twice as much greenhouse gas releases as natural gas produced by conventional methods (Howarth 2014).

Although oil and gas activities promote some types of economic development and creates jobs, some of its associated pollution is harmful to humans and economically inefficient. By inefficient we mean the standard definition of efficiency developed and used by most economists. That is, given the current technological and physical state of the industry, if

UCONGA-related pollution were reduced, the total economic benefits created by the industry could be made larger.

This framework of inefficiency is the heart of the economic case for imposing monetary costs on certain levels of pollution produced by UCONGA. These costs could be in the form of impact fees levied on some UCONGA. The purposes of this report are to: 1) explain and illustrate the economic efficiency case for imposing impact fees; 2) to explain the tools used by economists and policy makers to go about setting efficient impact fees to regulate and/or control the air pollution created by UCONGA; and 3) to provide guidance to policy analysts and policy makers on the advantages and disadvantages of each tool, or perhaps combinations of tools, for purposes of designing efficient impact fees, as well as communicating to stakeholders and the public. UCONGA has exploded in several parts of the United States in the last decade and much of the analysis in this report will be useful to any community faced with rapid expansion. However, this report will pay particular attention to UCONGA in Colorado.

The report proceeds as follows. In Section II, we explain and illustrate the economic efficiency argument for the control and regulation of polluting activities. We then extend this argument to the reasons efficient policy design requires information on the costs and benefits of pollution control. Section III briefly discusses evidence on the costs of controlling UCONGA-related pollution. In Section IV, we critically review the four major tools used to estimate the monetary value of the damages resulting from air pollution. We also provide a

comprehensive review of the many studies using these tools to measure the damages resulting from pollution. Section V concludes with our ranking of the four major tools and some policy recommendations.

II. ECONOMIC EFFICIENCY AND AIR POLLUTION

A. Market and Non-Market Resources and Property Rights

Nearly all human activities create some form of pollution, or waste products. But economists distinguish between efficient and inefficient pollution. Briefly, efficient pollution happens when the benefits of the polluting activity exceed the costs of the activity, including all of the costs of the resulting pollution. Conversely, inefficient pollution costs more than it's worth.

How does economically inefficient pollution happen? The problem lies in the difficulty or impossibility of establishing and enforcing property rights over some resources. Property rights do not present problems for market resources, such as an iron ore deposit. Property rights do present problems for non-market resources such as the atmosphere.

For illustration, consider two resources used to produce things people value: an iron ore deposit and the atmosphere. The iron ore deposit is a market resource that can be used to produce steel. People value steel and purchase it at market prices. To produce steel, the iron deposit must be identified and

the ore extracted and moved to a refinery. If someone other than the holder of the property right (owner) were to try to remove the iron ore, the action could be easily noticed and prevented. The result is that, in order to put the iron ore to use, the iron deposit's owner must give her consent. She usually does so after somebody agrees to pay her. Thus, ownership of the iron ore deposit is easily established and enforced and the use by someone other than the owner happens only after a mutually agreed-upon payment is made. That is, property rights to iron ore deposits are easy to establish and enforce.

The atmosphere also produces things that people value. Breathing comes to mind, first, and perhaps, second, good health. In addition, the atmosphere is also used to grow crops and produce thousands of market and non-market goods and services. But the atmosphere is also used as a dumping ground, a place to put waste, such as methane from grazing cattle, carbon monoxide from driving vehicles, and arsenic and mercury from burning coal and making cement. The oil and gas industry use the atmosphere as a dumping ground for dozens of pollutants. Examples include volatile organic compounds (VOC) (e.g. benzene, toluene), harmful chemicals such as nitrogen compounds (NOX) and sulfur compounds (SOX), and particulates such as soot and liquid droplets of harmful chemicals that clog and irritate human lungs, degrade scenic vistas, and reduce crop yields.

Yet, unlike an iron ore deposit, specific parts of the atmosphere are difficult to identify and their uses are not easily noticed, nor very preventable. And, unlike iron ore, payments for the myriad uses of the

atmosphere are seldom made. It would be nearly impossible for a private owner, claiming a part of the atmosphere, to know when her part of the atmosphere was being used and to enforce payment for that use. That is, property rights for a non-market resource such as the atmosphere are extremely difficult to establish and enforce.

B. Efficient Use of a Non-Market Resource

As a valuable non-market resource with difficult to establish and enforce property rights, what is the most efficient use of the atmosphere? Economists

have tackled this problem and have derived the conditions for the most efficient use of the atmosphere. Illustrating the efficient use of the atmosphere as a dumping ground for air pollution is a focus of this report.

The efficient conditions economists have derived are based on two facts: First, damages to human health and other human activities (e.g. agriculture) occur when pollution is put into the atmosphere. For example, more air pollution causes more people to prematurely die, more people to suffer from cardiovascular disease, and more incidents of respiratory distress for people with asthma (see e.g. Saunders et al. 2018).¹ Some pollution, such as



Credit: WildEarth Guardians

ozone, degrades scenic vistas, reduces crop yields, and slows tree growth. Pollution-related damages generally increase with the amount of pollution and, when these damages are put into monetary terms, are called marginal damage costs (MDC). MDC are the costs, in dollars, of additional damages resulting from a bit more pollution. Figure 1 shows a stylized MDC curve. As shown, MDC usually start small when pollution is low and increase as pollution increases.

The second fact is that reducing, or abating, pollution is costly. Scrubbers, filters, and other technologies can capture pollution and more careful attention to machinery can reduce emissions from gas wells, but generally the more pollution is reduced the higher the costs. Plugging leaks in wells, pipelines, and storage tanks or even using different technologies will abate pollution, but may be more expensive. Pollution can also be abated by reducing the production of goods, such as oil and natural gas. But pollution abatement by reducing production is also costly because the oil and gas is not available for peoples' beneficial use.

The costs of reducing, or abating, pollution are called marginal abatement costs (MAC). A stylized MAC curve is shown in Figure 1. As pollution is abated, MAC usually increase. Typically, MAC increase very rapidly as complete pollution abatement is approached. In Figure 1, note that complete abatement of pollution occurs at the intersection of MAC and the vertical axis at the left of the graph. If there is no intersection, the MAC of reducing pollution to zero is infinite. In other words, it is typically extremely expensive, and economically

inefficient, to reduce pollution to zero.² In stylized form, the efficient level of pollution occurs when MDC and MAC intersect and are equal. In Figure 1 this occurs at e_0 . Why is e_0 the efficient level of emissions? If emissions were abated below e_0 , say e_1 , the additional costs of abatement would be greater than the additional damages avoided and efficiency would be lost. Conversely, if emissions were abated less than at e_0 , say e_2 , the marginal damages from additional emissions would exceed the marginal abatement costs of reducing emissions and efficiency would, again, be lost. Thus, only at e_0 is it the case that $MAC=MDC$ and as much benefit as possible is attained from the use of the atmosphere, both as a source of benefits and place to dump undesirable emissions.

C. Implementing the Economically Efficient Use of the Atmosphere

Since property rights to the atmosphere are nearly impossible for private citizens to establish and enforce, many countries, including the United States, have granted some level of government the right to control the atmosphere's uses. In the United States, this right has been codified in many laws, notably the Clean Air Act of 1970, Clean Air Act Amendments of 1977, and Clean Air Act Amendments of 1990. We call these collective Acts CAA. CAA are administered by the U.S. Environmental Protection Agency (EPA) in coordination with state, local, and tribal governments.

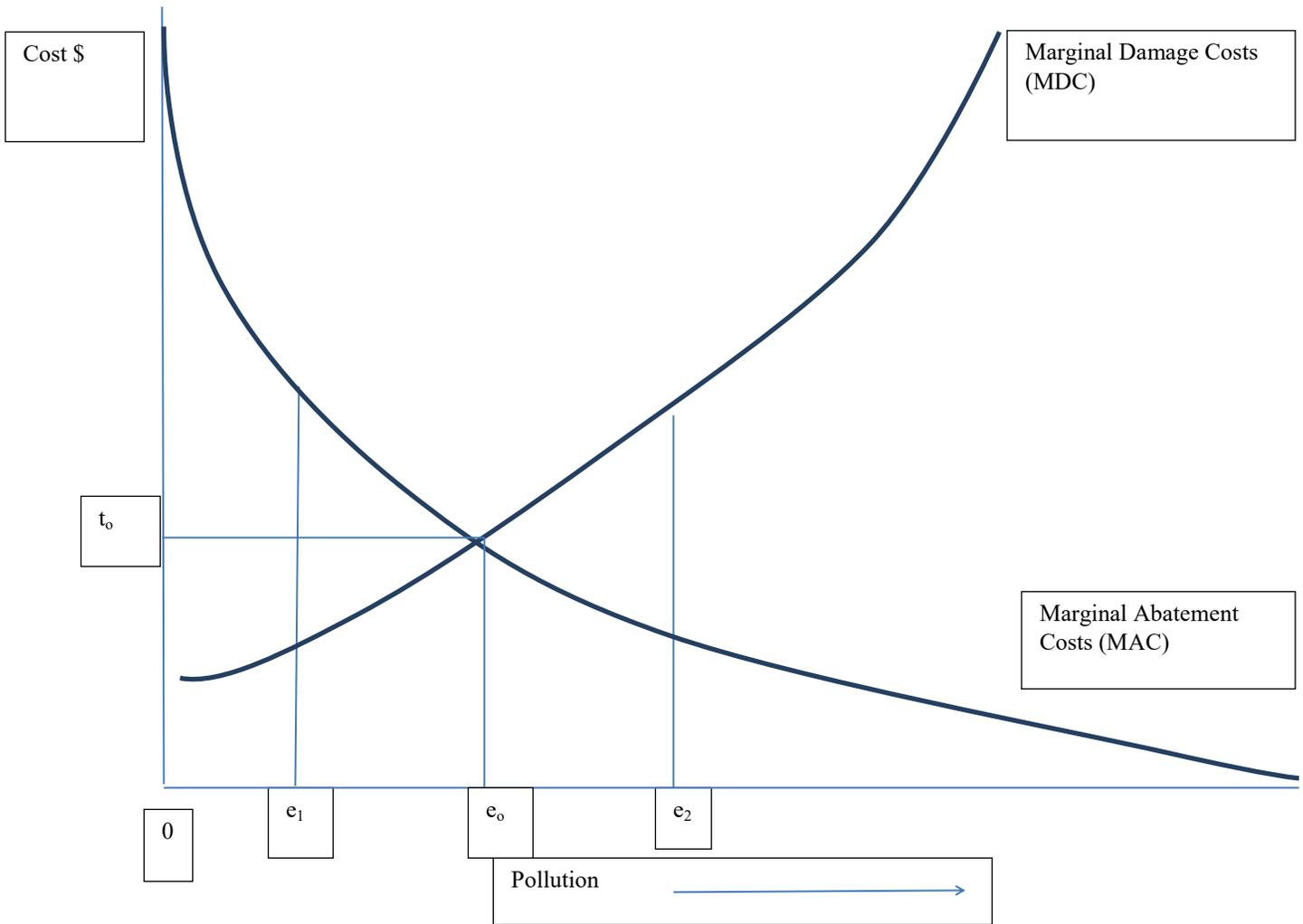


Figure 1
Marginal Abatement Costs (MAC) and
Marginal Damage Costs (MDC) Vary
with Amount of Pollution.

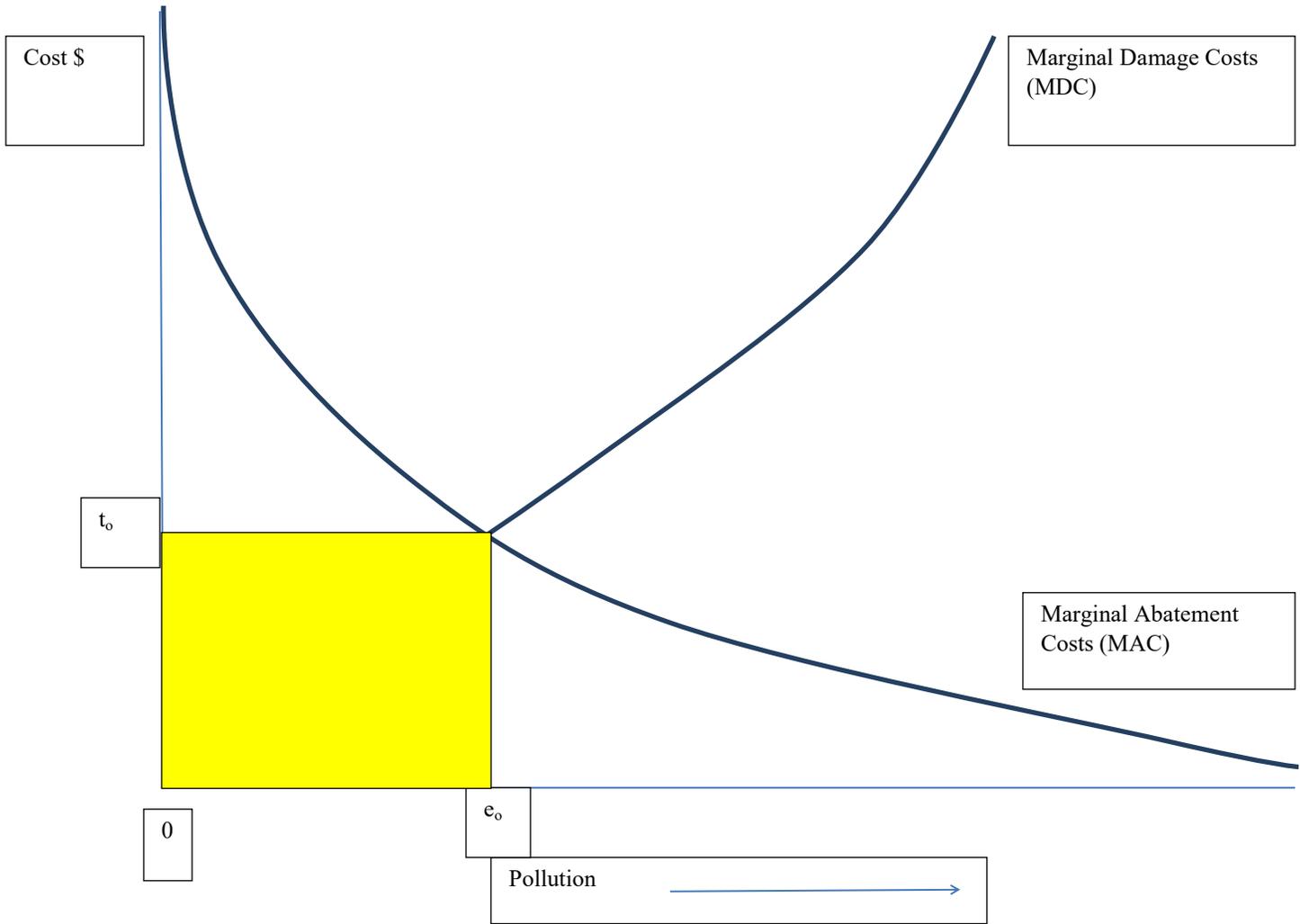


Figure 2
The User (Impact) Fee (t_0)
Results in an Efficient Level
of Pollution (e_0)

One solution to the problem of efficiently using the atmosphere is to charge the atmosphere's polluters a user, or impact, fee. EPA has used this method to control sulfur emissions (SOX) from coal-fired electric generating plants and lead from petroleum refineries. A key to setting the appropriate fee is to do so in a way that leads to the economically efficient use of the atmosphere. In Figure 2, the user fee that does this is t_0 . Faced with the prospect of paying t_0 for each unit of pollution, the atmosphere's users can choose to either pay the impact fee or abate pollution. When polluters can abate pollution at costs below t_0 , users will find it less expensive to abate. With MAC higher than t_0 , users will pay the impact fee on all of the pollution they continue to emit. The total impact fees paid by polluters are shaded in yellow in Figure 2.

The difficulty in implementing this solution lies in determining the correct level of the impact fee. In other words, what is t_0 ? Answering this question requires knowing something about both MAC and MDC. To these requirements we now turn.

III. ESTIMATING MARGINAL AIR POLLUTION ABATEMENT COSTS

The marginal costs of abating air pollution in the oil and gas industry has been widely studied because of interest in reducing greenhouse gas emissions, such as methane. Often these studies are based on



Credit: imjefp

detailed analyses of the industry's technology and practices at multiple stages of oil and gas production and estimating the costs of abatement. Often these studies pay close attention to such equipment as reciprocating compressors, intermediate bleed pneumatic devices, and storage tanks (ICF International 2014). Moreover, government agencies, such as the U.S. Department of Energy and EPA fund research on greenhouse gas abatement costs (see USEPAc. 2011, Natural Gas STAR 2004). Dozens of studies on the marginal costs of abating greenhouse gases exist and are reviewed in Gillingham and Stock (2018).

A stylized and simplified version of MAC are given in Figure 3. The MAC of various abatement strategies are sorted in increasing order, so that less methane is released into the atmosphere moving from left to right, but the MAC also increases.

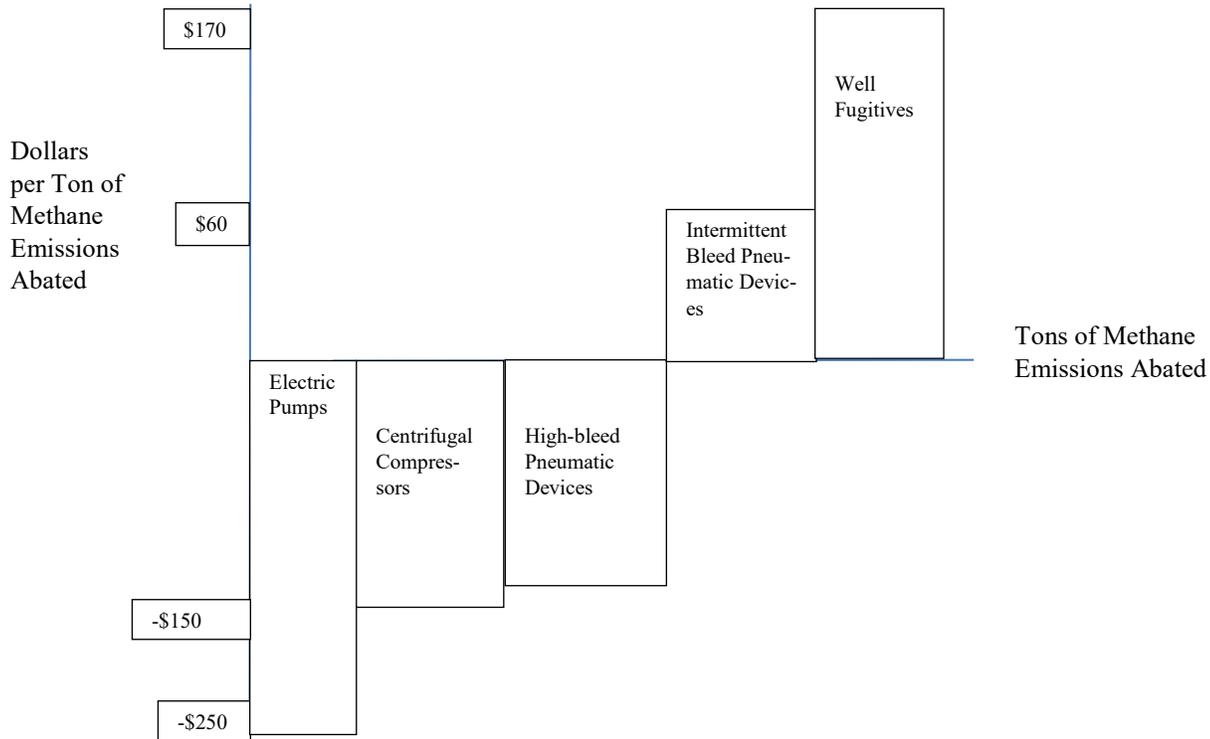


Figure 3
Estimates of Methods and Marginal
Costs of Abating Methane Emissions

Surprisingly, many estimates of MAC, including ICF International’s (2014) suggest that some abatement costs are actually negative; that is the marginal costs of abatement are actually less than the revenue that could be gained from selling the recovered methane. Of course, whether or not there are negative MACs depends on the assumed market price of the recovered methane. However, ICF (2014) concludes that there are considerable opportunities for abating methane emissions and some of these opportunities are available at negative costs to oil and natural gas producers.³

There are two caveats to using studies such as ICF International (2014) to apply to the problem of setting impact fees for UCONGA in Colorado. First, these MAC estimates are for methane alone, not for the myriad of other air pollutants produced by UCONGA (see the next section). Some of the pollutants (e.g. some VOCs, propane, and butane) are removed at early production stages, so the MAC in Figure 3 may not apply to these non-methane pollutants. The second caveat is that MACs are likely to differ by production region. Specifically, Colorado regulations have been recently updated (Colorado Air

Quality Control Commission no date). If these regulations have already been applied, some abatement strategies considered by ICF may be unavailable in Colorado. Nevertheless, it appears that the extant research provides sufficient knowledge about MAC to help determine the efficient use of the atmosphere.

IV. ESTIMATING MARGINAL AIR POLLUTION DAMAGE COSTS

Economists and others have developed four methods of measuring MDC and have applied these methods to the task of measuring MDC for air pollution. In the sections below, we will discuss these methods, describe their applications, and discuss their advantages and disadvantages for use in estimating MDC in order to establish efficient impact fees.

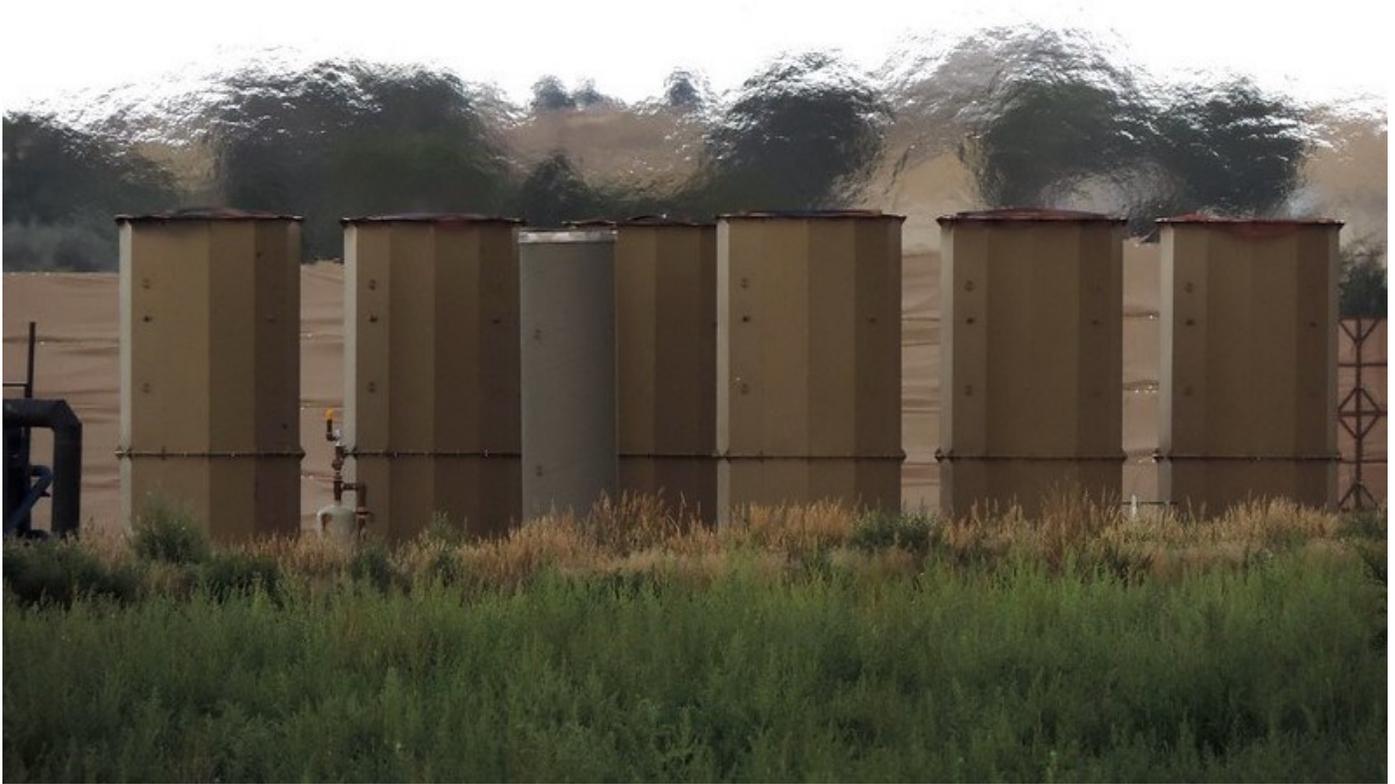
A. Health-Related Costs of Air Pollution

Air pollution damages human health. Air pollution is strongly linked to early death, chronic and acute bronchitis, respiratory-related emergency room visits, asthma, lost work days and lost school days (USEPAa 2011 and USEPAb 2011). These damages to human health come at enormous costs. This section describes how the health-related costs of air pollution have been estimated and used to inform public policy.

The public health costs associated with air pollution include three general categories: treatment costs, lost work, and pain and suffering. The monetized health endpoints from air pollution include market costs for health treatment, lost work production, and statistical values of life. Damages from air pollution also include non-market health costs -- primarily pain and suffering. For example, high ozone levels make it harder to breathe for people who suffer from asthma - which can cause them to worry every time they are short of breath and have trouble breathing.

The U.S. Congress recognized the importance of comparing the costs and benefits of implementing the Clean Air Act and its Amendments (CAA). Congress has twice directed the U.S. Environmental Protection Agency (EPA) to conduct studies of the costs and benefits of CAA. The latest of these studies (USEPAb 2011) estimates that, by 2020, annual public and private costs of controlling air pollution will be \$65 billion, but annual benefits will exceed \$2 trillion. The majority of the EPA's estimated benefits are in the form of avoided health-related costs. That is, the monetized value of avoiding undesirable health outcomes by implementing CAA requirements. For example, USEPAb (2011) estimates the avoided annual costs of premature death in 2020 at \$1.7 trillion, and the avoided costs of chronic bronchitis at \$36 billion (USEPAb 2011, Table 5.6).

In producing such estimates, medical researchers, public health officials, engineers, and economists have devoted enormous efforts to developing, refining, and implementing methods of estimating the costs and benefits of air pollution abatement.



Credit: WildEarth Guardians

Estimates of the health-related damages resulting from UCONGA can take advantage of these efforts to estimate efficient impact fees.

a. Air Pollution from UCONGA

We follow extant studies of the health-related effects of air pollution (e.g. Fann et al. 2012, Chestnut 2005, USEPAa 2011, USEPAb 2011) and focus on three major air pollutants strongly associated with UCONGA. These are: ground level ozone (O₃), various compounds of nitrogen (NO_x), and small suspended particulate matter (PM_{2.5}). O₃ is a gas capable of irritating human lungs at very low concentrations. Breathing O₃ creates a hazard for

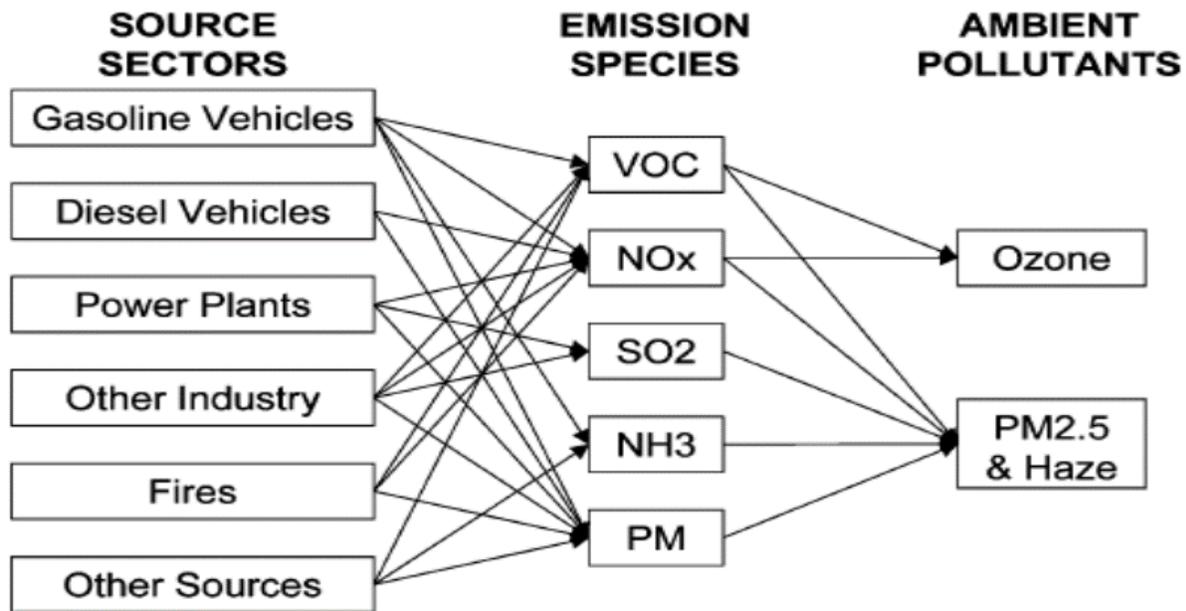
anyone with heart or lung disease (Bates 2005). PM_{2.5} is a form of particulate pollution and a complex mixture of small particles and liquid droplets, composed of acids, organic chemicals, soil, and dust. Inhaled, particulate pollution affects the heart and lungs. PM_{2.5} are particles less than 2.5 microns in diameter (USEPA 2018) and can penetrate deeply into human lungs. NO_x contributes to O₃ and particulate pollution. O₃, NO_x, and PM_{2.5} are three of only six 'criteria' pollutants regulated under CAA. EPA is required to set national standards for these six and to extensively monitor them. Sulfur compounds (SO_x) are another criteria pollutant associated with some oil and gas production, but SO_x does not appear to be important in Colorado.⁴

O3, NOX, and PM2.5 are largely caused by fossil fuel releases, including direct releases (e.g. open gas tanks, flow back water and gases from oil and gas wells, and leaking natural gas wells, pumps, and pipelines) and combustion (e.g. vehicle engines, furnaces, industrial boilers, and natural gas flaring). Emissions of these pollutants can be traced to many sources, including gasoline and diesel engines, electric generating plants, wildfires, refineries, and many other industrial activities.

O3, NOX, and PM2.5 are complex pollutants formed in various ways. For example, VOCs are direct

emissions from fossil fuel production and use, but they interact with NOX, PM2.5, and sunshine to form O3. NOX and PM2.5 are precursor pollutants to the criteria pollutant O3. In addition, NOX also contributes to PM2.5 (USEPA no date). Figure 4 illustrates the complex relationship between many pollutants emitted by various sources and O3 and PM2.5 criteria pollutants. Table 1 shows the precursors, major sources, and health endpoints commonly associated with O3, NOX, and PM2.5.

O3 is of particular relevance to Colorado because in 2015 some parts of the state were deemed out of



**Figure 4
Pollution Sources, Mixing, and Criteria Pollutants**

Reprinted by permission from Springer Nature. Environmental Management, 40. 545-554. An integrated framework for multipollutant air quality management and its application in Georgia. Cohan, D., J. Boyhan, A. Marmur, and M. Khan. 2007

compliance with EPA’s three year average 8 hour maximum O3 standard of 70 parts per billion (Marmaduke 2015).⁵ To achieve compliance, large areas of Northeastern Colorado are required to take strong and expensive measures, including new regulations for power plants, reformulated gasoline, and new oil and gas regulations.

b. Steps for Estimating Marginal Damage Costs

Figure 5 illustrates the several steps needed to estimate health-related MDC. First, multiple types of air pollution are emitted by multiple sources. Air pollution laws and regulations usually distinguish

Pollutant	Precursors	Major activity Sources	Other Activity Sources	Major Health Endpoints
NOX nitrogen oxide and nitrogen dioxide	None	Motor vehicles, power plants, industry	Decaying organic matter, lightning	See O ₃ , and PM _{2.5}
O ₃ Ozone	Volatile organic compounds VOCs, NOX,	Motor vehicles, electric power plants, industry		Mortality, respiratory hospital emissions (age ≥ 65), respiratory hospital admissions (age ≤ 2), emergency room visits for respiratory illness, school loss days, acute respiratory symptoms, minor restricted activity, worker productivity loss.
PM _{2.5} Suspended particles	NOX, VOC	Transportation, industry, power plants	Wood smoke, grain processing, and construction	Mortality (adults), Mortality (infants), chronic bronchitis, nonfatal heart attacks, cardiovascular hospital admissions (adults), emergency room visits (children), acute bronchitis (children), asthma exacerbations (children), upper respiratory symptoms (children with asthma, lower respiratory symptoms (children), minor restricted activity days (adults), work loss days (adults).

Source: Chestnut and Mills (2005)

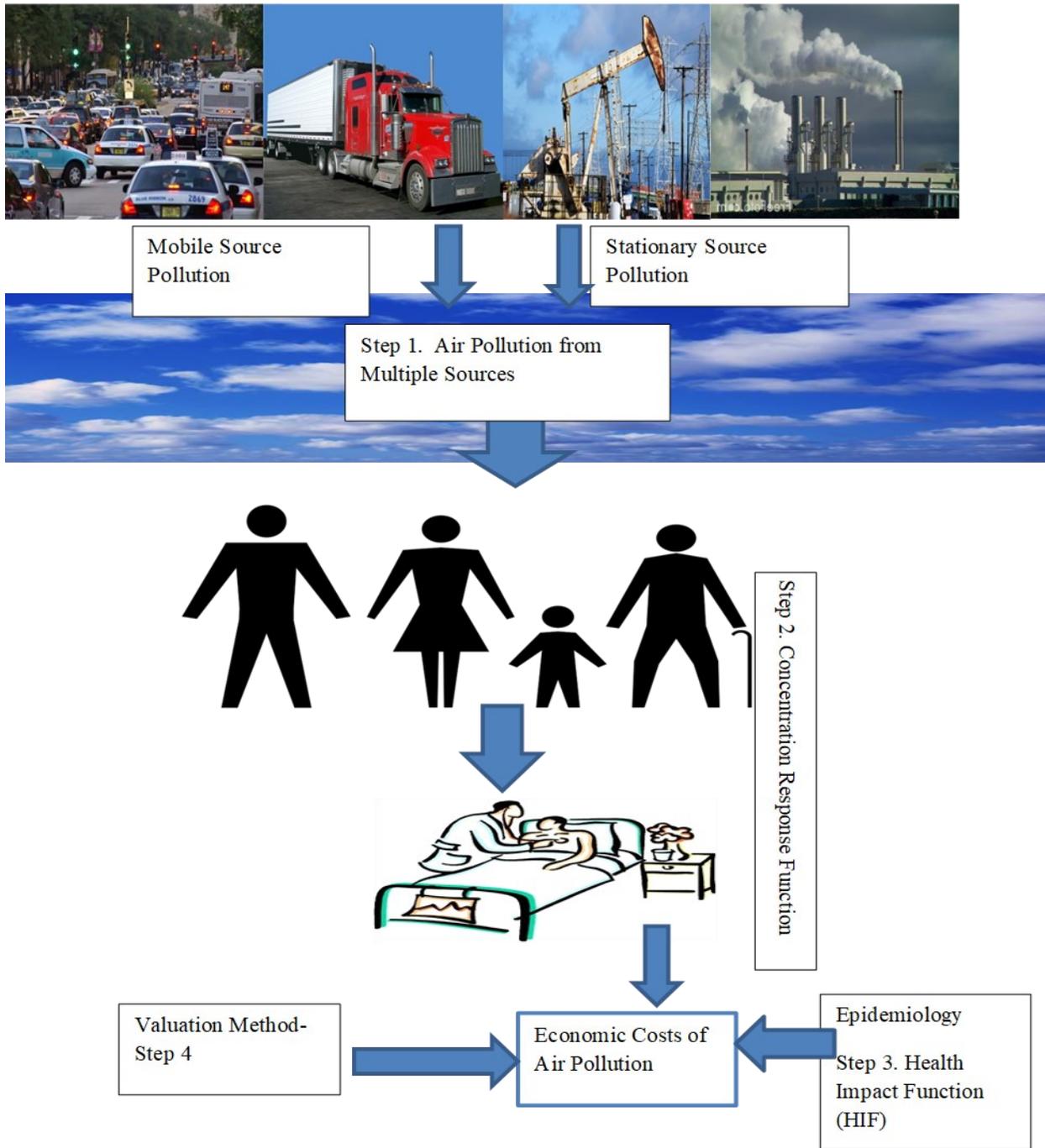


Figure 5
Steps in Estimating Health-Related Costs of Air Pollution

mobile sources (e.g. autos, trucks, trains, and airplanes) and stationary sources (e.g. power plants, factories, oil pumping stations, and natural gas dehydration plants) Each of these sources emits a heterogeneous mix of pollutants and these pollutants combine freely in the atmosphere to form a more-or-less homogeneous media in the lower atmosphere, or troposphere. This is the air and air pollution people breathe. In the second step, medical researchers study how and in what ways pollution leads to damages to peoples' health. They conduct or draw on empirical studies of the relationships between pollution levels and the various health outcomes (also called endpoints) to develop concentration response functions (C-R). C-Rs are usually mathematical functions allowing empirically-based predictions of

how changes in pollution levels will affect health endpoints in various human populations. In other words, how does pollutant x lead to health response y.

For example, concentrations of PM2.5 are most often reported in micrograms per cubic meter of air. The population C-R might be the number of asthma-related hospital visits per day per 100,000 population at various levels of PM2.5.

In the third step, for purposes of estimating benefits, the C-Rs are used to develop health impact functions (HIF). HIFs use C-Rs to develop mathematical relationships between changes in pollutant x (Δx) into changes in a population's health response y (Δy).

Figure 6 illustrates a hypothetical HIF.

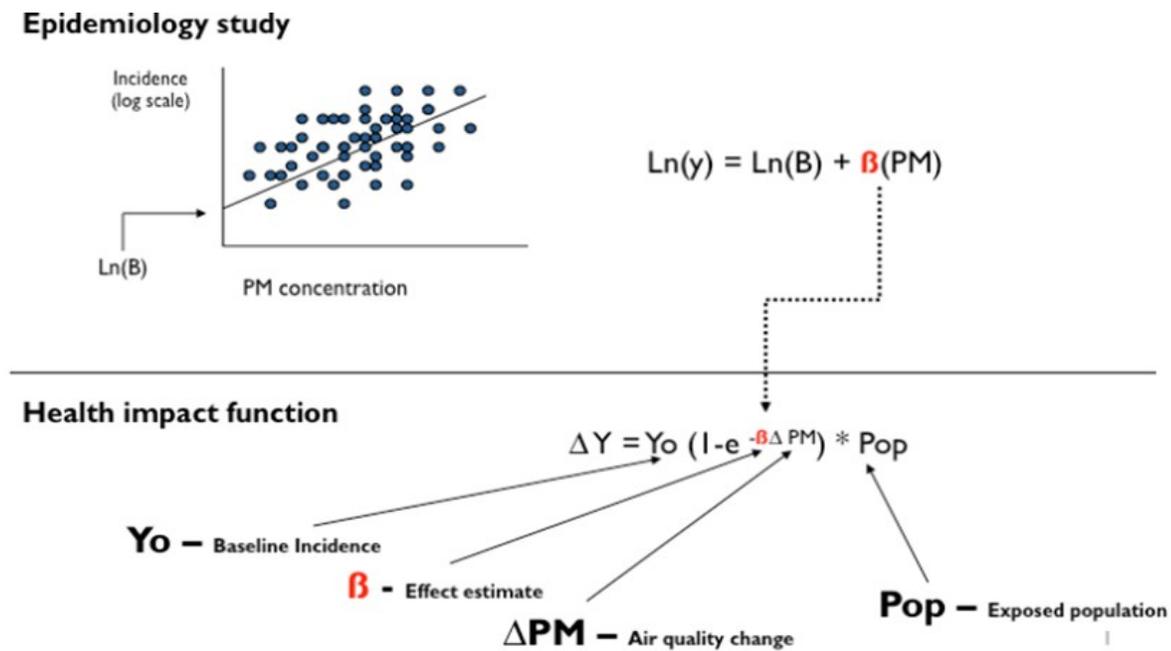


Figure 6
Health Impact Function
 Source: USEPA 2018

The final step in estimating the health-related costs of air pollution is to draw on various valuation methods developed by economists to monetize, or place dollar values on, the health damages attributed to air pollution, or the benefits of avoided health endpoints. There are probably countless health endpoints that are affected by air pollution, but most empirical work is devoted to those listed in Table 1. The costs attached to various health endpoints can also be thought of as the economic value of avoiding the adverse health effects. Examples of these value estimates are in Table 2.⁶ The combination of HIF's and economists' estimates of value allows derivation of the MDC shown in Figure 2.

c. BenMAP

EPA has developed a tool to implement the steps shown in Figure 4.⁷ BenMAP (USEPA 2018) is a user-friendly yet flexible tool designed to facilitate estimation of the MDC of air pollution. BenMAP begins with user-specified changes in ambient pollution levels; it then relates air pollution changes to health endpoints by means of internal or user-supplied C-Rs and HIFs. The incidence of health endpoints is then multiplied by the affected population and estimates of economic values to arrive at MDC of air pollution changes.

BenMAP relies on the extant economics literature to obtain economic values for various health endpoints. The total value to society of an avoided health endpoint is composed of three parts: a) the cost of the medical resources used to treat the illness (termed COI); b) the cost of the lost economic productivity (termed WAGES); and c) the amount

those affected by the illness would be willing to pay to avoid the associated pain and suffering (termed WTP).

When calculating MDC, BenMAP relies on one or more extant estimates of COI, WAGES, and WTP. In some cases, the value estimate is at the users' discretion. When only using COI, the resulting MDC is almost certainly biased downward, maybe by a substantial amount. The MDC will be biased downward because COI alone does not consider the non-market costs of pain and suffering (See Appendix A). For the fifteen health endpoints listed in Figure 2, BenMAP documentation indicates two are derived from WAGES, four from WTP, three from COI, three from COI and WTP, and the method is unclear for the remaining three (USEPA 2018 and authors' calculations).

The method of using health-related damages to estimate the benefits of pollution reductions is well established, well documented, and has been applied in many cases. Chestnut and Mills (2005) used BenMAP and other tools to estimate the health benefits of reduced PM_{2.5} due to implementing the Acid Rain Program (Title IV of the 1990 CAA). Their estimate is roughly \$100 billion. The State of Georgia's Environmental Protection Division used BenMAP to compare various air pollution control strategies and communicate cost and benefit impacts to stakeholders and citizens (Cohan et al. 2007). Most recently, Fann et al. (2012) used BenMAP to estimate the economic benefits of PM_{2.5} reductions across the U.S. Overall, BenMAP has been used as a research tool for at least twenty peer-reviewed articles.⁸

Table 2
Monetary Benefits of a Single Avoided Health Effect from Reduced PM_{2.5} and O₃.

Health endpoints from PM _{2.5} reductions	Monetary value per avoided health endpoint (2019 dollars)	Health effects from O ₃ reductions	Monetary value per avoided health endpoint (2019 dollars)
mortality (adults)	\$8,499,634	Mortality	\$8,450,989.29
mortality (infants)	\$10,833,175		
chronic bronchitis	\$562,575		
nonfatal heart attacks(adults)	\$121,284		
respiratory hospital admissions (age>=65)			\$25,965.00
respiratory hospital admissions (age<=2)			\$11,219.44
respiratory hospital admissions	\$21,377		
Emergency room visits for respiratory illness			\$360.63
cardiovascular hospital admissions	\$31,121		
emergency room visits for asthma (children)	\$409		
acute bronchitis (children)	\$512		
asthma exacerbations (children with asthma)	\$51		
upper respiratory symptoms (children with asthma)	\$38		
lower respiratory symptoms (children)	\$25		
minor restricted activity days (adults)	\$76		
work loss days (adults)	\$16		
school loss days			\$108.35
acute respiratory symptoms, minor restricted activity			\$295.66

Source: Chestnut and Mills (2005). The dollar amounts in the table are estimates of the monetary value of avoiding a single incident of the endpoint. 2000 dollars are converted to 2019 dollars using 1.4425 factor (Historical Consumer Price Index for all Consumers: US City Average).

d. Evaluation of BenMAP Model

To date, BenMAP has been used primarily to estimate the health-related benefits of pollution reductions. However, it could also be used to estimate the health-related damages resulting from the increased UCONGA-related air pollution. Such estimates could aid in establishing credible and defensible impact fees directly related to the health costs of UCONGA-related air pollution. This would require atmospheric scientists to project reasonable air pollution scenarios likely to follow increased UCONGA in various parts of Colorado. Geologists might also project the likely locations of future UCONGA based on known oil and natural gas reserves. Moreover, it seems feasible to use BenMAP to provide not just a single estimate, but multiple estimates reflecting different UCONGA development paths. By varying the projected levels of UCONGA and modeling the locations and levels of the resulting pollution, researchers could estimate location-specific MDCs, such as depicted in Figure 2.

Figure 5 is oversimplified in several ways. First, mobile and stationary sources emit various air pollutants, but when these pollutants mix in the atmosphere they are transformed into other pollutants. For example, many types of hydrocarbon molecules (VOCs) are emitted by many sources and interact with NOX and sunlight to form O₃ (USEPAa 2011). The complex relationships between various sources, various pollutants, and O₃ and PM_{2.5} are shown in Figure 4. However, almost always, air pollution policy analysts surmount this complexity by translating these myriad pollutants into criteria

pollutants such as O₃, NOX, and PM_{2.5} (e.g. USEPAa 2011).

Second, once pollutants enter the atmosphere, it is difficult to determine their sources. For example, both mobile and stationary sources emit VOC's, but once mixed in the atmosphere, complicated and expensive efforts are required to determine where they come from. In spite of these difficulties, there is substantive evidence of a link between UCONGA in western states and air pollution.

Field et al. (2015a and 2015b) used various methods to sample air pollutants in Wyoming's Pinedale Anticline and Jonah Basin oil and natural gas plays. Their evidence is strong that VOC⁹ emissions often arise from UCONGA. They found three VOC hotspots, one in an area with intensive oil and natural gas production and a second in a facility recycling and treating waste water from fracked wells. They also found a NOX hotspot attributable to vehicle traffic.

Thompson et al. (2015) took air samples of non-methane hydrocarbons from Platteville (in the heart of UCONGA in NE Colorado), Erie/Longmont (on the edge of UCONGA) and Denver (south of major UCONGA). The authors used chemical signatures to differentiate between two emissions sources—urban/motor vehicle and UCONGA. They found non-methane hydrocarbons 18-77 times higher than background levels in Erie/Longmont. Benzene and toluene were higher in the Platteville area, with oil and natural gas emissions the dominant source. Motor vehicle emissions dominated in Denver. Most recently, the National Center for Atmospheric Research released evidence that motor vehicles and

oil and gas operations were each responsible for 30-40 percent of O₃ observed on the Colorado Front Range (National Center for Atmospheric Research 2017).

From this evidence, it appears that air pollution sources can be identified, especially with motor vehicles and UNCOGA. Their effects on O₃, NO_x, and PM_{2.5} concentrations and locations could be modelled in BenMAP and their interactions explored.

Third, air pollution does not stay put. Wind and other factors mean that people may be exposed to pollution emitted by far away sources. Evans and Helmig (2017) address this uncertainty by correlating

wind observations with elevated O₃ events in Boulder, CO. They estimate that UCONGA emissions to the northeast (Weld County, CO) are responsible for sixty-five percent of the elevated O₃, while emissions from the Denver area are responsible for nine percent.

Rodrigues et al. (2009) use complex weather and O₃ formation models to estimate the link between oil and gas activities and increases in O₃ in pristine air quality areas in western states. The authors find substantial effects, especially in SW Colorado and NW New Mexico. However, Rodrigues et al. (2009) do not report on O₃ effects in urban areas, nor do they discuss economic impacts.



Credit: Richard Carter

Fourth, air pollution produces other well-known damages not directly related to health, specifically in the forms of reduced agricultural and forest productivity and decreased visibility. There is strong evidence that elevated levels of O3 decrease crop and forest productivity. For crops relevant to Colorado, Table 3 presents estimates of productivity changes used by the USEPAa (2011) in its assessment of the benefits of decreased pollution from CAA. Overall, USEPAa (2011) estimated more than \$1 billion in annual benefits from reduced O3 on agricultural and forest lands. But this is only a small fraction of the total estimated benefits of over \$2 trillion. However, this percentage may be much higher for Colorado given the \$386 million agricultural industry in Weld and Boulder Counties alone and the 24 million acres of Colorado forestland.

For Colorado, reduced visibility may be an especially relevant damage from UCONGA because of outdoor

recreations’ importance in the state. Degraded visibility, largely due to O3 and PM2.5, has been studied by weather scientists and the valuation of improved visibility has been the subject of considerable economic research (USEPAb 2011). For purposes of valuation, two types of visibility benefits are recognized. Recreational visibility reflects the value people assign to the enjoyment of scenic vistas in recreational areas, such as Rocky Mountain National Park. Residential visibility reflects the value assigned to improved visibility where people live. Poudyal et al. (2013) estimated the influence of recreational visibility on visitations to Great Smokey Mountain National Park, the most visited park in the U.S. They find that the number of park visits is sensitive to average visibility levels and conclude that policy changes resulting in greater visibility will provide more recreational benefits.

Table 3
Average Estimated Percentage Increases in Productivity from O₃ Reductions

Crop	Percent Increase
Barley	.02%
Corn	.56%
Potato	6.5%
Spring wheat	.25%
Winter wheat	3.5%
Softwood/Conifer trees	6.11%
Source: USEPAa (2011) Table 6.5, p. 6-19	

Based on prior research valuing visibility, USEPAb. (2011) estimated that increased visibility from implementing the 1990 Clean Air Act Amendments will be \$19 billion for recreational visibility and \$49 billion for residential visibility (USEPAb 2011).

Fifth, exposure to air pollution and the consequences of that exposure can vary across different locations and lifestyles. For example, even with equal levels of local O₃, those living in homes with air conditioning are less likely to suffer health effects from O₃ than those without air conditioning (Bates 2005). C-Rs and HIFs commonly differentiate between various age groups. BenMAP modelling easily accommodates these age group variations by allowing the importation of demographic information.

In spite of these caveats, it appears feasible to estimate the health-related costs of UCONGA-related air pollution using BenMAP. Because BenMAP is a well-established tool widely used in peer-reviewed studies and by government agencies, the resulting estimates would likely be credible and able to withstand potential criticisms. BenMAP flexibility would also allow investigations of multiple scenarios using different assumptions about pollution source locations, pollution levels, and pollution transport. Such sensitivity analyses would give BenMAP results additional credibility and facilitate communication with stakeholders and citizens. In addition, it seems feasible to augment BenMAP to produce monetary estimates of the additional impacts of changes in agriculture and forest productivity, and visibility.

B. Stated Preference Methods

The second method of estimating economic costs from air pollution developed by economists is stated preference (SP). SP methods obtain observations of peoples' preferences (values) by asking survey respondents questions about the choices that they would make if they were to confront various options in real life. SP studies use mail, telephone, personal interviews, and, increasingly, internet-based surveys to elicit peoples' responses. The resulting answers are referred to as "stated choices" because they reflect what people say that they will do, rather than what they are actually observed doing. Economists have been arguing for decades about whether or not stated choice methods reflect actual behavior (see e.g. Portney 1994 and Diamond and Hausman 1994).

There are two broad types of SP, contingent valuation (CV) and choice experiments (CE).

a. Contingent Valuation

State of the art CV questions use a referendum format. Referenda formats are preferred because voters face similar formats when they vote on local initiatives, such as bond issues. Survey respondents are presented with a single "yes" or "no" question, such as the following:

Would you be willing to pay _\$X_ more on your monthly electricity bill to purchase electricity produced by wind power, rather than electricity produced using coal as a fuel. Mark only one choice below:

Yes, I would pay \$X more per month to purchase wind power electricity.

_____ *No, I would not pay \$X more per month to purchase wind power electricity.*

Each survey respondent is presented with only one \$X, but by varying \$X across multiple respondents, the researcher is able to estimate the average and median values placed on the non-market good (in this example, the costs and/or benefits of wind power). The CV question is always prefaced with a summary of the environmental issues involved (this is called framing) and often followed with questions about how certain the respondent is in her responses and the respondents' demographic characteristics.

We are aware of only one contingent valuation study related to UCONGA. Throupe et al. (2013) surveyed potential home buyers in Texas and the Florida/Alabama Gulf Coast. Respondents were asked whether or not they would bid various amounts (\$X) to buy a home under two scenarios. The 'Fracking heavy' scenario consisted of a home located one quarter mile from a drilling site, which was visible from the home. 'Fracking light' consisted of a home located further from a drilling site which was not visible from the home. Both scenarios concerned homes dependent on well water.

Throupe et al. (2013) used a telephone survey conducted by a professional survey firm (NSON, Inc.). The reported results were based on 570 respondents. Taking only the top quarter of the bids, to better reflect bids likely to be accepted in a real market, the authors report six and fifteen percent discounts for Texas and Gulf Coast respondents for 'fracking heavy', respectively. For 'fracking light' the authors

estimate a discount of six percent for Gulf Coast respondents.¹⁰

b. Choice Experiments

Economists borrowed the CE method of estimating economic value from the marketing industry. Consumers were asked which of several models of a consumer good they would buy. The models differ from one another in their characteristics, or attributes. For example, automobile models have different sticker prices, engine sizes, two or four doors, fuel efficiency, and so on. By varying the sticker price and the attributes in systematic ways, CE researchers are able to estimate the average or median values consumers place on each attribute.

CE has been adapted to environmental issues by using scenarios with different levels of non-market goods, such as more or less air pollution. Each scenario comes with an \$X, such as different tax rates or different prices. By systematically varying \$X, CE researchers are able to estimate the value consumers place on the non-market good in question.

We know of only one CE study related to fracking. Popkin et al. (2013) ask New York residents to choose between purchasing electricity generated by natural gas produced by fracking versus electricity produced with non-fracked fossil fuels. They also varied the distance between the residents' homes and the nearest fracking site. An example of the choices presented to survey respondents is given in the figure below.¹¹

Popkin et al. (2013) estimate that average consumers are willing to pay an additional 10 percent (\$28-

You said that you pay \$100. Your current electricity source is largely fossil fuel. Now consider only the following options, as proposed for your county. How would your household vote?

	<u>Option A</u>	<u>Option B</u>	<u>Option C</u>
Source	Natural gas from Hydraulic Fracturing	Natural gas from Hydraulic Fracturing	Largely Fossil Fuel
Your new monthly electric bill	\$ 75 (25% less)	\$ 125 (25% more)	\$ 100 (No change)
Distance of drill site from your household	50 miles	250 miles	No Drilling

- I would choose Option A and pay 25% less on my household electric bill
- I would choose Option B and pay 25% more on my household electric bill
- I would choose Option C

\$48.00) of their monthly electricity bill to purchase electricity not generated by fracked natural gas. Consumers who lived closer to actual fracking sites said they were willing to pay more than consumers further away.

c. Applying Stated Preference Methods to UCONGA

SP methods such as CV and CE may be adaptable to the issue of UCONGA in Colorado. Researchers would need to design scenarios with various levels of UCONGA and various costs (\$X). These scenarios would have to be realistic and believable to Colorado residents. Following state-of-the-art practice, researchers would have to carefully design the CV or CE survey with extensive public input and pre-testing.

Survey implementation would have to be done professionally as well.

SP-based values are widely used. In fact, SP-based damage estimates can be presented as evidence in U.S. courts deciding natural resource damage cases (Portney 1994). Some of the health-related benefits used in BenMAP to value reductions in air pollution are obtained from CV and CE studies (USEPA 2018). A panel of Nobel Prize winners, convened by the National Atmospheric and Oceanic Administration, concluded SP can yield valid estimates of damage values if best practices are carefully followed (Arrow et al. 1993). Other studies find evidence that SP-based estimates mimic actual choices made by voters on local referenda, such as bond issues (e.g. Vossler and Kerkvliet 2003).

Still, estimates based on stated preference surveys remain very controversial (Diamond and Hausman 1994). The crux of the controversy is the hypothetical nature of the CV or CE questions and responses. Although survey respondents are instructed to consider the financial implications of their answers, the actual financial implications for respondents are hypothetical, not real. As such, many economists and others question the credibility of non-market value estimates from CV and CE studies. A recent review of 50 papers finds evidence that SP methods tend to over-estimate what consumers are actually willing to pay for non-market goods, such as health benefits (Kanya et al. 2019).

If SP methods were used to estimate MDC of UCONGA in Colorado, great care must be taken to ensure that the study meets the highest professional standards for design, administration, and analysis. Even then, it is reasonable to expect that the results would be strongly questioned by critics and some policy makers.

C. Hedonic Method

The hedonic method is grounded on the reality that homes are located near various levels of desirable and undesirable characteristics. Desirable characteristics are called amenities and include better air quality, better schools, less crime, less noise, and more convenient access to work and shopping. Undesirable characteristics are called disamenities and include lower air quality, poorer schools, more noise, and less convenient access to work and shopping. Homes in areas with more or better amenities will have higher property values and

command higher sales prices. Conversely, homes in areas with disamenities will have lower property values and command lower prices, because owners are more willing to sell and buyers less willing to buy.

Hedonic studies statistically analyze variations in actual property sales' prices to isolate the price effects of environmental amenities and disamenities. To produce accurate and unbiased estimates of amenities and disamenities, the studies must also control for other factors affecting sales prices. These other factors include characteristics of the property (e.g. square footage of house and lot, date of construction, number of rooms, number of bathrooms), characteristics of the neighborhood (e.g. nearness to shopping, traffic congestion, crime rate) and characteristics of the region (e.g. schools and hospitals, distance to major city, employment opportunities).

a. Hedonic Studies of UCONGA

In the hedonic methods, the marginal damages from air pollution are assumed to be capitalized as lower property values. In the case of UCONGA, if buyers and sellers of houses recognize the undesirability of air pollution and other disamenities caused by UCONGA, houses located nearer UCONGA or more intense UCONGA will sell for less.

The extant hedonic studies applied to fracking always use some measure or measures of fracking activity with distance and temporal components. For example, Bennett and Loomis (2015), in their study of Weld County, CO properties, use the distance to the nearest well being drilled within two miles of the

property and within sixty days of the actual sale of the property, the number of wells drilled within one half mile of the property and up to sixty days of the property's sale, and the number of producing wells within one half mile of the property at the time of sale.

In an early hedonic study, Boxell et al. (2005) estimated the effect on property sales prices of oil and gas activities near Calgary, Alberta, CA. The study occurred before wide-spread fracking applications and so it relates more to conventional natural gas production and processing. The authors distinguish two types of disamenities. The first is the presence of hydrogen sulfide (H₂S) atmospheric emissions associated with producing 'sour' oil and gas. 'Sweet' wells do not produce significant H₂S emissions. H₂S emissions may affect the property even if there are no nearby wells due to the presence of transmission and processing facilities. The second type of disamenity is the property's proximity to 'sour' or 'sweet' wells. The authors find that H₂S emissions within four kilometers (km) of a property reduce the property's sales price by \$11,000 to \$13,000 CA (3.8-4.3%). The presence of wells within four km also reduces price, but the price effect varies with the type of well. At the sample average, the presence of 1.94 'sour' wells within four kilometers reduces a property's price by an average \$12,000 CA (4.3%). 'Sweet' wells also reduce property values, although not as much as sour wells. Combining the two types of disamenities, the authors' estimate that oil and gas activities in Alberta, CA reduce nearby property values by about \$24,000 CA (8 %).

Next, we give brief summaries of studies in the U.S., including geographic scope, methods employed, and the ways proximity to UCONGA are measured. For each study, we report the estimated price effects in dollar and percentage terms, where possible. We follow this review with a discussion of the lessons learned and guidance for potential future studies to estimate appropriate impact fees to achieve efficient levels of UCONGA-related pollution.

b. Colorado Studies

Four hedonic studies have focused on UCONGA in Colorado. Three of these studies are published in peer-reviewed journals. The first Colorado-based study is not peer-reviewed and was conducted by BBC Research and Consulting (BBC) (2006). BBC analyzed rural property sales of less than 160 acres in Garfield County, CO between 1980 and 2005. To measure the potential disamenities of UCONGA, BBC used whether or not a well had been drilled on the property, within 90 days of sale, within 2 years prior to sale, and more than two years prior to sale. BBC did not measure, or estimate the potential disamenities on nearby properties. BBC did not find statistically significant price effects for well drilling activity on the parcel prior to the time of sale. Although not statistically significant, BBC reported price decreases of \$48,000 (15%), \$32,000 (10%), and \$23,000 (7%) for properties with drilled wells within 90 days, two years, or greater than two years of sale, respectively.

There are five possible reasons for BBC (2006) not finding statistically significant price effects. First, less than one tenth of one percent of the properties in



Credit: WildEarth Guardians

their sample had drilled wells on the parcel. This small incidence can affect statistical reliability. Second, BBC implicitly assumed that drilling only affected properties containing the well(s). By assumption, adjacent properties could not be affected. Third, BBC did not have data on and could not estimate the effect of mineral rights. It is important to control for mineral rights because potential revenue streams from royalty or lease payments will be capitalized into property values if the property owner and the mineral rights owner are one and the same. Fourth, BBC did not have data on and could not estimate the potential effects of fracking on groundwater quality. Fifth, perhaps well drilling does not affect property values in Garfield County. BBC also found that other industrial activities (e.g. landfills, Interstate 70, rail lines, and high voltage power lines) did not affect prices.

Bennet and Loomis (2015) study sales prices of residential properties sold in Weld County, CO between 2009 and 2012. The authors measure the potential disamenities of UCONGA spatially and temporally, using three measures. The first is the distance to the nearest well being drilled within two miles of the property and within sixty days of the sale. The second is the number of wells drilled within one half mile of the property and up to sixty days of the property's sale. The third is number of producing wells within one half mile of the property at the time of sale. The authors' test for and conclude that the price effects are likely to differ between rural and urban properties. The authors define urban properties as those located in Greeley, CO and unincorporated towns; rural properties are all others. The authors report the results of twelve statistical models.

For rural properties, Bennet and Loomis (2015) find statistically significant price effects for only the first disamenity—distance to nearest well being drilled. Each meter closer to the nearest well being drilled results in an estimated \$12.21 decrease in property sale price. In other words, a property located within 1000 meters of a well being drilled would sell for \$12,210 (5-6 %) less than a property located 2000 meters away.

For urban properties the authors find conflicting evidence. An additional well being drilled at the time of sale decreases sales price by \$1,354-\$1,805 (.6-.8 %). Each increase in the number of producing wells increases price by an estimated \$289 and increasing distance to a well being drilled decreases price by an estimated \$2.62 to \$3.71 per meter.

The authors discuss possibly serious limitations to their study. First, the authors' data do not allow them to control directly for mineral rights. A property whose deed includes mineral rights may realize a financial benefit from selling those rights. Lease bonuses and production royalties could offset some or all of the potential UCONGA disamenities. Second, the authors' data do not account for household water source, because such data are not available. Potential contamination of well water is a suspected disamenity associated with UCONGA and not controlling for it could mask other disamenity effects in unknown ways (Bennet and Loomis 2015, pp. 1181-1184).

He et al. (2018) also conduct a hedonic housing price study of properties in Weld County, Colorado, using

data on sales from October 2014 through March 2017. The authors measure the potential disamenities of UCONGA by the number of pending and approved well permits within various distances from the property and various temporal windows around the time of sale. For example, one specification uses the number of permitted wells within one half mile of the property within six months prior to the date of sale. The authors also analyzed a restricted sample of houses near pending, but not approved, permits. This strategy is based on the logic that houses located near wells with approved permits are likely to be subject to UCONGA disamenities and, potentially, the benefits of lease bonuses and royalty payments if the property deed includes mineral. Conversely houses near pending, but not approved permits, will not be subject to UCONGA disamenities, but will potentially benefit from payments for mineral rights.

In their statistical analysis, He et al. (2018) find no statistically significant evidence of price effects. In their many statistical models and samples, the estimated price effect of UCONGA effect was always negative but never statistically different from zero.

He et al.'s (2018) findings have limitations because of their use of well permit data to measure the proximity to UCONGA. Just because a well is permitted does not mean that the well has been drilled. Companies can and do stockpile permits. Also, a well permit can be for a new well in a producing field or a new well in a new field. Well permit data does not tell us whether or how many wells exist near the property.

Boslett et al. (2019) analyze real estate sales prices in Colorado's Garfield, Mesa, and Rio Blanco counties. The authors' strategy to account for mineral rights ownership is to distinguish between properties which had been conveyed by the U.S. government to private owners under the 1916 Stock-raising Homestead Act (SRHA) versus properties so conveyed by the Homestead Act of 1862. Unlike other conveyances of federal property to private ownership, the federal government retained mineral rights conveyed by SRHA. The authors estimate that properties without mineral rights located within one mile of a producing well sell for \$63,788 (34.8%) less than similar properties without a producing well within one mile. This result holds for several model variations. In addition, the authors provide evidence that failure to account for mineral rights ownership results in much smaller (in absolute value) and statistically weak estimates of negative price effects of UCONGA.

c. Texas and Oklahoma Studies

Moving away from Colorado-based studies, we turn to hedonic studies conducted in Texas and Oklahoma. Weber et al. (2016) consider the effects of rapidly increasing property tax bases on housing prices in Dallas/Fort Worth. Tax bases increased rapidly in the study area because Texas counties levy property taxes on natural gas wells as soon as production begins. The increases in tax revenue may lead to improved public services (e.g. schools) and/or decreased tax payments for residential property owners. The authors hypothesize that both effects will lead to housing price increases. Rather than use sales of individual properties, Weber et al. (2016) use zip code level Zillow Home Value Index from 1997 to

2013 as observations. The Dallas/Fort Worth area is about equally divided between zip codes with and without Barnett shale substrate.

While not the focus of the study, Weber et al. (2016) control for potential disamenities with a variable measuring the cumulative well density within a zip code between 2000 and 2013. The results suggest that increases in tax revenue increased house prices. The average effect is a \$6,525 (7.4 %) increase in housing values in zip codes with natural gas wells and each \$1 increase in tax base led to a \$0.15 increase in the sales price of the typical house. Conversely, the authors find a statistically significant disamenity effect. Holding the tax base constant, the cumulative well density in a zip code lowered the value of nearby houses by an average \$600 (0.72 %).

Balthrop and Hawley (2017) use the hedonic method to estimate the effect of oil and gas wells in the Dallas/Fort Worth/Arlington area of Tarrant County, TX for 2005-2011. The authors use distance to gas wells as a measure of potential disamenities. The authors find robust negative effects on property values of \$4,720-\$5,900 (2.8 - 3.5 %) for properties with 1-6 wells located within 3500 feet of a fracking well. The negative effect on sales price is roughly the same for properties with 7-12 wells within 3500 feet and seems to disappear for properties with more than 12 wells. The authors speculate that properties with 12 or more wells are likely owned by a person who also owns mineral rights. The authors also estimate the effect of wells under construction and find an additional depression of sales prices of -1.8% per well and find a larger disamenity effect for unconventional wells relative to conventional wells.

Feirreira et al. (2018) use the hedonic method to estimate the effect of wastewater injection seismicity risk in Oklahoma County, OK by comparing repeat house prices for homes located at varying distances from wastewater injection wells and production wells. The authors estimate the disamenity effect of being near a wastewater injection well is a decrease in property values of \$4,541 (2.4 %) for houses within two km of an injection well.

d. Marcellus Shale Studies

The remainder of the hedonic studies concern UCONGA in the Marcellus gas play of Pennsylvania and New York. Gopalakrishnan and H. Klaiber (2013) analyze the housing price effect in Washington County, PA. Their measure of potential disamenities is the number of fracking wells within one mile of the property permitted six months prior to the property's sale. The authors find statistically significant negative effects of fracking activity, but these effects vary widely with types of land use near the property. These types include: 1) whether the surrounding land is primarily agricultural or not; 2) water source (public or private well); and 3) proximity to major roadways. The estimated effect of well count within one mile of the sold property are: 1) \$1,576 (+1%) for a property surrounded by less than 20 percent agricultural land; 2) -\$2,467 (-1.6%) for a property surrounded by more than 80 percent agricultural land; 3) -\$8,288 (-5%) for a property with private well water and 80 percent agricultural land; and 4) -\$4,244 (-2.8%) for a property with 20% agricultural land and private water. The effects of fracking intensity were always more negative (and statistically significant) for

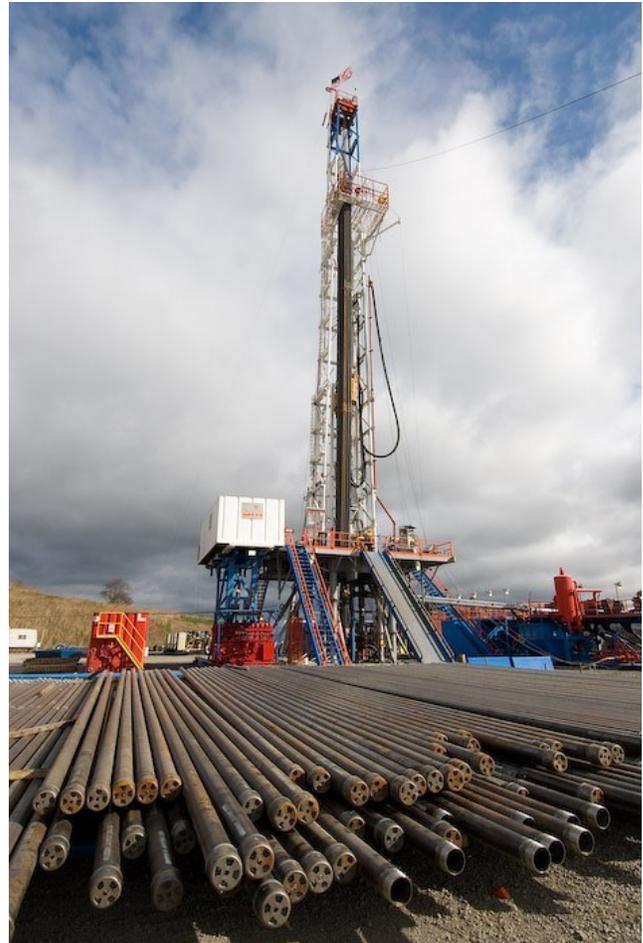
properties located closer to major roadways. The authors attribute this finding to the congestion and noise associated with the 200-400 truck trips required to develop a typical well.

Muehlenbachs et al. (2015) use housing sales data from 36 Pennsylvania counties from 1995 to 2005¹² to estimate the potential disamenity effects of being located close to drilling well pads. Using various statistical methods, including triple difference estimation, the authors find robust negative effects of adjacency for properties located close to well pads and relying on private well water sources. They also find small positive effects for properties located close to well pads but sourcing water from public water suppliers. For properties relying on groundwater and located within one km of a well pad, the net adjacency effect is a negative 13.9 percent, while adding an extra well pad within 1.5 km decreases sales prices by 6.5 percent. The authors also find small, but statistically significant and negative vicinity effects for well pads within 20 km of a property. The negative effects of adjacency for groundwater dependent homes disappear at 2 kilometers. The authors attribute finding of the positive effects at 1.5 kilometers for houses with public water supplies to the positive effects of lease payments and other adjacency effects. Exploring further by distinguishing between producing wells which provide royalty payments and non-producing wells, which do not, the authors find that positive adjacency effects are likely driven by royalties. They further find the putative royalty effects only apply if the wells are not visible from the property (Muehlenbachs et al. 2015, p. 3650).

Delgado et al. (2016) use a variety of econometric methods to identify the effects of unconventional gas wells on property prices in two Pennsylvania counties. Across many specifications the authors do not find statistically significant evidence of either positive or negative impacts. Four exceptions are worth noting. First, for one county (Bradford), there is statistical evidence of a \$12 to \$238 (0.1 – 2.0%) decrease in sales price for properties within 1 mile of a well. Second, using matching methods, the authors find evidence of a 15 percent reduction in sales price for houses within one mile of a well in both counties. Third, using non-parametric methods to estimate non-linear effects, the authors find evidence of a \$5,000 (4 %) sales price reduction for houses located in Bradford County and within 1-2 miles of a well. This effect disappears at about four miles. Fourth, the authors employ the geographic boundary of Marcellus shale in Lycoming County to distinguish between potential positive effects of royalties and lease payments from potential negative externality effects. They find statistically significant positive effects for houses on the edge of the Marcellus shale boundary but far from actual well. The authors attribute this finding to the potential for economic benefit from mineral rights ownership, but little potential for external costs.

e. Lessons Learned

Hedonic studies have been widely used to estimate the potential effects of UCONGA on real estate prices. One of the clear advantages of the hedonic method is its basis in actual market transactions. The data used in hedonic studies reflect the actual



Credit: Penn State Outreach

prices paid and received by real estate buyers and sellers and therefore reflect actual behavior, with real financial consequences.

Another advantage is that hedonic methods are closely aligned with the methods used by local governments to arrive at appraised property values for tax purposes. For example, Fryar (2017) reports that appraised values in Boulder County exceed \$60 billion and most of that value is in non-rural properties. Hedonic studies use two of the three

methods used by Boulder County, CO to determine property value: “evaluation of real market data that reflect actual sales in the market place and comparisons of properties of ‘like’ characteristics and location using state-of-the art modelling software” (<https://www.bouldercounty.org/property-and-land/assessor/assessment/#valuation>, accessed 04/08/2019).

The above review shows that hedonic studies provide mixed results and are far from conclusive about whether UCONGA effects are positive, zero, or negative. Still, there are lessons to be learned from the extant studies. They can provide guidance on how to conduct a state-of-the art hedonic study and how to appropriately interpret and wisely use the results of future studies.

First, there are potentially both benefits and costs related to UCONGA. The potential costs have been discussed above. Potential benefits include employment opportunities, increased tax revenue, investment, and, for owners of mineral rights, leasing bonuses and royalty payments. The theory behind hedonic studies is that costs will be capitalized into lower real estate sales prices, but benefits will be capitalized into higher prices. The theory also allows for the possibility that benefits and costs cancel each other out.

To provide convincing results, hedonic studies must statistically control for both benefits and costs. The first major difficulty in using hedonic methods is that such control is not always done nor, perhaps, even possible. To fully control for costs and benefits, extant studies point to at least two property

attributes that must be addressed: mineral rights and household water source.

If the surface property owner also owns subsurface rights, the property’s sales price will reflect the potential for actual lease and/or royalty payments. Payments to owners of these rights can be substantial and even the potential of these payments can affect the price of a property being sold. For example, in 2017 Weld County CO leased some of the 40,000 ‘mineral’ acres it owns for an average of \$7,072 per acre (Silvy 2017). If oil and gas is extracted from the leased properties, the county will also receive royalties.

Data on mineral rights ownership, especially in relationship to surface property ownership seem to be devilishly hard to find. Boslett et al. (2019) focus attention on the importance of controlling for mineral rights, in their finding that properties with severed mineral rights are strongly and negatively affected by UCONGA, but if mineral rights are not statistically controlled for, the negative effect is much weaker and less statistically strong. The authors also describe the difficulty of finding data on mineral rights in Colorado: *“Mineral right ownership information is held in county deeds offices and is not commonly included in property deeds. The chain of title can be unclear, especially when the mineral estate was separated from the surface estate after the property was originally conveyed. Charting mineral rights ownership over time is the full-time job of a mineral abstractor... Suffice it to say, it would be difficult for researchers to successfully obtain mineral rights ownership for a large property transaction database.*

One of the authors of this study spent a day at Pennsylvania's Bradford County's Register and Recorder office researching mineral rights transfers and can attest to this (Boslett et al. 2019 p. 4, footnote 4).

Three of the four hedonic studies conducted in Colorado fail to include mineral rights in their analyses (Bennett and Loomis 2015, He et al. 2018 and BBC Research and Consulting 2006). This may account for the findings of positive, zero, or small price effects.

Second, the potential for water contamination associated with UCONGA make it critical to statistically control for household water source in hedonic studies. Without accurate data on water source, it would be difficult for hedonic studies to distinguish between price effects caused by potential household water contamination versus those caused by air pollution or other disamenities. Hedonic estimates of property value impacts of fracking in Pennsylvania strongly suggest the size and even the sign (negative or positive) of the impact depends on water source. Muehlenbachs et al. (2015) find large negative impacts for groundwater-dependent homes, but piped-water-dependent homes show small, positive impacts. Gopalakrishnan and Klaiber (2014) report qualitatively similar findings.

Unfortunately, some evidence suggests that controlling for water source may not be possible in Colorado. Bennett and Loomis (2015) acknowledge this in stating: "Since water issues are some of the most prevalent issues associated with fracking in Colorado, the absence of data on household water

supply may be masking some of the effects of fracking that might be ... capitalized into housing prices (p. 1181)."

Boslett et al. (2019) also acknowledge this potential difficulty in their study of Colorado real estate properties: "In Colorado, data do not exist as to which properties have private vs. public water supply. Our split-estate properties exist outside of municipal boundaries, which is a proxy for public water service. However, it is possible that some of our properties have access to public water systems...Therefore our estimates may not be applicable to households that face the risk of groundwater contamination (p. 15)."

He et al. (2018) attempt to control for water source by designating properties located in Designated Basin and Groundwater Management Districts as being groundwater-dependent. In their sample of over 11,000 Weld County properties, 99.6% are not groundwater-dependent. The accuracy of this empirical strategy is not known, nor addressed by the authors.

Third, Extant hedonic studies have ignored some of UCONGA's potential pollution sources. Moore et al. (2014) detail five stages of the natural gas life cycle: preproduction, production, transmission/storage/distribution, use, and well production end-of-life.

Raw natural gas is produced in numerous wells in a basin, gathered in a network of pipelines and compressor stations, and processed in centralized processing plants. These plants remove contaminants (e.g. water, acids, natural gas liquids, condensate, and oil) to produce pipeline quality natural gas, composed largely of methane and ethane

and an odorant to aid in leak detection. Distribution to consumers involves thousands of miles of pipeline, over one thousand compressor stations, and a vast network of storage facilities. Each stage potentially produces a different mix of air pollutants.

Because hedonic studies have mainly focused on the first two stages and ignored the remaining three stages, these studies' estimates of the effects of UCONGA may be biased. For example, emissions from liquid condensate storage tanks are responsible for 66 percent of the non-methane volatile organic compounds (including benzene, toluene, ethylbenzene, and xylenes) produced by UCONGA in northeast Colorado (Moore et al. 2014).

Another example are wells that are abandoned at the end of life which can contaminate underground drinking water by acting as a conduit for drilling fluids or contaminated surface water. Both surface water pollution and methane pollution can occur years after the well has been plugged and abandoned (Morton and Kerkvliet 2019).

A final limitation of hedonic studies is the ability to measure only localized effects. All the hedonic studies reviewed here have relied on some measure of adjacency to UCONGA as an indicator of potential disamenities. However, this strategy may not capture disamenities if they occur at long distances from the activities. This may be especially important in the case of air pollution and perhaps water pollution. If, for example, the air pollutants produced by UCONGA result in increased O₃ dozens of miles away, hedonic studies are not likely to capture this effect. There is some evidence that this is important for Colorado as

air pollution produced in Weld County appears to contribute to O₃ in Boulder County at considerable distance from the actual UCONGA (Evans and Helmig 2017).

D. Benefit Transfer Method

Benefit transfer (BT) is the final method reviewed for estimating marginal damages due to UCONGA-related air pollution to design efficient impact fees. As defined in a 2018 review, BT "is the use of pre-existing empirical estimates from primary studies at one or more sites or contexts where research has been conducted to predict ... [monetary damage] estimates at unstudied sites or contexts" (Johnson et al. 2018, p. 77).

In our explanation of the BT methodology, we will illustrate and clarify some points using the potential example of BT applied to all the extant hedonic property value studies described above. A second possible BT application might take estimates of health-related damages from multiple cities, states, or even countries and "transfer" these damage estimates to Colorado, or specific counties in Colorado.

a. Unit Value Benefit Transfer

Hundreds of diverse BT studies have been conducted in the last thirty years (Johnston et al. 2018, Nelson and Kennedy 2009, Johnston and Rosenberger 2010). These studies divide into two basic types: unit value transfers and benefit function transfers (Johnson et al. 2018). A unit value transfer simply takes some estimate or combination of estimates of damages and applies, or "transfers", it to the unstudied site.

As an example of benefit transfer methods, Bennett and Loomis' (2015) estimated effects on Weld County property values (2015) could be transferred to Boulder County properties. Or Bennett and Loomis' different estimates for rural versus urban properties could be applied to Boulder County's urban and rural properties. A more sophisticated benefit transfer method could apply the average property value reduction from Bennett and Loomis (2015) combined with those from Boslett et al. (2019). Or perhaps an average could be applied based on all of the hedonic studies in Colorado.

b. Benefit Function Transfer

BT's employing benefit function transfers are more complicated and mostly done using a statistical method called Meta-analysis (Nelson and Kennedy

2009). Here, variations in damage estimates from multiple prior studies are statistically explained with independent variables, such as the characteristics of the primary studies, characteristics of the primary studies' sites, and quality measure of the primary studies (Nelson and Kennedy 2009). The equation derived from this statistical analysis is the benefit transfer function and is used to adjust the transferred value to the site of interest. In our example, a benefit function transfer could estimate an equation to control for the different characteristics of the areas in Colorado, Pennsylvania, Texas, Oklahoma, and Alberta where the studies were conducted. In addition, a quality measure of the prior study might look for differences between peer-reviewed and not-peer-reviewed studies.



Credit: WildEarth Guardians

c. Pros and Cons

What are the pros and cons of BT? In BT's favor is its wide-spread use, especially in policy analysis.

Although other methods (e.g. hedonics and stated preference) are generally preferred, in the many benefit-costs analyses required for U.S. rulemaking, time and financial imperatives often prohibit the use of primary studies to estimate non-market values (Johnston et al. 2018). Hence USEPA studies usually employ BT (e.g. USEPAa 2011).

Another BT advantage is its widespread use in policy analyses has prompted the U.S. and other governments and many economists to devote considerable attention developing "best practices" for conducting BT. In 2016, U.S. EPA conducted a workshop entitled Benefit Transfer: Evaluating How Close is Close Enough (Johnston et al. 2018).

Under ideal circumstances, BT methods, especially those employing benefit function transfer, utilize all available data and capitalize on all of the effort expended on primary studies. BT can even synthesize studies using different methodologies. For example, a benefit function transfer could use data from both the hedonic and stated preference studies discussed above. Recent BT studies can take advantage of readily available and easily searched data bases to identify all relevant prior studies (e.g. Van de Ploeg and de Groot 2010). More recently, software tools to facilitate estimates for benefit function transfer using Meta-analysis have become available (TOPTIP Bio 2019).

On the con side, BT has many critics among economists and policy makers, even the ones that use them (see Johnston et al. 2018). Economists criticize BT's lack of theoretical foundation. Accurate and defensible BT studies must satisfy the criteria of commodity, spatial, and temporal consistency. That is, the commodity or non-market good must be the same in the primary studies and the target of the benefit transfer. The time periods must be roughly the same and the geographic area of the studies must be similar.

There are methods of adjusting or controlling for some commodity, spatial and temporal inconsistencies. Each advance in these methods adds to complexity, cost, and time required for conducting a BT study. As complexity, cost, and time increase, some of BT's advantages (e.g. quick and inexpensive) are reduced.

V. CONCLUSION

This report first describes and illustrates the case of a user or impact fee on unconventional oil and gas activities (UCONGA) leading to the economically efficient use of a non-market good, such as the atmosphere. The report then reviews four tools used by economists and policy analysts to estimate an efficient impact fee, based on the monetized marginal damages of air pollution. We conclude by presenting a ranking of these tools based on our review. The ranking is meant to provide only guidance to policy makers. Policy making may introduce concerns given

little or no weight in this report. For example, most of the studies reviewed here are from peer-reviewed journals and place great attention on the statistical reliability of estimates. In contrast, legal defense of proposed impact fees may give little weight to statistical reliability and, instead, rely on other standards, such as reasonableness.

Our highest ranked method estimates the marginal damage costs of air pollution based on changes in human health. The U.S. Environmental Protection Agency has developed a tool, BenMAP, specifically for this purpose. BenMAP (USEPA 2018) is widely used and provides flexible modelling of changes in levels and locations of air pollutants. It then translates these changes into changes in health endpoints and values these endpoint changes into monetized damage estimates. BenMAP use requires some expertise from atmospheric scientists and economists, but the software is well-documented and free. Moreover, we conclude it is likely that BenMAP could be augmented to provide estimates of air pollution damages to crops, forests, and reduced visibility.

The second rank goes to benefit transfer (BT) methods. BT uses pre-existing air-pollution damage estimates and applies them to new sites and conditions. BT applications can vary from simple (unit value transfers) to very complex (benefit function transfers). Simple BT is quick and inexpensive, but more vulnerable to criticism and challenges. Complex BT takes more time and expertise, but is more resilient. In many cases, BenMAP uses BT marginal damage estimates.

The third rank goes to stated preference methods. These survey-based methods are flexible and may be designed to address an array of potential damages; not just health, but noise, congestion, and social disruption. SP can be used to estimate the pain and suffering category of health-related costs. Properly done SP studies require expensive professional design, vetting, and analysis following established 'best practices' (Arrow et al. 1994). Even when carefully designed and implemented, SP damage estimates are very controversial because they are based on hypothetical actions, not actions with real financial consequences for survey respondents.

We assign the lowest rank to hedonic studies of property values. Ordinarily, carefully-done hedonic studies are highly credible because estimated damages are based on actual market data. However, the hedonic studies reviewed here are suspect because they fail to account for mineral rights and/or household water source. If, however, Colorado authorities decided mineral rights and water source data should be collected for other policy purposes (e.g. permitting or economic impact studies), hedonic studies using these data may rank much higher.

Finally, some of these four methods may complement one another. For example, a single BenMAP study of representative Colorado counties could use the resulting damage estimates in BT for other counties.

VI. REFERENCES

- Apergis, N. 2019. Impact of fracking activities on Oklahoma's housing prices. *Energy Policy*. 128. 94-101.
- Arrow, K., R. Solow, P. Portney, E. Leamer, R. Schuman. 1993. Report of the NOAA panel on contingent valuation. *Federal Register*. 58. 4601-4614.
- Balthrop, A. and Z. Hawley. 2017. I can hear my neighbor's fracking. The effect of natural gas production on housing values in Tarrant County, TX. *Energy Economics*. 61. 351-362.
- Bates, D. 2005. Ambient ozone and mortality. *Epidemiology*. 16. 127-129.
- BBC Research and Consulting. 2006. Garfield County land values and solutions study. Denver, CO.
- Bennett, A. and J. Loomis. 2015. Are housing prices pulled down or pushed up by fracked oil and gas wells? A hedonic price analysis of housing values in Weld County, Colorado. *Society and Natural Resources*. 28. 1168-1186.
- Boslett, A., T. Guilfoos, C. Lang. 2019. Valuation of the external costs of unconventional oil and gas development. *Association of Environmental and Resource Economists*, preprint. DOI 10.1085/702340.
- Delgado, M., T. Guilfoos, A. Boslett. 2016. The cost of unconventional gas extraction: a hedonic analysis. *Resources and Energy Economics*. 46. 1-22.
- Boxall, P., W. Chan, M. McMillan. 2005. The impact of oil and gas facilities on rural residential property values: a spatial hedonic analysis. *Resources and Energy Economics*. 27. 248-269.
- Chestnut, L. and D. Mills. 2005. A fresh look at the benefits and costs of the US acid rain program. *Journal of Environmental Management*. 77. 252-266.
- Cohan, D., J. Boyhan, A. Marmur, and M. Khan. 2007. An integrated framework for multipollutant air quality management and its application in Georgia. *Environmental Management*. 40. 545-554.
- Colorado Air Quality Control Commission. no date. Regulation Number 7 (5 CCR 1001-9)
- Diamond, P. and J. Hausman. 1994. Contingent valuation: is some number better than no number? *Journal of Economic Perspectives*. 8. 45-64.
- Evans, J. and Helmig, D. 2017. Investigation of the influence of transport from oil and natural gas regions on elevated ozone in the northern Colorado front range. *Journal of the Air and Waste Management Association*. 67.196-211.
- Fann, N., Lamson, A., Anenberg, S. Wesson, K. Risley, D. and B. Hubbel. 2012. Estimating the national public health burden associated with exposure to ambient PM2.5 and ozone. *Risk Analysis*. 32. 81-95.
- Ferreira, S., H. Lui., Brewer, B. 2018. The housing market impacts of wastewater injection induced seismicity risk. *Journal of Environmental Economics and Management*. 92. 251-269.
- Field, R., Soltis, J., Ballesta, P., Grandesso, E. and D. Montague. 2015a. Distributions of air pollutants associated with oil and natural gas development measured in the upper Green River Basin of Wyoming. *Elementa: Science of the Anthropocene*. 3:000074. Doi: 10.12952/journal.elements.000074. elementascience.org.
- Field, R, J. Soltis, M. McCarthy, S. Murphy, and D. Montague. 2015b. Influence of oil and gas field operations on spatial and temporal distributions of atmospheric non-methane hydrocarbons and their effect on ozone formation in winter. *Atmospheric Chemistry and Physics*. 15. 3527-3542.
- Fryar, S. 2017. Assessor: big increase in reappraised Boulder County taxes. *Times-Call Region News*. April 20, 2017.
- Gillingham, K. and J. Stock. 2018. The cost of reducing greenhouse gas emissions. *Contemporary Economic Policy*, forthcoming.
- Gopalakrishnan, S. and H. Klaiber. 2013. Is the shale energy boom a bust for nearby residents? Evidence from housing values in Pennsylvania. *American Journal of Agricultural Economics*. 96. 43-66.

- He, X., Lu, N., Berrens, R. 2018. The case of the missing negative externality? Housing market effects of fracking in the Niobrara shale play, Colorado. *Journal of Environmental Economics and Policy*. 7. 223-243.
- Howarth, R. 2014. A bridge to nowhere: methane emissions and the greenhouse gas footprint of natural gas. *Energy Science and Engineering*. 2. 47-60.
- ICF International. 2014. Economic Analysis of Methane Emission Reductions Opportunities in the U.S. onshore oil and natural gas industries. Fairfax, VA. March.
- Johnston, R., J. Rolfe and E. Zawojka. 2018. Benefit transfer of environmental and resource values: progress, prospects, and challenges. *International Review of Environmental and Resource Economics*. 12. 177-266.
- Johnston, R. and R. Rosenberger. 2010. Methods, trends, and controversies in contemporary benefit transfer. *Journal of Economic Surveys*. 24. 479-510.
- Kanya, L., S. Sanghera, A. Lewin, and J. Fox-Rushby. 2019. The criterion validity of willingness to pay methods: a systematic review and meta-analysis of the evidence. *Social Science and Medicine*. 232: 238-261.
- Lindaas, J. 2018. Investigating contributions to elevated surface ozone in the Colorado front range during summer 2015. Master's Thesis. Colorado State University. Fort Collins, CO.
- Marmaduke, J. 2015. Colorado's ozone fight could drive up costs. *Coloradoan*. November 6.
- McGartland, A., R. Revesz, D. Axelrad, C. Dockins, P. Sutton, and T. Woodruff. 2017. Estimating the health benefits of environmental regulations. *Science*. 357. 457-458.
- Moore, C., B. Zielinska, G. Petron, and R. Jackson. 2014. Air impacts of increased natural gas acquisition, processing, and use: a critical review. *Environmental Science and Technology*. 48. 8349-8359.
- Morton, P. and E. Hjerpe. 2016. A Review of the Economic Factors Surrounding the Capture of Methane from Oil and Natural Gas Development on Federal Public Land, Conservation Economics Institute. (available at www.conservationecon.org).
- Morton, P. and J. Kerkvliet. 2019. Impact Fees for Covering the Fiscal Costs of Oil and Gas Development. Research Report. Conservation Economics Institute. (available at www.conservationecon.org)
- Muehlenbachs, L., S. Spiller, and C. Timmins. 2015. The housing market impacts of shale gas development. *American Economic Review*. 105. 3633-3659.
- National Center for Atmospheric Research. 2019. Scientists pinpoint sources of front range ozone. <https://news.ucar.edu/129774/scientists-pinpoint-sources-front> (accessed April 15, 2019)
- Natural Gas STAR. 2004. U.S. Environmental Protection Agency.
- Nelson, J. and P. Kennedy. 2009. The use (and abuse) of meta-analysis in environmental and natural resource economics: an assessment. *Environmental and Resource Economics*. 42. 345-377.
- Popkin, J., J. Duke, A. Borchers, T. Ilvento. 2013. Social costs from proximity to hydraulic fracturing in New York State. *Energy Policy*. 62. 62-69.
- Portney, P. 1994. The contingent valuation debate: why economists should care. *Journal of Economic Perspectives*. 8. 3-17.
- Poudyal, N., B. Paudel, G. Green. 2013. Estimating the impact of impaired visibility on the demand for visits to national parks. *Tourism Economics*. 19. 433-452.
- Rodriguez, M., M. Barna, and M. More. 2009. Regional impacts of oil and gas development on ozone formation in the western United States. *Journal of the Air and Waste Management*. 59. 1111-1118.
- Silvy, T. 2017. Weld County cashes in on oil and gas leases. *The Tribune*. May 1. (<https://www.greeleytribune.com/news/local/weld-county-cashes-in-on-oil-and-gas-leases-including-potential-record-price-per-mineral-acre/>). Accessed February 13, 2019).
- Saunders, P., D. McCoy, R. Goldstein, A. Saunders, and A. Munroe. 2018. A review of the public health impacts of unconventional natural gas development. *Environmental and Geochemical Health*. 40. 1-57.

Thompson, C., J. Hueber, and D. Helmig. 2015. Influence of oil and gas emissions on ambient atmospheric non-methane hydrocarbons in residential areas of Northeastern Colorado. *Elementa: Science of the Anthropocene*.2:000035. 1-17.

TOP TIP BIO. 2019. 13 best free meta-analysis software to use. (<https://toptipbio.com/free-meta-analysis-software/> accessed April 14, 2019)

Throupe, R., R. Simons, and M. Xue. 2013. A review of hydro 'fracking' and its potential effects on real estate. *Journal of Real Estate Literature*. 21. 205-232.

U.S. Environmental Protection Agency. USEPAa. 2011. The benefits and costs of the Clean Air Act from 1990-2020. Final Report-Rev. A. Office of Air and Radiation. April.

U.S. Environmental Protection Agency. USEPAb. 2011. The benefits and costs of the Clean Air Act from 1990-2020. Summary Report. Office of Air and Radiation. April.

U.S. Environmental Protection Agency. USEPAc. 2011. Natural gas STAR program recommended technologies and practices.

U.S. Environmental Protection Agency. USEPA. 2018. BenMAP: Environmental Benefits Mapping and Analysis Program, Community Edition. July.

U.S. Environmental Protection Agency USEPA c. no date. Volatile organic compounds emissions. <https://www.epa.gov/roe/>

U.S. Environmental Protection Agency. USEPA 2018. User's Manual BenMAP: Environmental Benefits Mapping and Analysis Program-Community Edition. July.

Van der Ploeg, S. and R. de Groot. 2010. The TEEB valuation database-a searchable database of 1310 estimates of values of ecosystem service. Foundation for sustainable development. Wageningen. Netherlands.

Vossler, C. and J. Kerkvliet. 2003. A criterion validity test of the contingent valuation method: comparing hypothetical and actual voting behavior for a public referendum. *Journal of Environmental Economics and Management*. 43. 631-649.

Weber, J., J. Burnett, I. Xiarchos. 2016. Broadening benefits from natural gas extraction: housing values and taxation of natural gas

wells as property. *Journal of Policy Analysis and Management*. 35 (3). 587-643.

Endnotes

¹See later sections for more detail on public health impacts of UCONGA.

²If the MDC is extremely high at even tiny levels of pollution, it could be economically efficient to reduce pollution to zero by ceasing production.

³Morton and Hjerpe (2016) studied 13,493 gas wells in New Mexico and found, for most wells, the revenue from selling captured gas after plugging leaks exceeded abatement costs.

⁴Apparently, oil and natural gas produced in Colorado does not have high SOX content

⁵The EPA standard uses hourly measurements of ozone levels in parts per billion of air (ppb) to form 8-hour averages. The highest 8 hours average is the daily maximum. After ignoring the three highest daily maximum, if the 4th daily maximum averages more than 70ppb over three years, the EPA's standard is exceeded.

⁶McGartland et al. 2017 argue that there are many other health endpoints that may be affected by pollutants and have important monetized values.

⁷A somewhat dated list of articles using BenMAP is available at <https://www.epa.gov/BenMAP/BenMAP-ce-applications-articles-and-presentations#articles> (visited March 15, 2019)

⁸The VOCs measured were benzene, toluene, ethylbenzene, and xylene isomers.

⁹Texas respondents were not presented with the 'fracking light' scenario for unreported reasons.

¹⁰Figure is from Popkin et al. 2013.

¹¹CoreLogic provided the data

¹²The per acre bids ranged from \$22,550 to \$960.

Appendix A. Pain and Suffering is a Non-Market Cost of Air Pollution

*Evan Hjerpe, Ph.D.*¹

The societal value for reducing the risk of air pollution health effects from oil and gas development is centered on the value of avoiding medical treatment expenses, avoiding lost work productivity, and avoiding associated decreases in quality of life through pain and suffering (Freeman 2003, Chestnut and Mills 2005, and McGartland et al. 2017).² Public health costs therefore include three general categories: lost work, treatment costs, and pain and suffering.

Table 2 shows mostly the marketized health endpoints from air pollution including market costs for health treatment, statistical values of life (SVL), and lost work production. Missing from most of these values are willingness to pay (WTP) measures for avoiding pain and suffering that also occur with pollution caused illnesses.

Lost work and costs of treatment are metrics that are relatively easy to track, as they have formal markets. However, in addition to the market health endpoints, damages from air pollution include non-market health costs----primarily pain and suffering or reductions in quality of life. For example, high ozone levels make it harder to breath for those with asthma which can cause a person to worry every time they are short of breath and have trouble breathing.

Pain and suffering are more difficult to calculate because they are generally non-market values that require non-market valuation techniques to assess willingness to pay to avoid such pain and suffering, or willingness to accept (WTA) compensation for pain and suffering. Determining total WTP to reduce health risks is, unfortunately, more costly and time consuming than measuring cost-of-illness which limits the availability of comprehensive primary studies for estimating air pollution health damages. Using just cost-of-illness measures will always underestimate total WTP to reduce health damages. Pain and suffering need to be valued with non-market techniques and likely make up a huge portion of the real marginal health damage costs of pollution and a large share of settlement amounts in legal cases.

BenMAP incorporates pain and suffering by using stated preference (or revealed preference) and WTP:

The program calculates the economic value of air quality change using both “Cost of Illness” and “Willingness to Pay” metrics. The Cost of Illness metric summarizes the expenses that an individual must bear for air pollution-related hospital admissions, visits to the emergency department and other outcomes; this metric includes the value of medical expenses and lost work, but not the value that individuals place on pain and suffering associated with the event. By contrast, Willingness to Pay metrics are understood to account for the direct costs noted above as well as the value that individuals place on pain and suffering, loss of satisfaction and

leisure time. (on this page: <https://www.epa.gov/benmap/how-benmap-ce-estimates-health-and-economic-effects-air-pollution>).

Stated preference methods are the best means for determining total damages, such as the market health endpoint discussed above, and for determining the public's WTP to avoid pain and suffering. While there remain many critics of state preference methods, the majority of the economics profession has faith in well done SP studies. Hjerpe and Hussain (2016) conclude:

Many empirical results have illustrated that willingness to pay estimates have been consistent with estimates from other methods (convergent validity), typically accord with economic theory and predictors (construct validity), and are generated from studies increasingly incorporating best practices (content validity) (Freeman 2003). The evolution from contingent valuation to conjoint analyses, such as choice experiments, has further reduced concerns of hypothetical bias by better framing substitution effects for participants and reducing scope concerns of participants not being able to distinguish between varying amounts and intensities of conservation (Boxall et al. 1996, Hanley et al. 1998). When estimated properly, the reliability of contingent valuation estimates, at least in the economics literature, is no longer a concern (Boyle 2003).

Determining willingness to pay, via revealed and/or stated preference methods, is the preferred way to determine all values for reducing health risks associated with oil and gas air pollution. Because COI metrics are more prevalent, many studies of health costs from air pollution only present partial values of total WTP to avoid adverse health effects.

Pain and suffering are not minor health damage costs coming from air pollution. They are additive to all the health endpoints typically considered. If the health endpoint is one additional asthma attack, the additional pain and suffering damages will be minimal. But when the health endpoint is cancer or any other serious health endpoint, the pain and suffering damage costs are major and likely greater than the medical treatment and lost output costs.

When determining health damage costs and impact fees from oil and gas development, any damages based on only "cost of illness" numbers must be qualified as being largely understated or underestimated. In fact, a 2000 Land Economics article by Alberini and Krupnick found WTP estimates to avoid air pollution health damages to be twice the amount of cost of illness measures. "As predicted by economic theory, WTP is greater than COI estimates, exceeding the latter by 1.61 to 2.26 times, depending on air pollution levels. These ratios are similar to those for the U.S..."

The entire premise of determining impact fees for health damages from industrial pollution should be based on society's willingness to pay (WTP) to reduce these risks and avoid these health damages. This is the basis used by economists, by the EPA, and by the courts.

From McGartland et al. (2017):

We focus on issues unique to benefits analysis for policies addressing health risks, where the goal is to estimate society's total willingness to pay (WTP) to reduce these risks and thereby improve health. WTP for health improvements encompasses the value of avoided treatment costs, of lost productivity, and of avoided pain, suffering, and discomfort. WTP may be estimated from market transactions or through survey techniques. Alternatively, BCAs may use more limited "cost of illness" estimates that reflect only direct medical costs and reduced productivity from missed work, and these values generally underestimate WTP. But, when available, values based on WTP are preferred; they are more comprehensive, represent preferences of affected individuals, and are consistent with economic theory.

Chestnut and Mills (2005) elaborate further:

The economic measure of value that captures all the reasons why people value reductions in health risks is called willingness to pay (WTP). WTP is a measure of the monetary tradeoffs people are willing to make in exchange for a reduction in risk, and it is expected to reflect the value people place on all the financial and nonfinancial implications of health risk, including medical costs, lost income, and quality of life. Over the last several decades, economists have developed and refined techniques to estimate the WTP

for reducing health risks. All the studies use either actual observed behavior (revealed preference studies) or responses to hypothetical scenarios presented to research subjects (stated preference studies). WTP estimates are used here for the monetary valuation of mortality and morbidity benefits when these estimates are available from the literature. For a few morbidity effects there are no WTP estimates available; in these cases, cost of illness measures are used. These include only medical costs and value of time lost and are therefore expected to understate WTP.

Finally, the EPA uses the following approach to value health benefits from pollution abatement regulations (<https://www.epa.gov/sites/production/files/2017-09/documents/ee-0568-07.pdf>; p. 7-12):

WTP to reduce the risk of experiencing an illness is the preferred measure of value for morbidity effects. As described in Freeman (2003), this measure consists of four components:

- "Averting costs" to reduce the risk of illness;
- "Mitigating costs" for treatments such as medical care and medication;
- Indirect costs such as lost time from paid work, maintaining a home, and pursuing leisure activities; and
- Less easily measured but equally real costs of discomfort, anxiety, pain, and suffering.

Methods used to estimate WTP vary in the extent to which they capture these components. For example, cost-of-illness (COI) estimates generally only capture mitigating and indirect costs, and omit averting expenditures and lost utility associated with pain and suffering.

References

Alberini, A., & Krupnick, A. (2000). Cost-of-illness and willingness-to-pay estimates of the benefits of improved air quality: evidence from Taiwan. *Land Economics*, 37-53.

Boxall, P. C., W. L. Adamowicz, J. Swait, M. Williams, and J. Louviere. 1996. A comparison of stated preference methods for environmental valuation. *Ecological Economics* 18(3):243-253.

Boyle, K. J. 2003. Contingent valuation in practice. Pages 111-169 in P. A. Champ, K. J. Boyle, and T. C. Brown, editors. *A primer on nonmarket valuation*. Volume 3. Kluwer Academic, Dordrecht, The Netherlands.

Freeman, A. M. (2003). *The Measurement of Environmental and Resource Values*. Resources for the Future. Washington DC.

Hanley, N., Wright, R. E., & Adamowicz, V. (1998). Using choice experiments to value the environment. *Environmental and resource economics*, 11(3-4), 413-428.

Hjerpe, E., & Hussain, A. (2016). Willingness to pay for ecosystem conservation in Alaska's Tongass National Forest: a choice modeling study. *Ecology and Society*, 21(2).

McGartland, A., Revesz, R., Axelrad, D. A., Dockins, C., Sutton, P., & Woodruff, T. J. (2017). Estimating the health benefits of environmental regulations. *Science*, 357(6350), 457-458.

Endnotes

¹Executive Director at Conservation Economics Institute

²Freeman (2003) also includes averting behaviors, such as moving away from proximate oil and gas development, as a fourth primary health risk reduction cost.



Credit: WildEarth Guardians