ADDENDUM INDEX

DISTRICT COURT, BOULDER COUNTY, COLORADO Address: 1777 Sixth Street Boulder, Colorado 80302 Phone: (303) 441-3771	
PLAINTIFFS: COLORADO OIL & GAS ASSOCIATION; and COLORADO OIL & GAS CONSERVATION COMMISSION; **PLAINTIFF-INTERVENOR:** TOP OPERATING, CO. v. **DEFENDANT:** CITY OF LONGMONT, COLORADO **DEFENDANT-INTERVENORS:** OUR HEALTH, OUR FUTURE, OUR LONGMONT; SIERRA CLUB; FOOD & WATER WATCH; and EARTHWORKS.	**COURT USE ONLY** Case Number: 2013CV63
Attorneys for Our Health, Our Future, Our Longmont, Sierra Club, Food and Water Watch, and Earthworks Name: Kevin Lynch (Atty. Reg. #39873) Address: 2255 E. Evans Avenue, Suite 335 Denver, CO 80208 Phone Number: 303.871.6140 FAX Number: 303.871.6847 E-mail: klynch@law.du.edu *Attorney for Sierra Club and Earthworks* Name: Eric Huber (Colo. Bar No. 40664) Address: 1650 38th St. Ste. 102W Boulder, CO 80301 Phone Number: 303.449.4494, ext. 101 E-mail: eric.huber@sierraclub.org	Div.: 3 Courtroom: K
AFFIDAVIT OF RON THROUPE	

1. My name is Ron Throupe. I am of legal age and competent to give this declaration. This Affidavit is based on my personal knowledge and experience.

2. I am a managing partner with American Valuation Partners. I am also an Associate Professor at the University of Denver, in the Franklin L. Burns School of Real Estate & Construction Management.

3. I have a PhD and a Masters degree in Real Estate/Finance from the University of Georgia. I have published numerous articles in this field. My CV, which includes a full list of my positions, degrees, and publications, is attached as Exhibit 1.

4. I am an author of a paper on the potential effects of fracking on real estate values. This article is attached as Exhibit 2.

5. Oil and gas drilling operations, including fracking, pose a potential threat to real estate values though effects on mortgage accessibility, marketability of property, proximity, view effects, trespass claims and related stigmatization of property.

6. Drilling leases on property can create problems in relation to mortgage financing, lender's insurance, and homeowners insurance. Mortgages typically stipulate that an owner is not to allow damage, destruction or substantial change to collateral including the use, disposal, storage or release of hazardous materials. I am also aware that some lenders are now hesitant to refinance properties with oil and gas leases in place.

7. Oil and gas operations can also impact prospective sellers in ways that are separate from the ultimate purchase price, such as through extended time of the property on the market or failed sales. These circumstances lead to additional costs to property owners in the form of maintenance, mortgage payments, property taxes, insurance, and HOA fees.

8. I am familiar with the literature on the effects of oil and natural gas extraction on property values. Although more research is needed to better understand the impacts, the available studies show that proximity to drilling sites and views of drilling sites are associated with negative effects to real property values.

9. The first study I am aware of that evaluated the effects of oil and gas extraction on property values was conducted in 2005 (Boxall, Chan, and McMillan). I have read this study and I find it to be reliable authority on the subject matter it addresses. This study uses a hedonic pricing model based on data in the vicinity of the City of Calgary, Alberta. The study found a negative impact on residential property values from proximity to traditional oil and gas facilities. The visibility of wells, especially sour gas wells, also decreased property values. This study is attached as Exhibit 3.

10. Another study examined the effects of shale gas exploration on property values in Washington County, Pennsylvania using a hedonic pricing model (Gopalakrishnan and Klaiber 2014). I have read this study and I find it to be reliable authority on the subject matter it addresses. The study found negative impacts dependent on the interaction of proximity and intensity of shale drilling activity. The negative impact increases for properties that have private well water as a source of drinking water, as well as for properties near major roadways due to the concern of increased extraction activities on surrounding properties. This study is attached as Exhibit 4.

11. Other researchers reviewed the literature on real estate valuation methods related to hydraulic fracturing (Lipscomb, Wang, and Kilpatrick 2012). I have read this study and I find it to be reliable authority on the subject matter it addresses. This paper found that information about shale gas development and how it is used is critical. Therefore, the paper concluded that "stated preference" methods such as contingent valuation shows advantages over "revealed preference" methods, providing more salient information instead of sales prices. This paper is attached as Exhibit 5.

12. Along with two co-authors, I conducted a contingent valuation survey to test the effects of fracking operations on real estate values (Throupe, Simons, and Mao 2013). The overall conclusion from this paper was that the expected loss in property values near fracking sites would be 5-15% in a robust real estate market. In a weaker real estate market, the reduction in values could be as high as 25%.

13. Based on the contingent valuation survey results, only 26-27% of prospective buyers would bid to buy a home situated similarly to those described in the fracking scenarios. Many of those prospective buys who would bid on a home would discount their offers so much that sellers would probably refuse them within a reasonable marketing period.

14. It is my opinion, based on my own research and review of the work of others, that proximity and view of oil and gas drilling sites have been associated with negative effects to real property values. Particularly where the surface property owner does not receive money from leases or royalties, which is often the case in Colorado, fracking operations can be expected to have a negative financial impact on property owners near actual or proposed fracking sites.

I declare under penalty of perjury that the foregoing is true and correct to the best of my knowledge, information, and belief.

Ron Throupe

Ron Throupe, PhD. MRICS

Date: 5/29/14

NOTARY STATEMENT

Subscribed and affirmed before me, a notary public, this 29 day of MAY, 2014, in the county of DENVER, State of Colorado. The above signed personally appeared and has proven to be the person whose name is subscribed to the within instrument.

Signature of Notary (Seal on page)

Commission expires: 11/12/2017

MONICA L HUMBLE
Notary Public
State of Colorado
Notary ID 20094035110
My Commission Expires Nov 12, 2017

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Daniels College of Business
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Denver. CO 80208
(303) 871-3748

Education

Doctor of Philosophy Business 1995	University of Georgia, Terry School of Business Athens, Georgia Emphasis: Real Estate/Finance Dissertation Title: **Portfolio Diversification of Retail Centers Stratified by Center Type, Chair Hugh Nourse**
Master of Business 1989	University of Georgia, Terry School of Business Athens, Georgia **Emphasis: Finance/Real Estate, Research assistant for James Kau**
Bachelor of Science 1983	University of Connecticut Storrs, Connecticut Emphasis: Civil Engineering
Bachelor of Arts 1983	Fairfield University Fairfield, Connecticut
Appraisal Institute Courses	410, 420, 510, 520, 530, 550, USPAP updates, 420 Business Practices and Ethics & updates WA St. certified general licensed appraiser # 1101681 CO certified general license appraiser # 100016449
Argus Software	Certified Argus DCF and Developer Certified Instructor

University Employment

2007 - Current	University of Denver, Burns School of Real Estate & Construction Management, Denver CO. Associate Professor
2005-2006	North Seattle Community College Commercial Real Estate Curriculum
2003	University of Illinois at Chicago, Great Cities Institute. Teaching area: Real estate finance, Distance learning and professional programs

1999-2002	Associate & Acting Director: Runstad Center for Real Estate Studies, University of Washington (Acting Director: 2001-2002) Directed daily operations of The center and research activities; Directed graduates students and employees work; Presentations on current topics to the real estate community. Teaching area: Real estate finance, investments & valuation.
1997-1998	Washington State University acting Director of the Real Estate Program
1995 -1999	Assistant Professor, Washington State University. Teaching area: Real estate finance, investments, appraisal

Industry Employment

2009- present	American Valuation Partners, (AVP), Managing Partner, real estate valuation & economics for litigation
1996-present	Throupe & Associates LLC, Real estate economic analysis
2005-2007	Greenfield Advisors (formerly Mundy Associates LLC) Director of Operations
2002-2005	Mundy Associates LLC, Senior Analyst, Director of Operations, Focus on Economic & Market Analysis
1990 to 1992	Owner, Superior Design, Residential construction, Stratford, Connecticut
1985 to 1987	Project and field engineer, Walsh Construction Co., Trumbull, CT, A division of Guy F. Atkinson, CA
1983 to 1985	Junior engineer, Planning Research Corp., Stamford, CT

Publications

CCIM Members, Interests and Collaboration Opportunities with ARES, Chris Manning, Ron Throupe, Journal of Business & Economics, April 2014, Vol. 5, No. 4, 249-260.

Eminent Domain Post Kelo: State Law and Procedure Changes Effecting Litigation, Stephen Sewalk & Ron Throupe, Franklin Business & Law Review Journal, March 15, 2014.

A Review of Hydro "Fracking" and Its Potential Effects on Real Estate, Ron Throupe, Roby Simons, Xue Mao, Journal of Real Estate Literature, 2013, Vol. 21, No. 2, 205-232.

Residential Carbon Compliance and Costs, Ron Throupe, Stephen Sewalk, Journal of Sustainable Real Estate, 2013, Vol. 5, 90-120.

Publications cont'd

Real Options Analysis: A Switching Application for Mixed Use Development, Ron Throupe, Stephen Sewalk, Jungcheng Zhong, Chen Huo, Pacific Rim Property Research Journal, 2012, Vol. 18, No. 3, 277-291.

Transit Corridor Valuation for Eminent Domain, Wayne Hunsperger, Amy Mcguire, Ron Throupe, Appraisal Journal Summer 2012, Vol. 82, 235- 249.

Contamination, Trespass & Underground Rents: Andrew Krause, Ron Throupe, John Kilpatrick, Will Speiss, Journal of Property Investment and Finance, Spring 2012, Vol. 30, No. 3, 304-320.

Debundling Property Rights for Contaminated Properties: Valuing the Opportunity Cost of the Right to Sell Using Cumulative Options, Ron Throupe, Roby Simons, International Real Estate Review, Spring 2012, Vol. 15. No 2. 231-252.

The Use of Focus Groups for Valuation, Ron Throupe, Appraisal Journal, Fall 2011, Vol. 80, 301-313.

Meta- Analysis of Contaminated Commercial Properties, Ron Throupe, Roby Simons, Jesse Saginor, Journal of Property Investment and Finance, 2010, Vol. 29, No. 4, 460 – 478.

Valuation of Impaired Property, Ron Throupe, John Kilpatrick, Bill Mundy, Will Spies, The Environmental Law Reporter, 2007, Vol. 37, No. 7, 10562-10572.

The Impact of Transit Corridors on Residential Property Value, John Kilpatrick, Ron Throupe, John Carruthers, Journal of Real Estate Research, 2007, Vol. 29, No.3, 303-320.

An Exploratory Review of the Effects of Toxic Mold and Real Estate Values, Roby Simons, Ron Throupe, Appraisal Journal, Spring 2005, Vol. 76, 156 – 166.

Corporate Value of Low Income Tax Credit Housing, Ron Throupe, William Goolsby, Journal of Applied Real Property Analysis, May 2004.

The Future of Real Estate, John Carruthers, John Kilpatrick, Bill Mundy, Ron Throupe, Real Estate Issues, Fall 2003; Vol. 28, No. 3, 10-16.

Books, Chapters & Monographs

Valuation of Impaired Property Ron Throupe, John A. Kilpatrick, Bill Mundy, and Will Spiess, Chapter 6 in *When Bad Things Happen to Good Property*, Robert Simon, ed., (Washington, DC: National Environmental Law Center, July 2007.

Introduction to Real Estate, Prentice Hall, July, 1995, ISBN # 0-536-58939-9

Commercial Real Estate, Chapter nine, Washington Association of Realtors, licensing education,1996.

Instructor's manual for Real Estate Principles, Charles Floyd, and Marcus Allen, Dearborn Financial Publishing, Fifth Edition, February 1997.

Other Publications

Metro Colorado Springs Apartment Survey, 1st Qtr 2014

Metro Denver Single Family Survey, 1st Qtr 2014

Colorado Single Family Survey, 1st Qtr 2014

Colorado Multi Family Survey, 1st Qtr 2014

Metro Colorado Springs Apartment Survey, 4th Qtr 2013

Metro Denver Single Family Survey, 4th Qtr 2013

Colorado Single Family Survey, 4th Qtr 2013

Metro Colorado Springs Apartment Survey, 3rd Qtr 2013

Metro Denver Single Family Survey, 3rd Qtr 2013

Colorado Single Family Survey, 3rd Qtr 2013

Metro Denver Apartment Survey, 2nd Qtr 2013

Metro Colorado Springs Apartment Survey, 2nd Qtr 2013

Metro Denver Apartment Survey, 1st Qtr 2013

Metro Colorado Springs Apartment Survey, 1st Qtr 2013

Metro Denver Single Family Survey, 1st Qtr 2013

Colorado Single Family Survey, 1st Qtr 2013

Metro Denver Apartment Survey, 4th Qtr 2012

Metro Colorado Springs Apartment Survey, 4th Qtr 2012

Metro Denver Apartment Survey, 4th Qtr 2012

Metro Colorado Springs Apartment Survey, 4th Qtr 2012

Metro Denver Apartment Survey, 3rd Qtr 2012

Metro Colorado Springs Apartment Survey, 3rd Qtr 2012

Metro Denver Apartment Survey, 2nd Qtr 2012

Metro Colorado Springs Apartment Survey, 2nd Qtr 2012

Metro Denver Apartment Survey, 1st Qtr 2012

Metro Colorado Springs Apartment Survey, 1st Qtr 2012

Colorado Single Family Housing Survey, 1st Qtr 2012

Metro Denver Apartment Survey, 4th Qtr 2011

Metro Colorado Springs Apartment Survey, 4th Qtr 2011

Other Publications cont'd
Metro Denver Apartment Survey, 3rd Qtr 2011

Metro Colorado Springs Apartment Survey, 3rd Qtr 2011

Office Market Conditions quarterly, Runstad Center for Real Estate Studies, University of Washington

R&D/Office Market Update, National Council of Real Estate Investment Fiduciaries, (NCREIF), 1996, 1st Quarter report.

Landlord Tenant Law (with Jack Purdie), Spokesman Review, 1995.
Shopping Center Research: Are All Centers Alike?, Centerview, Fall 1994, pg. 10.

WA State University Real Estate Program Update, Centerview, on-going.

Awards
Highly Commended Award Winner, Emerald Literati Awards for Excellence, for best published paper of the year 2012, May 2013
Provost special recognition dinner for top researchers, University of Denver, Fall 2013.
Provost special recognition dinner for top researchers, University of Denver, Fall 2012.
Best Paper, ARES national meetings, 2012, Apartment Distress: A Multi City Approach.
Summer Research Grant 2013, Daniels College of Business, University of Denver.
Summer Research Grant 2011, Daniels College of Business, University of Denver.
Summer Research Grant 2010, Daniels College of Business, University of Denver.
Center for Ethics and Sustainability Research Grant 2011, University of Denver.
Social Science Research Network: top ten Downloads: 2008, Monitors which research is most widely read.

Work in Progress
What is so Special About Special Purpose Property, Xue Mao, Ron Throupe, Kaifeng Zhang. Appraisal Journal

Valuation of Agricultural Lands for Eminent Domain, Kay Zhang, Ron Throupe, Wayne Hunsperger, working paper. Target Appraisal Journal.

Apartment Price Discounts for Duress, Ron Throupe, Qi Tian, Paul Books, Steven Saules, under revision -2 at Journal of Real Estate Research.

Apartment Pricing with Sample Selection and Endogeneity Corrections, Ron Throupe, Qi Tian, Paul Books, Steven Saules, Under review, Journal of Real Estate Finance and Economics

Work in Progress Cont'd
Housing Pricing Effects From Proximity to Hydro Fracking: an Empirical Analysis, Xue Mao, Qi Tian, Ron Throupe. Target : Journal of Sustainable Real Estate.

Airports Price Effects Before and After Decommissioning, Ron Throupe, Tom Thibideau, Chen Huo, ARES 2012, under review Journal of Real Estate Finance and Economics.

Corporate Real Estate Asset Condition Monitoring and the Capital Budgeting Decision, Ron Throupe, Xue Mao, Minching Kao, target Journal of Corporate Real Estate.

Eminent Domain, Moral Hazard, Alignment of Interest, Does it pay to Contest Eminent Domain? Ron Throupe, Andy Krause, & Kaifeng Zhang. Journal of Housing Research.

The Event Study Windows and Real Estate Detrimental Conditions, under revision-3 at the Appraisal Journal, Ron Throupe.

The Statistical Properties of Paired Sales Adjustments, Max Kummerow, & Ron Throupe, Andy Krause, under revision (3), Appraisal Journal.

Eminent Domain: Do all Agencies Pay Fair Market Value? Ron Throupe, Paul Books, Under revision for Journal of Real Estate Research.

The Herfindahl Index and the Real Estate Brokerage Industry, Ron Throupe and Paul Books. Revising for Journal of Housing Research.

Time for a Little Inflation, Roby Simons, Yougme Sou, Ron Throupe, target: Journal of Housing Economics, special issue on inflation.

Academic Presentations
April 2014, Agricultural Land Values, American Real Estate Society annual meeting, San Diego, CA Ron Throupe, Kaifeng Zhang.

April 2014, Hydro Fracking, Proximity and View, an Empirical Analysis, American Real Estate Society annual meeting, San Diego, CA Xue Mao, Qi Tian, Ron Throupe.

April 2014, Apartment Modeling for Distress with Sample Selection and TOM, American Real Estate Society annual meeting, San Diego, CA, Qi Tian, Ron Throupe.

April 2014, Online Education Programs, Critical Issues Seminar, ARES national meeting San Diego CA.

April 2013, Eminent Domain and the Threat of Legal Action, presented at the American Real Estate Society annual meeting, Kohala Coast, Hawaii, Ron Throupe, Andy Krause, Minching Kao.

April 2013, Asset Condition Monitoring and the Capital Budgeting Decision, presented at the American Real Estate Society annual meeting, Kohala Coast, Hawaii, Ron Throupe, Xue Mao, Minching Kao.

Academic Presentations, Cont'd

April 2012, Fracking and Real Estate Values, paper presented at the American Real Estate Society annual meeting, St. Petersburg, FL. Ron Throupe, Roby Simons, Chen Huo.

April 2012, Airport Closure and Housing Prices, paper presented at the American Real Estate Society annual meeting St. Petersburg, FL. Ron Throupe, Thomas Thibideau, Chen Huo.

April 2012, Distress Apartments and Pricing: A Multi-City Approach, paper presented at the American Real Estate Society annual meeting St. Petersburg, FL. Ron Throupe, Paul Books, Chen Huo, Steven Saules.

April 2012, Real Estate Economics: Time for a Little Inflation?, paper presented at the American Real Estate Society annual meeting St. Petersburg, FL. Roby Simons, Youngme Sou, Ron Throupe.

April 2012, CCIM and Research Needs Assessment, paper presented at the American Real Estate Society annual meeting St. Petersburg, FL. Chris Manning, Ron Throupe April 2012,

Moderator, American Real Estate Society Education and Critical Issues Seminar, St. Petersburg, FL.

April 2012, Session Chair, Apartment Valuation, American Real Estate annual meeting, St. Petersburg, FL.

April 2011, The Option to Pollute, paper presented at the American Real Estate Society annual meeting, Seattle WA. Roby Simons, Ron Throupe.

April 2011, Valuation of Distress Multi – Family, paper presented at the American Real Estate Society annual meeting, Seattle WA. Ron Throupe, Paul Books, Steven Saules.

April 2011, Discussant: A Public Trust Doctrine for Hong Kong, American Real Estate Society annual meeting, Seattle WA.

April 2011, Eminent Domain: Moral Hazard, Alignment of Interests, paper presented at the American Real Estate Society annual meeting, Seattle, WA. Ron Throupe, Marc Mueller.

April 2011, Session Chair, Valuation, American Real Estate Society annual meetings, Seattle, WA.

April 2011, Moderator, American Real Estate Society Education and Critical Issues Seminar, Seattle, WA

November 2011, Meta -Analysis of Contaminated Commercial Properties, Appraisal Colloquium, Clemson University. Ron Throupe, Roby Simons.

April 2010 Eminent Domain Law and Appraisal Requirements Post Kelo, paper presented at the American Real Estate Society Annual Conference, Naples, Florida. Ron Throupe, Peter Bivens.

April 2009, Panel member: Distressed Properties with Tom Jackson, Joint Appraisal Institute & American Real Estate Society, one day Critical Issues seminar, Monterey, CA.

Academic Presentations, Cont'd
April 2009, Session Chair: Valuing Real Estate Assets During the Financial Crisis, and Beyond, American Real Estate Society annual meeting, Monterey, CA.

April 2009, Valuing Real Estate Assets During the Financial Crisis, and Beyond, Panel member with, Thomas Jackson: Texas A & M, Bill White: Principle Real Capital Analytic, Rick Wincott: Director, Price Waterhouse, American Real Estate Society annual meeting, Monterey, CA.

April 2009, Session Chair, Valuation of Real Property I, American Real Estate Society annual meetings, Monterey, CA.

April 2009, <u>The Use of Focus Groups for Real Estate Valuation</u>, paper presented at the American Real Estate Society annual meeting, Monterey, CA. Ron Throupe.

April 2008, <u>Takings Under Eminent Domain: Do All Agencies Pay "Fair Market Value</u>", paper presented at the American Real Estate Society Conference, Captiva Island, FL, 2008. Ron Throupe, Brian Fulbright.

April 2008, Session Chair; American Real Estate Society annual meeting, Capitva Island FL, Valuation II.

April 2008, Discussant; Hurricanes and Property Value, American Real Estate Society Conference, Capitva Island Fl, Valuation.

April 2007, <u>Valuation of Underground Rent</u>, paper presented at the American Real Estate Society Conference, San Francisco, CA, Andy Krause, Ron Throupe, John Kilpatrick, Will Speiss.

April 2007, <u>Automated Valuation Systems an Appraisal Value</u>, paper presented at the American Real Estate Society Conference, San Francisco, CA, Max Kummerow, Ron Throupe.

March 2007, <u>Valuation of Contaminated Property, 13th</u> Pacific-Rim Real Estate Society Conference Fremantle, Western Australia, Vicki Adams, Max Kummerow, John Kilpatrick, Bill Mundy & Ron Throupe.

April <u>2006, The Effect on Property Values of A Transit Tunnel</u>, American Real Estate Society Conference. Key West, Fl. Ron Throupe, John Kilpatrick, John Carruthers.

April 2006 Session Chair; American Real Estate Society annual meeting, Key West Fl, Global Markets III, Cross Market Comparison.

April 2005, <u>A Meta-Analysis of Contaminated Commercial Properties</u>, paper presented at the American Real Estate Society annual meeting, Santa Fe NM. Ron Throupe, Roby Simons.

April 2005 Expert Panel, Experts in Litigation, American Real Estate Society annual meetings, Santa Fe NM.

April 2003, <u>Market Impact of Housing in a Known Flood Plain</u>, paper presented at the American Real Estate Society annual meeting, Monterey, CA.

Academic Presentations, Cont'd

April 2003, Toxic Mold and House Price Effects, paper presented at the American Real Estate Society, annual meeting, Monterey, CA.

April 2002, Performance of Students in Real Estate Principles, paper presented at the American Real Estate Society annual meeting, Naples, FL, Ron Throupe.

April 1998, Value Range Marketing: Theory and Evidence, paper presented at the American Real Estate Society annual meeting, Monterrey, CA, Ron Throupe.

Industry Presentations

October 2013, CCIM National Convention, Property Damages, Denver CO.

July 2013, Denver Apartment Association, Keynote Speaker on apartment market conditions, Apartment Economics Conference.

July 2013, IROC conference on Apartments, Denver CO

January 2013, CLU National conference on Eminent Domain, Guest speaker: Eminent Domain and Natural Disasters, Miami FL.

August 2012, CLU legal Conference on Eminent Domain, Guest speaker: Eminent Domain and Event Study Application, Denver CO.

June 2012, Colorado Homes Exhibition, Keynote Speaker on housing market conditions, Denver CO.

Winter 2012, Denver Apartment Association, Keynote Speaker on apartment market conditions, Apartment Economics Conference.

Summer 2011, Denver Apartment Association Speaker on Apartment Survey Results.

October 2011, Housing Colorado, Annual conference, Keynote Speaker on real estate economic conditions.

January 2009, DMCAR, Denver Board of Commercial Realtors, CRE, CCIM, annual education symposium. Keynote Speaker on Commercial Real Estate & Economic Update.

November 2008, Colorado Assoc. of Realtors, Annual convention, Colorado Springs, CO. Keynote Speaker: "Commercial Real Estate Today".

May 2005, Pacific Northwest Economics Conference, Bellingham, WA. Commercial Real Estate Session Chair.

March 2005, Law Seminars International Residential Redevelopment of Contaminated Property conference, Seattle WA. Keynote Speaker: "Challenges of Approving a Residential Project".

May 2004, Moderator: "Commercial Real Estate Issues", Pacific Northwest Economics Conference, Tacoma WA.

Industry Presentations Cont'd
May 2004, "Flood Prone Housing", National Hazards Mitigation Conference, Phoenix AZ.

November 2003, Current Trends in Commercial Real Estate, Appraisal Institute Seattle Chapter.

May 2001, "Real Estate Portfolios and the Investment Opportunity Set, Seattle WA.

September 2000, UW Real Estate, IREM Education, Seattle WA.

June 1998, Alternative Geographical Regions, U.S. Census Regions, NCREIF spring meeting Boca Raton, FL.

June 1996, Low Income Housing Tax Credit, Appraisal Institute's Northwest Chapter.

April 1996, The MAI Designated School Program, Appraisal Institute's Northwest Chapter.

February 1993, NACORE (National Association of Corporate Real Estate Executives) training session, Coral Gables, FL.
June 1993, How to Succeed in Corporate Real Estate, NACORE, Conference, Chicago, IL.

Other Community and Professional Service Activities
American Real Estate Society, ARES Officer, Director of Critical Issues, current

American Real Estate Society, Governance Committee, current

Editorial Board: Journal of Sustainable Real Estate, American Real Estate Society, 2010-current.

Reviewer, American Real Estate Society, best paper awards, 2013

Reviewer, Journal of Sustainable Real Estate, 2010, 2011, 2012, 2013, 2014

Reviewer special issue Land Economics and Evironmental Effects 2014.

Reviewer, Journal of Environmental Planning and Management, 2012, 2013.

Reviewer, Journal of Real Estate Portfolio Management, 2011.

Reviewer, Real Estate Sustainability, Special Monograph Series, ARES, 2009.

Reviewer, Journal of Real Estate Finance & Economics, 2009, 2010.

Reviewer, ARES special issue monograph series, Indigenous People and Real Estate, 2006.

Book Reviewer, Dearborn Financial Publishing, Prentice Hall, Richard Irwin.

Reviewer for Real Estate, Jack Corgel, Halbert Smith, and David Ling, Richard Irwin, 3rd edition.

Reviewer for Real Estate Principles, Charles Floyd and Marcus Allen, Dearborn Financial, 11th edition, May 2014.

Reviewer for Real Estate Principles, Charles Floyd and Marcus Allen, Dearborn Financial, 10th edition, May 2007.

Reviewer for Real Estate Principles, Charles Floyd and Marcus Allen, Dearborn Financial, 8th edition.
Reviewer for Real Estate Principles, Charles Floyd and Marcus Allen, Dearborn Financial, 5th edition.

Election to "NCREIF", National Council of Real Estate Investment Fiduciaries, February, 1996.

Habitat for Humanity, Donate time to building homes, 1997 - current.

Professional Memberships (current)
Appraisal Institute (Associate Member), 1994 – current.

Elected to Membership, Royal Institution of Chartered Surveyors (RICS), 2011-current.

American Real Estate Society, Member: 1994- current. Director: Critical Issues, Governance Committee

American Real Estate and Urban Economics Association, Member: 1994- current.

National Council of Real Estate Investment Fiduciaries (NCREIF), Member: 1996- current. Research Committee

A Review of Hydro "Fracking" and its Potential Effects on Real Estate

Ron Throupe
University of Denver

Robert A. Simons
Cleveland State University

Xue Mao
University of Denver

Abstract
In this paper we review the phenomena of hydro "fracking" operations for oil and gas in the United States. We provide background information on fracking, a summary of federal and state fracking disclosure and management regulations, and an evaluation of the potential surface and subsurface effects. We then examine case studies of claims of contamination from several shale-heavy states. Lastly, we report the results of survey research related to proximity to fracking operations in Texas and Florida. Our contingent valuation surveys show a 5%–15% reduction in bid value for homes located proximate to fracking scenarios, depending on the petroleum-friendliness of the venue and proximity to the drilling site.

As the international thirst for hydrocarbons continues unabated, domestic exploration in the United States has turned away from oil and natural gas in underground and offshore pockets to other alternatives. In the 1980s, we had an abortive quest to exploit oil shale in Colorado. The Canadian tar sands process was initiated at about the same time, and is just now gathering momentum where its products can be delivered to the U.S. and other markets by a controversial pipeline though the northern Midwest. For the past few years, a relatively "new" exploration procedure, "fracking" or "hydro-fracking," has been developed to extract natural gas trapped in dense shale deposits. Tens of thousands of shale extraction leases have already been signed, keeping many landmen busy, but very little is known about the effects of the fracking process on the local environment and on proximate real estate markets. There is almost no real estate sales data on this issue, indicating a need for alternative methods such as contingent evaluation analysis. Yet, there is tremendous urgency to move forward with exploration, for many viable reasons.

The speed of this exploration will likely be driven by the price of natural gas [currently $4.04 per million British Thermal Units (BTUs)][1] compared with the price of extracting the gas from the ground. In general, based on hydrocarbon BTUs, shale gas is much cheaper to extract than oil, and is much less polluting than coal, thus better for greenhouse gas emissions. Within the shale deposit options, some like the Marcellus and Utica shale deposits in Ohio, Pennsylvania, and New York cost less than $2 per metric cubic feet (MCF) to extract, while shale in other locales are only profitable above $3 per million BTU's of energy.[2] Further, there's a political controversy if hydro-fracking is an alternative energy. Since it's a hydrocarbon, some say it's not, especially compared with renewable sources like solar or wind. However, the big energy company players involved, plus some others, argue that hydro-fracking is a new source of energy. In a down economy, economic development (especially the gold standard: job creation) from shale exploration and production potential is quite large. In manufacturing-heavy Ohio, for example, the unemployment rate shrank from above the national average in most years, to a point below the national average in August, 2012 (7.2% vs. 8.3%).[3]

The oil and gas industry continues to claim that there has never been a case of fracking fluid in ''direct'' contamination to drinking water. They promote fracking as safe, but the number of documented spills, blowouts, leaks, trucking accidents, and pollution from normal drilling activities appears to contradict these benign claims. The focus has been clearly on the well and casing maintenance, not on other effects or conditions. One main concern is the potential for fracking to invade historic groundwater drinking wells near drilling areas, or old oil and gas wells, where the new operations could blow out their seals or create a vertical conduit to upward aquifers or the surface. The oil and gas industry continues to say the mixture is mostly water and sand and a little bit of chemicals on a percentage basis. However, when even very small amounts of chemical exposure are hazardous (e.g., benzene toxicity, which is measured in parts per billion), this is a potential concern. The actual amounts of chemicals are tens of thousands of gallons per well.

The oil and gas industry in the U.S. is an economic driver, and has evolved over the last 20 years from a public focus on offshore drilling and traditional exploration to a more diversified set of activities. Technological advances in drilling have created the ability to extract oil and gas deposits that were not economically feasible a decade ago. Hydraulic fracturing is frequently used in the completion of gas wells, particularly those involved in what's called ''unconventional production,'' such as production from so-called ''tight shale'' reservoirs. The process has been used on over 1 million producing wells. As the technology continues to develop and improve, operators now fracture as many as 35,000 wells of all types (vertical and horizontal, oil and natural gas) each year.[4] This circumstance and an exemption from monitoring of drilling operations have led to a boom in drilling operations and in particular the ability to ''frack'' a new or existing well to create a producing well when previously not economically feasible.

This paper introduces the concept of hydraulic fracking as a new lexicon for oil and gas drilling. Fracking is now associated with drilling of all types, whether a well is actually fracked or not. Although the fracking (injecting a mixture of water, sand, and chemicals into the groundwater to facilitate hydrocarbon recovery) process has been used since at least the late 1970s in the Rangely Oil Field of northwestern Colorado, to facilitate secondary or tertiary recovery of oil and gas, its focus was never as a primary technique. What's new is a primary recovery of shale gas, and vastly upgraded horizontal drilling techniques. Thus, due to the maturity of the on-shore, hydrocarbon extraction business in the U.S., it's expected that a majority of wells drilled in the near future will be fracked multiple times over their production life.

The organization of the paper is as follows: We first provide background information on fracking, including the concept, history, locations of deposits, and chemical concerns. We continue with a summary of federal and state fracking disclosure and management regulations. This is followed by existing peer-reviewed literature on petroleum damages to residential property and evaluation of the potential surface and subsurface effects. We then examine case studies of claims of contamination from several shale-heavy states. Next, we discuss the results of survey research related to proximity to ''fracking'' operations in Texas and Florida. We close with policy recommendations and calls for future research.

Background on Fracking

Hydraulic fracturing is not a ''drilling process'' but a process used after the drilled hole is completed. Hydraulic fracturing or ''fracking'' is the propagating of fractures in a rock layer caused by the presence of a pressurized fluid creating small cracks, or fractures, in deep, underground geological formations to liberate oil or natural gas. This process is used to release petroleum, natural gas (including shale gas, tight gas, and coal seam gas), or other substances for extraction, via a technique called induced hydraulic fracturing. ''Protecting groundwater contained in intervening aquifers are important steps to take during the fracking process. In this process, chemical-and-sand-laden watery fluid will be pumped down into the well and the watery oil or gas will eventually be collected. Therefore, in order to prevent the fluid from entering the water supply, steel surface or intermediate casing need to be inserted into the well. Normally the depths of the insertions are between 1,000 and 4,000 feet. Also, cement needs to be filled into the annulus, the space between the casing strings and the drilled hole. Once the cement has set, then the drilling continues from the bottom of the surface or intermediate cemented steel casing to the next depth. This process is repeated, using smaller steel casing each time, until the oil and gas-bearing reservoir is reached (generally 6,000 to 10,000 feet).''[5]

To fracture the formation, fracturing fluids—water and sand, and proprietary chemical mixes—are injected down the well bore into the formation. The fluid, injected under pressure, causes the rock to fracture along weak areas. The fluids that create the initial fractures are then mixed with thicker fluids that include sand and gelatin. These thicker fluids lengthen the openings in the rock. When the fractures are complete, and pressure is relieved, a portion of the fluids flows back up the well where it is captured and stored for later treatment or disposal. As the fluids flow back up, sand remains in the fractures and props the rock open, maintaining an open pathway to the well. This allows the oil and gas to seep from the rock into the pathway, up the well and to the surface for collection. A distinction can be made between low-volume hydraulic fracturing used to stimulate high-permeability reservoirs, which may consume typically 20,000 to 80,000 gallons of fluid per well, with high-volume hydraulic fracturing, used in the completion of tight gas and shale gas wells; enormous amounts of water, up to 5 million gallons of water for a single well. After the fracturing procedure is complete, 15% to 80% of the fluid returns to the surface as waste water, often contaminated by fracturing chemicals and subsurface contaminants including toxic organic compounds, heavy metals, and naturally occurring radioactive materials. Left untreated or not adequately secured, this wastewater can have detrimental environmental and health effects. Exhibit 1 is an overview of the fracking process.

HISTORY OF FRACKING IN THE U.S.

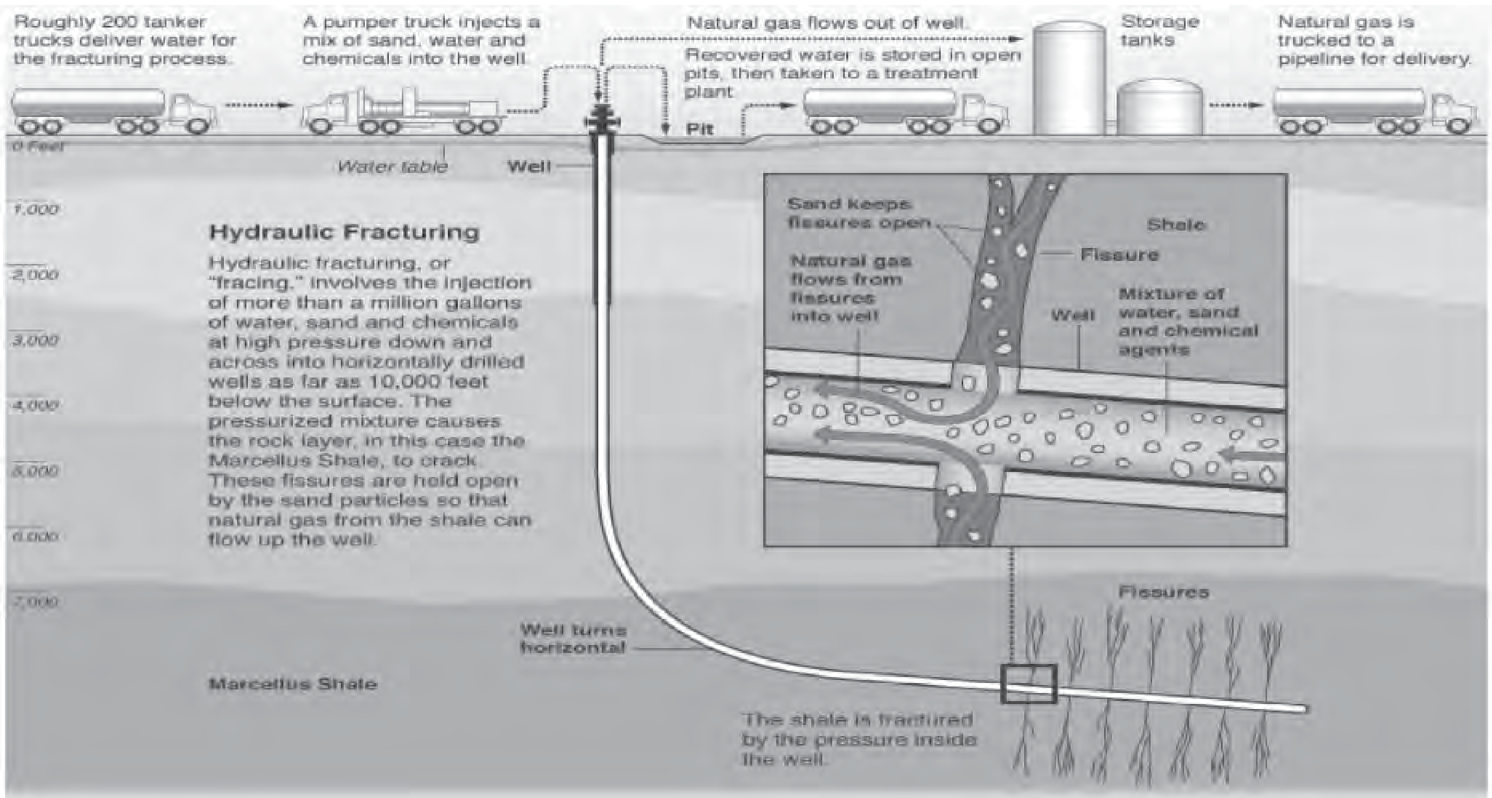
The first fracking operation in the U.S. was performed in 1947 in the Hugoton Kansas gas fields by Halliburton. However, hydraulic fracking did not become economical for commercial use for several decades. Significant R&D was necessary before hydraulic fracturing could be commercially applied to shale gas deposits, due to shale's high porosity and low permeability. In the 1970s, the federal government initiated both the Eastern Gas Shale Project and the Gas Research Institute. The Eastern Shale Project was a dozen public-private hydro-fracturing pilot demonstration projects. The Gas Research Institute was established as a gas industry research consortium receiving approval for research and funding from the Federal Energy Regulatory Commission. During that time, Sandia National Laboratories was conducting research into microseismic imaging for use in coal beds. Sandia contributed its geologic micro-mapping software, which proved to be crucial for the commercial recovery of natural gas from shale. In the late 1970s, the Department of Energy (DOE) pioneered massive hydraulic fracturing, a drilling technique, later improved upon for the economic recovery of shale gas. In 1986, a joint DOE-private venture completed the first successful multi-fracture horizontal well in shale. The DOE later subsidized Mitchell Energy's first successful horizontal drilling in the north-Texas Barnett Shale in 1991. Mitchell Energy engineers developed the hydraulic fracturing technique known as ''slickwater fracturing,'' the addition of chemicals to water to increase fluid flow. This innovation was implemented in 1996, and started the modern shale gas boom.

ADVANCES IN DRILLING: GOING HORIZONTAL

Technological drilling advances allow drillers to deviate from vertical drilling, and steer the drilling equipment to a location that is not directly underneath the point of entry. This is in contrast to 'slant drilling' where the well is drilled at an angle instead of directly vertical. New technology is allowing for the drilling of tightly curved well holes where 90-degree turns can be accomplished within several feet underground. Traditional directional drilling takes several thousand feet to turn 90 degrees.[6] These new technologies are aided by borehole telemetry to gain real time information from steerable drilling motors.

Conventional vertical wellbore suffers from a lack of exposure to the shale formation in comparison to horizontal wellbores. Horizontal drilling is particularly useful in shale formations that do not have sufficient permeability to produce economically; therefore, it is becoming more and more pervasive, especially in North America (Seale, 2007). In the U.S., tight reservoirs such as the Bakken (ND and Montana), Montney, Barnett, and Haynesville (Texas/Oklahoma) Shale and most recently Marcellus Shale (NY, Pennsylvania, and Ohio) are drilled, completed, and fractured using this method.

Exhibit 1
The Fracking Process



Source: ProPublica: Graphic by Al Granberg and Krista Kjellman Schmidt.

HARVESTING GAS AFTER DRILLING

After the drilling rig is moved off site, water tanks and water-hauling trucks arrive at the site. The day the operation is to begin, the sand haulers, pump truck, blender, and control van arrive. The equipment will all be connected together and then connected to the well head with high pressure hoses. After testing the equipment, the actual fracture stimulation will begin. The operation may take several hours to several days depending on the number of fracture zones. The equipment noise and truck traffic is the most noticeable occurrence during the operations.[7]

FRACKING HOT SPOTS IN THE U.S.

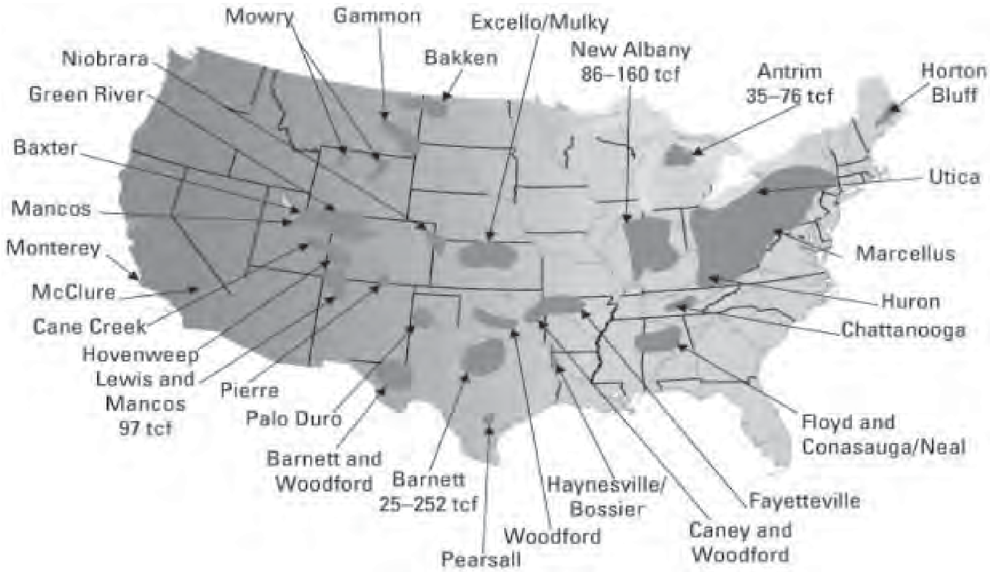
While the locations of gas-bearing shale have been known for some time, the confluence of advanced technology and market demand for clean-burning fuel has made development of these resources more urgent. Exhibit 2 shows U.S. locations where oil and gas reserves are being fracked, or where extraction is likely. About 20 states can expect to feel the effects of fracking exploration. The densest deposits are the Marcellus and Utica shale belts stretching from New York through Pennsylvania, Ohio, and Indiana into Illinois. Some states, like Texas, Oklahoma, Colorado, and Wyoming, are also experiencing resource extraction near populations. Others, like North Dakota and Montana, are largely rural.

FRACKING MIX OF CHEMICALS

Many of the communities in these locations face a choice of potential economic booms, along with potential exposures, accidents, congestion, and a loss of quiet enjoyment of property.

Water is the largest component of fracking fluids. Over its lifetime, an average well can require five million gallons of water for the initial hydraulic fracturing operation and possible restimulation. The large volumes of water required have raised concerns about fracking in water shortage areas such as Texas, which has been in a multiple-year drought. Chemical additives used in fracturing fluids typically make up less than 2% by weight of the total fluid. Nonetheless, over the life of a typical well, this may amount to 100,000 gallons of chemical additives.[8] These additives include some that are known carcinogens, some are toxic, and some are neurotoxins. These include benzene, lead, ethylene glycol, methanol, boric acid, and 2-butoxyethanol. High levels of iodine-131 (a radioactive tracer used in hydraulic fracturing) are the major contributor to the generally elevated radiation levels found near hydraulic fracturing sites. However, it is not listed among the chemicals to be monitored in the U.S. Environmental Protection Agency's Hydraulic Fracturing Draft Study Plan. The 2011 U.S. House of Representatives investigative report on hydraulic fracturing chemicals showed that there are 750 compounds in hydraulic fracturing products. ''More than 650 of these compounds contained chemicals that are either known or possible human carcinogens, regulated under the Safe Drinking Water Act, or listed as hazardous air pollutants.''[9] This report also showed that between 2005 and 2009, many components were listed as ''proprietary'' or ''trade secret'' on their Occupational Safety and Health Administration (OSHA) required Material Safety Data Sheets (MSDSs).

Exhibit 2
Fracking Locations



Source: www.ehelpfultips.com.

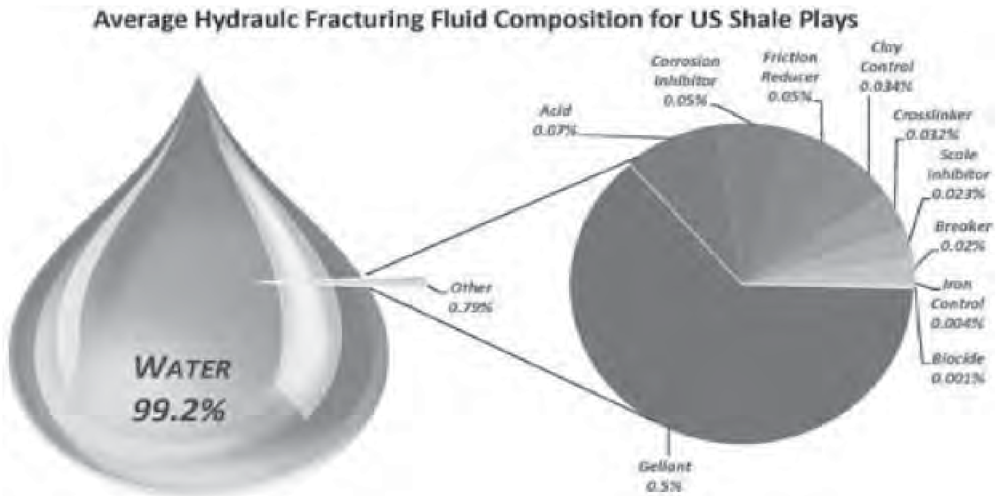
When asked to reveal the proprietary chemical components, most companies participating in the investigation did not do so. This non-disclosure prevents government regulators from monitoring and documenting the changes in the components, thereby making it impossible to prove that hydraulic fracturing is contaminating the environment (Fitz Patrick, 2011). Without knowing the identity of the proprietary components, regulators cannot pass measures requiring testing for their presence.

In his 2012 State of the Union, Barack Obama stated his intention to force fracking companies to disclose the chemicals they use, but proposed guidelines were criticized for failing to specify disclosure of the chemicals used. This and other prior intentions are known as part of the proposed Fracturing Responsibility and Awareness of Chemicals Act (FRAC Act).[10] Exhibit 3 shows the categories of chemicals that are potentially part of a fracking fluid mix.

VOLATILE ORGANIC COMPOUNDS

One group of emissions associated with natural gas development and production are those associated with combustion. They include particulate matter, nitrogen oxides, sulfur oxide, carbon dioxide, and carbon monoxide. Another group of emissions that are routinely vented into the atmosphere are those linked with natural gas itself, which is composed of methane, ethane, liquid condensate, and volatile organic compounds (VOCs). The VOCs that are especially impactful on health are benzene, toluene, ethyl

Exhibit 3
Fracking Fluid Composite



Source: FracFocus.com.

benzene, and xylene (BTEX). The health effects of exposure to these chemicals include neurological problems, birth defects, and cancer.

VOCs, including BTEX, mixed with nitrogen oxides from combustion and combined with sunlight can lead to ozone formation. Ozone has been shown to impact lung function, increase respiratory illnesses, and is particularly dangerous to lung development in children.[11] In 2008, measured ambient concentrations in rural Sublette County, Wyoming, where ranching and natural gas are the main industries, were frequently above the National Ambient Air Quality Standards (NAAQS) of 75 parts per billion (ppb) and have been recorded as high as 125 ppb (Urbigkit, 2011). A 2011 study for the city of Fort Worth, Texas that examined air quality around natural gas sites ''did not reveal any significant health threats.'' The Fort Worth *Star-Telegram* characterized that report as ''the most comprehensive study of urban gas drilling to date.''[12]

GOVERNMENT REGULATIONS ON FRACKING

A number of federal laws and regulations, including the Federal Oil Pollution Control Act, address petroleum extraction. Further, the Environmental Protection Agency (EPA) may also regulate the chemicals that oil and gas companies use. A detailed accounting of this is beyond this research, but we do address three pertinent topics: the 2005 Energy Policy Act, the ongoing EPA study of fracking, and regulations pertaining to obtaining permission to drill wells on federal lands.

2005 ENERGY POLICY ACT

''The oil and gas industry received a helping hand from the federal government during the Bush Administration. Although fracking was never regulated by the federal government when it was a less prevalently used technique, it was granted explicit exemptions, despite dissent within the EPA, from the Safe Drinking Water Act, the Clean Air Act, and the Clean Water Act by the Energy Policy Act of 2005, the wide-ranging energy bill crafted by Dick Cheney in closed-door meetings with oil-and-gas executives and what has become known as the ''Halliburton Loophole.'' Thus, drilling firms do not need to disclose to the public their practices. Congressional hearings held by the House Energy and Commerce Committee have been taking place since 2009, but proposed legislation to eliminate the Halliburton Loophole has made little progress'' (Bateman, 2010).

''Claiming that the information is proprietary, drilling companies have not fully disclosed the components of their fracking fluids; however, activists and researchers have been able to identify some of the chemicals.[13] According to Theo Colborn, a noted expert on water issues and endocrine disruptors, at least half of the chemicals known to be present in fracking fluid are toxic; many of them are carcinogens, neurotoxins, endocrine disruptors, and/or mutagens. Colborn has estimated that a third of the chemicals in fracking fluid remain unknown to the public'' (Bateman, 2010).

ENVIRONMENTAL PROTECTION AGENCY

The major role and competency of the EPA is protecting human health and safeguarding the environment. In terms of oil and gas extraction, the EPA is responsible for researching and assessing the air and water contamination that is harmful to the public health and safety, along with evaluating the detrimental physical, chemical, and biological changes to the environment. To be more specific, the EPA has an obligation associated to four aspects: (1) improving understanding of hydraulic fracturing; (2) providing regulatory clarity and protections against known risks; (3) assuring regulatory compliance; and (4) promoting transparency and conducting outreach.

The House of Representatives Appropriation Conference Committee identified the necessity of a study on hydraulic fracturing in its 2010 fiscal year. On behalf of the Congress, the EPA fracking study is aimed at studying if there is a relationship between hydraulic fracturing and the ground water and drinking water by conducting research and monitoring the water use in hydraulic fracturing. This study, after many delays, is expected to be completed in 2014.[14]

According to the final plan of the study, the EPA is expected to implement different approaches including analysis of existing data, case studies, scenario evaluation, laboratory studies, and toxicity assessments. On one hand, the data analysis focuses on the existing data regarding well location and construction, chemicals, operating procedures, spills, and wastewater disposal. Furthermore, the EPA sent a letter to nine randomly chosen oil and gas companies to request additional information to support the study, in August 2011. The requested information includes quantity and quality of well cement, extent of integrity testing, identity of products or chemicals used, drinking water resources near the well or through which the well passes, and extent of baseline water quality monitoring. In order to assess the impact of hydraulic fracturing on the drinking water resources, seven cases were identified that include five retrospective cases (Killdeer, Dunn County, ND; Wise County, TX; Bradford & Susquehanna Counties, PA; Washington County, PA; Animas & Huerfano Counties, CO) and two prospective cases (DeSoto Parish, LA; Washington County, PA). As shown in the February 2012 progress update of the EPA study, verification of potential issues in the five retrospective cases is finished. The final study plan was amended based on a peer review from the EPA's Science Advisory Board, which is an independent, external federal advisory committee and comments from the stakeholders including individual citizens, communities, tribes, state and federal partners, industry, trade associations, and environmental organizations.

FEDERAL LAND PROCESS

The process for obtaining drilling permits on federal land is separate from individual state procedures. State laws for drilling are now developing and are addressed in the next section. The Federal land process for drilling is as follows. A copy of ''a notice of intention to drill'' must be given to the surface owner, but surface owner permission is not required prior to entry. The exploration period begins 30 days after notice is given and lasts 60 days. During exploration, the ''entry'' onto the surface owner's land does not allow for use of mechanized equipment, the construction of roads, drill pads, or the use of hazardous materials, and may not cause more than ''a minimal disturbance of surface resources.''

Failure to reach agreement requires the operator to post two bonds with the Bureau of Land Management (BLM). The surface use bond must cover damages to crops, permanent improvements, and your land's grazing value. The bond must exceed $1,000 and be provided to the landowner, along with a description of their right to appeal the bond. A second copy must be submitted to the BLM. If the bond is insufficient, the landowner may challenge it with the BLM within 30 days. If the BLM decides the bond is sufficient, you may appeal again. The reclamation bond must cover the cost of plugging wells and reclaiming and restoring land and surface waters. Standard bond amounts per company are: $10,000 per lease, $25,000 for all leases in a state, or $150,000 for all leases nationwide. If a landowner determines the total reclamation costs will exceed the bond, they can ask the BLM to increase the bond.

Before mineral operators can begin an oil and gas operation they must submit an Application Permit to Drill (APD) and a drilling plan. Once the APD is filed, the BLM must consult with other federal agencies and other appropriate interested parties. Surface owners have 30 days to comment. The drilling plan details the location of proposed roads, well pads, and other facilities, along with methods for handling waste such as garbage, sewage, and produced wastewater, and reclamation plans and other requirements. One can contact the BLM field office for a copy of the drilling plan.

Within 15 days of receiving a complete APD, the BLM must conduct an on-site inspection. Surface use and reclamation stipulations are developed during the inspection. By participating, the surface owner can press for tough reclamation requirements and responsible siting of roads and other infrastructure. The BLM will decide whether to incorporate the surface owner's suggestions.

STATE LAW INITIATIVES

A growing number of states have passed their own set of disclosure regulations. Wyoming was the first state, in September 2010, followed by Arkansas, Pennsylvania, and Michigan. In June 2011, Texas became the first state to pass a law requiring companies to disclose what chemicals are being injected into the ground at each well. Several other states, including North Dakota and Colorado, have recently enacted disclosure regulations. Colorado was the first to require disclosure of the chemicals used for fracking (family of chemical).

In December 2011, Colorado regulators approved new disclosure rules that are associated with the disclosure of hydraulic fracturing chemicals used during the fracking process. The chemical disclosure registry, by definition, means the chemical registry website known as fracfocus.org developed by the Ground Water Protection Council and the Interstate Oil and Gas Compact Commission. If the website becomes permanently inoperable, then chemical disclosure registry shall mean another publicly accessible information website designated by the Commission.[15]

Texas was the first state to pass a law requiring companies to disclose the concentration of hydraulic fracturing chemicals by listing the chemicals on a national registry. Similar to the law in Texas, Colorado's disclosure rules require a company to disclose the concentration of all chemicals used in hydraulic fracturing, along with the chemical family of the ingredients; however, the exact chemicals are very often considered a trade secret. The companies are required to disclose the secret ingredients in emergencies. The Colorado rules took effect on April 1, 2012.

Even though some state disclosure regulations only require the companies to disclose the concentration of hydraulic fracturing chemicals or the ingredient's chemical family, physicians and other medical professionals may request specific information of certain chemicals and gases for diagnosis or treatment purposes. However, the legislations can forbid them from disclosing the information for any purpose other than those two stated above.

In Ohio, the medical gag rule, introduced in the amendment of SB 315 that passed on May 15, 2012, requires a medical professional who receives information about trade secret chemicals to keep the information confidential. In Pennsylvania, Act 13, which was approved in early February 2012, allows the companies to not provide trade secret or proprietary information to physicians and others who work with citizen health issues. Also, the regulation forbids health care professionals from telling their patients, specialists, or the community.

Severance taxes are excise taxes on non-renewable natural resources that are extracted from the earth. They historically have been a significant revenue generator in energy-rich states. Currently, at least 36 states have some form of severance tax; 31 of which are especially on oil and gas extraction; at least 11 states are considering either imposing new or amending existing ones. However, Pennsylvania, the largest natural gas-producing state, has no such tax. Some states impose impact fees rather than taxes. In Pennsylvania, H.B. 1950 was enacted in early February 2012 to impose an impact fee based on the average natural gas price in the following year, with a cap at $355,000 per well within 15 years.

Due to different geological factors, different states have various ways of addressing fracking waste management and monitoring. These include addressing transportation, the use of open pits, and testing for fracking waste. Some states are taking steps in reducing risks related to the transportation of fracking disposal waste. In Pennsylvania, the pending H.B. 1741 would require placards to be posted on the outside of the vehicles if they are carrying hydraulic fracking wastewater. Drilling companies are experimenting with recycling frack fluid, reducing the amount of transport.

Some oil and gas companies evaporate fracking wastewater in large retention ponds for disposing purposes. Using retention ponds is dangerous because chemical oxidation and airborne toxins can potentially affect ''downwind'' areas. States, such as North Dakota, are regulating and attempting to reduce the number of open pits for frack fluid storage. If a new pit is the only alternative, it is required to have liners to attempt to prevent ground water contamination.

Fracking locations are required to be tested for waste in recent law enactments. A Statewide Groundwater Baseline Sampling and Monitoring rule, being the first rule for groundwater testing both before and after drilling, was approved by Colorado regulators on January 7, 2013. It requires four water samples from aquifers to be collected. In New York, several pending bills require wastes to be tested for radioactive contaminants and samples to be gathered to identify contaminants of concern.

Moratoriums are established in some states by law in order to delay or ban hydraulic fracking operations until the effects are better known. In New York, a moratorium of 120 days is established by pending A.B. 5547 after the EPA issues its reports on the effects of fracking treatment. A.B. 300, another pending bill, establishes a moratorium of 120 days on disposal of fluid after the EPA's report is released.

Several states are considering well setback regulations. In New York, pending A.B. 4237 prohibits drilling within 10 miles of the city water supply infrastructure. Fracking near a watershed is also prohibited by pending SB 1234. In Colorado, a hearing is required when oil and gas companies want to operate within 1,000 feet of a school or a hospital, under a newly proposed regulation. Also, in Texas, a bill was filed in 2011 to prohibit drilling within 1,200 feet of public schools; however, the bill did not pass due to industry opposition.

PEER-REVIEWED LITERATURE ON PETROLEUM CONTAMINATION

Since there is no peer-reviewed literature on fracking, the next closest body of research addresses petroleum groundwater contamination, primarily from leaking underground storage tanks. Four recent studies have addressed the effect of groundwater contaminated with benzene on residential property values (Simons, Bowen, and Sementelli, 1997, 1999; Simons, 1999a; and Simons and Winson-Geideman, 2005).

Simons, Bowen, and Sementelli (1997, 1999) focused on housing using municipal drinking water in Cuyahoga County, Ohio (Cleveland). Using regression analysis countywide, the observed losses ranged from 13% to 16% of property value. One case study of a higher priced suburban residential subdivision showed 16% losses. The houses were on municipal drinking water, and the contamination plume extended about one-quarter of a mile, and several dozen homes were involved.

A case study near Akron, Ohio in a rural subdivision on well water had losses of 25%, resulting from benzene contamination from a pipeline release (Simons, 1999a). These losses were about 10% higher than for homes on municipal drinking water. Simons and Winson-Geideman (2005) used contingent valuation analysis to gauge stated preference losses due to contaminated groundwater in several states, with losses in the 11%–27% range, depending on the severity of the scenario and location. To summarize, the residential leaking underground storage tank (LUST) literature indicates a loss of between 13% and 25% under various circumstances.

In similar fashion to this article, Wilde, Loos, and Williamson (2012) review the effect of pipelines on property values. Their review included the effect of proximity to pipelines, as well as from releases and ruptures. They conclude that research is limited and that results based on survey research in comparison to actual sales data requires further scrutiny to determine if the finding of their survey match the actual pricing effects for properties over time.

SUMMARY OF LITERATURE: POTENTIAL ISSUES

There is some concern that drilling leases may be problematic in relation to mortgage financing, lender's insurance, and homeowners insurance. In particular, mortgages typically stipulate that an owner is not to allow damage, destruction or substantial change to collateral including the use, disposal, storage or release of hazardous materials. In addition, the signing of a gas or drilling lease may require permission of the underlying lender. This result could give either of the federally-run companies (Fannie Mae and Freddie Mac) the right to demand immediate payment of the full loan.

Airborne chemicals (VOCs) and contaminated groundwater are types of toxic trespasses related to fracking, spills, and storage mishaps (Anderson, 2010).[16] The concept of an underground trespass and subsequent rent due for storage was developed by Krause, Throupe, Kilpatrick, and Speiss (2012). The concept being that chemical stored on the land of another constitutes a tenant status with rent due. The renter in this case would be the drilling firm who was aware of the chemicals used and left within the well during the fracking process. There are others who claim that a trespass per say is not due compensation unless there is damage to the surface rights (Anderson, 2010). For fracking where it is known that chemicals have been used, although not exactly which chemicals, residual effects to the surface from oil and gas drilling may be linked.

This type of easement is usually considered a temporary easement subject to paying rent. These easements typically last for a time period of less than a year. For natural gas operations, one could split the time into the period for when the well is initially drilled and then fracked versus a length of time that the well is in operation. During operation, there is a potential for visual degradation, traffic, and odor.

The development of a drilling site can create a loss of quiet enjoyment to adjacent property owners. Many times there is a need to create roads for access; and the transport to and from the site creates unwanted traffic and noise. Adjacent neighbors to drilling sites can also experience interruption from noise, lighting, and odor from releases of gases. For the local community, the discovery and extraction of natural gas or oil can create increased truck traffic, congestion, and noise effecting the quite enjoyment of the community.

The result of actual or perceived risk is based on various levels of knowledge (Mundy 1992a,b). The publicity and the lack of clarity from industry participants lead to a level of unknown risk to potential buyers. The result can be a discount for housing in proximity to drilling operations.

An onerous feature of gas drilling in New York is that the land owners by default will get stuck with the comprehensive liability for environmental clean-up, while the gas companies who leased the mineral rights have a more limited liability, like renters. Some leases protect land owners better than others, so there is some variety in how this issue is resolved.

Case Studies

The following examples from Pennsylvania, Ohio, Colorado, and Wyoming illustrate issues related to fracking.

PENNSYLVANIA

The town of Dimock, Pennsylvania, population 1,400, exemplifies the dangers posed by hydraulic fracturing. Dimock residents began noticing ill-smelling, brown, well water in 2008 after Houston-based Cabot Oil & Gas began fracking. Both the Pennsylvania Department of Environmental Protection (DEP) and the EPA found that at least 18 residential water wells were fouled by stray methane gas from Cabot's drilling operation. The town was later featured in the documentary ''Gasland'' by Josh Fox.

Residents claim that ''landmen'' from Cabot Oil & Gas, a midsize player in the energy-exploration industry, came knocking on doors to inquire about leasing the mineral rights to their land. Some residents claim the landmen told them that their neighbors had already signed leases and that the drilling would have no impact whatsoever on their land. ''Others in Dimock claim they were told that if they refused to sign a lease, gas would be taken out from under their land anyway, since under Pennsylvania law a well drilled on a leased piece of property can capture gas from neighboring, unleased properties'' (Bateman, 2010).

Cabot's drilling operations in Pennsylvania commenced in August 2008. Clearing and ground leveling were performed to make way for a four-acre drilling site less than 1,000 feet away from property owners. Residents claimed they could feel the earth beneath their home shake whenever fracking was initiated. A month later, their well water had turned brown and corrosive. They complained to Cabot, which eventually installed water-filtration systems in some homes. The problem appeared to be resolved, until additional DEP testing indicated high levels of methane.

Several incidents occurred after Cabot came to town. A truck turned over and caused an 800-gallon diesel fuel spill in April 2009. Also, in September 2009, up to 8,000 gallons of Halliburton-manufactured fracking fluid leaked from faulty supply pipes, with some seeping into surrounding wetlands and a stream, killing fish. By October 2009, the DEP had taken all the water wells in affected neighborhood offline. A major contamination was acknowledged with dangerously high levels of iron and aluminum, in addition to the methane found in the water. The residents relied on water delivery every week by Cabot. Some claim the value of their land was damaged. Others wanted to move but could not afford to buy a new house while carrying their current mortgage.

Residents are suing the company for diminution in value, negligence, breach of contract, and fraudulent misrepresentation, among other charges. Cabot declines to comment on the lawsuit but said that its operations are ''in full compliance with environmental and oil and gas drilling regulations'' and ''the accidental release of materials has occasionally occurred'' during its operations (Bateman, 2010).

In 2010, Cabot was banned by the DEP from drilling additional wells around the village of Dimock and required to take legal responsibility for the methane found in the wells, including constructing a pipeline to bring in clean water. Cabot contends that water wells in the area were tainted with the gas long before the company arrived. The company also says it met a state deadline to restore or replace Dimock's water supply. On November 30, 2011, Cabot won permission from state regulators to halt daily water deliveries. The environmental group ''The Sierra Club'' then arranged for trucks to continue to deliver water.

Confusion remains regarding whether the water in Dimock is safe to drink. On December 2, 2011, the EPA sent an email to several Dimock residents indicating that their well water presented no immediate health threat. However, on January 19, 2012, the EPA reversed its position, and asked that the agency's hazardous site cleanup division take immediate action to protect public health and safety (Gardner, 2012). Meanwhile, the Agency for Toxic Substances and Disease Regulation (ATSDR) continues to investigate the long-term effects of exposure to Dimock's water. This case illustrates: (1) the case illustrates the struggle of a lack of coordination, disruption to people's lives; (2) landmen ultimatums; (3) a debate of whether Cabot should continue supplying clean water and doing more tests relating to water quality; and (4) ongoing debate among the residents, DEP, the EPA, ATSDR, and Cabot.

OHIO

The eastern and central parts of Ohio and western Pennsylvania are imbued with the Marcellus Shale layer, a gas-rich rock formation. The Utica Shale formation (characterized as more liquid rich) is also in Ohio.[17] The shale formation has attracted the attention of many oil and gas landmen scrambling to obtain mineral rights to the deep (about 7,000 feet) shale formation under contract. In Northeast Ohio, Chesapeake Energy has been one of the more active firms in acquiring leases. This energy focus has started to ignite an economic mini-boom, and Ohio's unemployment rate has dropped below the national average for the first time in five years.[18] The battle for minds and influence has taken sides, with Cleveland State's Levin College of Urban Affairs conducting an economic impact analysis on behalf of the state addressing the positive side of the equation,[19] and the No Frack Ohio Coalition[20] taking the contrarian view, for both Pennsylvania and Ohio. Some assert that the potential employment from shale exploitation in these hard-hit areas is at least 10,000 jobs, and potentially as high as 40,000 jobs. Just on the Pennsylvania side, the estimate is over 23,000 jobs.[21] However, only a modest portion of these would be specific to the drilling locations. For example, a case study of Susquehanna County, Pennsylvania showed direct impacts of only a few hundred jobs and under $10 million in overall economic impact for 2010.[22]

On the downside, residents are concerned about increased truck traffic, the influx of new workers, and taxing local infrastructure, especially water. Although property value impacts have been mentioned on the No Frack Ohio website, no data are presented to back up claims.[23]

The other issue peculiar to Ohio is the incidence of modest seismic activity near Youngstown, Ohio in early 2012. Research shows fracking-related activity, notably water injections, have eluded control and ''slipped into a previously unknown fault line.'' The location has been linked to earthquakes in the area where there are over 150 horizontal fracking injection wells. A 4.0 magnitude earthquake near one of the deep disposal injection wells is likely linked to a disposal well for injecting wastewater used in the hydraulic fracturing process, according to seismologists at Columbia University. Consequently, Ohio has since tightened its rules regarding the wells, increased fees, and is considering a moratorium on the practice. The Youngstown area, thus, is at the epicenter of the Marcellus Shale exploration, incurring both the negative environmental effects of earthquakes and potential degradation of water quality, and the positive economic boom of having its moribund steel industry revived.

This case illustrates the tradeoffs of economic stimulus versus disruption of lives.

COLORADO

The process of hydraulic fracturing has been used for decades in Colorado, dating back to the 1970s. Hydraulic fracturing continues to be refined and improved and is now standard for virtually all oil and gas wells in the state, and across much of the country. But in Colorado, 206 chemical spills were linked to 48 cases of water contamination in 2008 alone. In Parachutte, Colorado, 1.6 million gallons of fracking fluid leaked and were transported by groundwater. According to state records, it seeped out the side of a cliff, forming a frozen waterfall 200 feet high. It was later melted into a tributary of the Colorado River.[24]

Reports of environmental degradation have come out of many places where natural gas drilling and fracking are occurring. The full extent of the problem is difficult to determine because much of the evidence is anecdotal because drilling companies are accused of buying people off when things go wrong. ‘‘In Silt, Colorado, a woman no longer talks about the adrenal gland tumor and other health complications she developed after her water was contaminated by a gas well drilled less than 1,000 feet from her home. (A state investigation into the matter concluded that a drilling failure had likely led to intermingling between the gas and water strata in the ground.) She signed a non-disclosure agreement as part of an agreement to sell her tainted land to EnCana, the large Canadian gas company that drilled the well. But perusing newspapers from towns where fracking was going on revealed how the issue refused to die, with headlines like ‘‘Fears of Tainted Water Well Up in Colorado,’’ ‘‘Collateral Damage: Residents Fear Murky Effects of Energy Boom,’’ and ‘‘Worker Believes Cancer Caused by Fracking Fluids’’ appeared regularly’’ (Bateman, 2010).

In Garfield County, Colorado, the location of the documentary ‘‘The Split Estate,’’[25] another area with a high concentration of drilling rigs, VOC emissions increased 30% between 2004 and 2006; during the same period there was a rash of health complaints from local residents. Epidemiological studies that might confirm or rule out any connection between these complaints and fracking are virtually non-existent (Brown, 2007). The health effects of VOCs are largely unquantified, so any causal relationship is difficult to ascertain; however, some of these chemicals are suspected carcinogens and neurotoxins.

‘‘Clusters of unusual health problems have popped up in some of these Colorado drilling hot spots. Kendall Gerdes, a physician in Colorado Springs, has told how he and other doctors in the area saw a striking number of patients come to them with chronic dizziness, headaches, and neurological problems after drilling began near their homes. One of Dr. Gerdes’s patients developed idiopathic hemorrhaging, or spontaneous bleeding, as well as neuropathy, a pituitary gland tumor, and a rare neurological speech impediment after alleged frequent exposure to noxious fumes from drilling. Although her health improved after she moved to another part of Colorado, she claims to continue to have trouble speaking and walking’’ (Bateman, 2010). In addition, the Colorado School of Public Health performed a study in 2011 regarding potential adverse health effects, concluding that residents near gas wells may suffer a series of ailments. This study was never published, after disagreements between drilling company and community members over the study’s methods.[26]

This case illustrates: (1) buy out of problems with gag orders; (2) long-term degradation of a community; and (3) oil and gas company ability to potentially thwart information.

WYOMING

Sublette County, Wyoming was the first site of groundwater contamination to be documented by a federal agency, the U.S. Bureau of Land Management, in 2008. Water from more than 88 drinking wells were contaminated and found to contain benzene, a chemical that causes leukemia, at concentrations up to 1,500 times a safe level. Researchers returned to take more samples, but were unable to open the water wells. Monitors showed they contained so much flammable gas that they were likely to explode (Lustgarten, 2008).

The industry pointed out the uniqueness of the location as the reason. Industry representatives say the gas wells in Wyoming were drilled under circumstances not found in most other fracking sites, with shallower wells, closer to water sources. Some of the fracking wells were drilled at around 1,200 feet, while most other shale drilling sites were between 4,000 and 14,000 feet, well below water sources. There were comments that the elevated levels of methane, benzene, and other petrochemical compounds found in EPA monitoring wells are naturally occurring because the wells were drilled ''into hydrocarbon-bearing zones.'' Thus, it is claimed to not be from fracking operations.

Another incident involving water was reported by residents near a gas field in Pavillion, Wyoming prompting the EPA to conduct a groundwater investigation. Pavillion is a town in Fremont County, Wyoming, with a population of 165 as of the 2000 census. Residents near the drilling sites in Pavillion asked the EPA in 2009 to investigate possible contamination after water from their wells started tasting and looking off. Canada's largest natural gas producer, Calgary-based Encana Corp. (ECA), owns about 150 wells in Pavillion. In 2010, the EPA opened an investigation into the possible contamination of groundwater approximately five miles east-northeast of Pavillion. Also in 2010, the Department of Health and Human Services recommended that Pavillion residents use alternate sources of water for drinking and cooking. While testing detected petroleum hydrocarbons in wells and in groundwater, the agency at the time said it could not pinpoint the source of the contamination. Meanwhile, Encana started providing drinking water to about 21 families in Pavillion in August 2010. A few days later the EPA released draft findings of contamination by hydraulic fracturing drilling operations in Wyoming. The industry's reaction was to attempt to find holes in the EPA's findings.

In December 2011, the EPA concluded that chemicals used in extracting natural gas through hydraulic fracturing were found in a drinking water aquifer in west-central Wyoming. The report also commented on contaminants in wells near pits, indicating that (frack) pits are a source of shallow ground water contamination. Two deep monitoring wells were dug by the EPA. They identified ''compounds likely associated with gas-production practices, including hydraulic fracturing.'' These chemicals in the deep wells were ''well above'' acceptable standards under the Safe Drinking Water Act. The EPA also found that the reports companies filed detailing jobs, listed chemicals as a class or as ''proprietary,'' ''rendering identification of constituents impossible.''

The draft EPA report also stated: ‘‘Alternative explanations were carefully considered to explain individual sets of data. However, when considered together with other lines of evidence, the data indicates likely impact to ground water that can be explained by hydraulic fracturing’’ (Phillips, 2011). The EPA also said that the type of contamination found is ‘‘typically infeasible or too expensive to remediate or restore.’’ Industry figures rejected the EPA’s findings. The location is now part of the EPA study on hydraulic fracking.

This case illustrates: (1) Sublette, Wyoming as the first time an agency has documented groundwater contamination; (2) Pavillion, Wyoming as the first time the EPA confirmed drinking water contamination; and (3) an inability to determine exact chemical identification.

Residential Buyer Market Survey

SETBACK LEGISLATION

Recent proposed legislation by multiple states has included setback requirements for fracking operations. As previously mentioned, these proposals address proximity to schools, residential property, and hospitals. A residential buyer survey was constructed to further study the potential impacts of fracking. This survey was designed to study proximity and general population sensitivity to fracking operations. Documented market transactions of properties are difficult to find and verify. Thus, a contingent valuation (CV) survey is used to investigate further. CV is a peer-reviewed procedure that can utilizes telephone calls to potential buyers, in this case homeowners in nearby counties, who are asked a series of questions about buying property, including acquisition of contaminated property.[27]

A professional survey firm (NSØN, Inc. of Salt Lake City, Utah) conducted telephone surveys under the direction of a researcher. The calls were made to a random sample of homeowners in ZIP Codes 77015, 77017, 77502, 77503, 77506, 77520, 77521, 77536, and 77587 in Metropolitan Houston, Texas, and ZIP Codes 32404, 32405, 32409, 36608, 36609, 36618, and 36619 along the Florida/Alabama Gulf Coast. Because Texas is a ‘‘petroleum friendly’’ location, we expected some differences in homeowner preferences, so we present the results separately.

The survey firm called names at random, until they reached a homeowner who was willing to participate in the brief 8-to-10-minute survey. Two different survey forms were used for this research (frack ‘‘heavy’’ and frack ‘‘light’’); one case (frack ‘‘heavy’’ only) was presented to both Texas and Florida respondents. Two hundred surveys of each type were collected for a total of 570 respondents. This number of responses generates statistically significant results with an approximate 90% level of confidence. The survey instruments contained a baseline case to establish value, and four scenarios with potential environmental or nuisance-related disamenities. Each survey was presented with a business park (harmless, meant to calibrate the survey form to show zero losses) with a leaking gas station scenario (meant to benchmark to the peer reviewed literature), and one of two fracking scenarios. Finally, one scenario in each survey subgroup relates to litigation, and these results are not presented here. With respect to the disamenities, the respondent is asked if they would make a bid on the property and, if so, how much. The instrument is quite detailed, and avoids key problems described in Mundy and McLean (1998a,b) and later expanded upon in Lipscomb (2011) and Lipscomb et al. (2011). These survey problems were originally debated as part of the Natural Resource Damages Assessment document (Federal Registrar 1996) produced by the National Oceanic and Atmospheric Administration. These include hypothetical bias with inflated responses because of the hypothetical nature of the questionnaire; and a self-interest bias based on respondents' motives; additional bias based on the survey instrument structure can be reviewed in Mitchell and Carson (1989).

We use an identical methodology to that used in peer-reviewed literature (Simons, 2002; Simons and Throupe, 2005; Simons and Winson-Geideman, 2005).[28] The instrument also did not specifically guide the respondent to a fracking scenario, but ''nests'' the issue in a broader context.

Each survey instrument was successfully pretested with 30 respondents (for each of the three groups) before beginning survey protocol. The pretests revealed no issues regarding survey design or respondent understanding.

INTERPRETING THE SURVEY RESULTS

There are two factors of major importance in evaluating survey results. The first is the portion of respondents that would bid on a scenario, which indicates any reduction in market demand. This is measured by the ratio of ''no bid'' to total responses. The second factor addresses potential value loss where there are bids. Of those that did bid, the ratio of maximum bid to baseline case reflects the percentage respondents state that they would pay. One minus this percentage reflects the discount. For example, if the person's baseline house price is $100,000, and the maximum they would bid on a particular scenario was $85,000, then that bid would reflect a 15% discount. The first part of the survey was a ''warm up'' and lets the respondent become comfortable with the bidding scale. It also determined a baseline property price in the context of a job move. In addition to the litigation and fracking scenarios, each respondent was asked about two other scenarios: a house near a business park and a house near a leaking underground storage tank (''LUST''). These scenarios were presented for benchmarking purposes and to familiarize respondents with the evaluation and bidding process. Bid percentages for these three comparative scenarios are presented in the data table, but are only discussed relative to methodology issues.[29] As mentioned above, two variations of the fracking situation were presented. Fracking ''heavy'' includes potential effects on groundwater, and was closer to the drilling site, which was visible from the house. About 200 Texas homeowners near Houston, Texas and a similar number of people in the Florida panhandle were asked about this scenario. In the fracking ''light'' scenario, the home was a mile away from the drilling site, and it was not visible from the home. Only Florida area homeowners were asked about this scenario. Thus, the difference could be attributable to a visual and possibly an auditory nuisance.

THE FIRST FRACKING SCENARIO (HEAVY)

Respondents to the group of surveys were asked to consider the following scenario:

The property is located at the edge of town. Last year, an energy company bought the rights to inject a pressurized mix of water, sand and chemicals into a lower groundwater aquifer to try to recover natural gas trapped under the property you are looking at buying. This is called hydraulic fracturing, or fracking. The drilling and injection equipment for this procedure is over one-quarter mile away, and is visible from the house. The house is on well water from a shallow aquifer, separate from the lower aquifer the natural gas is being recovered from. This process is expected to go on for five years. Except for this issue, the neighborhood is like yours, and the house is very similar to your house.

The bidding issue was determined by the following question: ''Using the scale below, where −3 means you definitely would not bid and +3 means you would, how likely is it that you would make any offer on this home?''[30] Of the 194 Texas respondents to the fracking heavy scenario, only 26% expressed a willingness to offer any bid on this scenario. In other words, 74% of the respondents would not even consider living in the house described in this scenario. This latter percentage reflects the reduction in the market demand for this type of property. These results as well as all other fracking scenario findings are reported in Exhibit 4. Of those who bid, the following question was asked: ''What is the most you would be willing to pay for the home?'' Of the 66 Texas bids on this fracking heavy scenario (within ¼ mile, drilling site visible, possible groundwater contamination), the prices offered were discounted by amounts between 0% (that is, no discount, or full price) and 99.9%. The average bid discount (i.e., value loss) for the property affected by fracking was 34% (median bid 32%). However, not all these bids necessarily would be in the market. Due to search costs, and the smaller number of bidders, the chances are reduced that any of the potential bidders would find a suitable home and place a bid that would be accepted by a seller. On the other hand, hugely discounted ''bottom fishing'' (very low) bids would have little value in the market, because it is the bids with the smallest discounts that would get the attention of likely sellers and culminate in a sale.[31] For this case, due to the reduced percentage of potential buyers (34% willing to make any offer), we considered market-clearing bids in the top half of the market (average loss of 14%) and the top quarter of the market (average loss of 6%). In other words, for this first fracking scenario offered to Texans, the average discount of the top half of potential bidders is 20% where information about the refinery's recent history of airborne chemical releases is known. Moving to the same fracking heavy scenario offered to 177 Gulf Coast Floridians, 36% offered any bid, a higher percentage than for Texas respondents; however, the discounts were deeper: 50% was the average bid, with 29% as the average of the top half bid, and 15% as the average of the top quarter bid. Thus, petroleum-friendly Texans had smaller discounts of about 10% with respect to the fracking heavy scenario (e.g., 6% for top quarter vs. 15% for top quarter bids for Floridians), than did those from places where petroleum exploitation is less commonly accepted.

Exhibit 4
Residential Contingent Valuation Survey

BUSINESS PARK: Several stores 3 blocks away. No unpleasant or unattractive uses.

	% Bidding Scenario	Average Bid	Top Half Discount	Top Qtr. Discount
Texas (*N* = 194)	83%	15%	−1%	−3%
Florida (*N* = 360)	78%	20%	2%	−4%

LUST: Closed gasoline service station with leaking underground storage tanks (LUST); gasoline components including MTBE in groundwater, on subject property; house on municipal drinking water.

	% Bidding Scenario	Average Bid	Top Half Discount	Top Qtr. Discount
Texas (*N* = 194)	21%	47%	28%	16%
Florida (*N* = 360)	20%	59%	37%	24%

FRACKING: Hydraulic fracturing injection site ¼ mile away; house on well water, drill site visible.

	% Bidding Scenario	Average Bid	Top Half Discount	Top Qtr. Discount
Texas (*N* = 194)	26%	34%	14%	6%
Florida (*N* = 177)	36%	50%	29%	15%

FRACKING: Hydraulic fracturing injection site one mile away; house on well water, no mention of drill site.

	% Bidding Scenario	Average Bid	Top Half Discount	Top Qtr. Discount
Florida (*N* = 183)	37%	41%	17%	6%

Source: Authors' surveys.

THE SECOND FRACKING SCENARIO (LIGHT)

Floridian respondents (183 people) to the second fracking scenario were asked about the following situation:

The property is located at the edge of town. Last year, an energy company bought the rights to inject a pressurized mix of water, sand, and chemicals into a lower groundwater aquifer to try to recover natural gas trapped under the property you are looking at buying. This is called hydraulic fracturing, or fracking. The drilling and injection equipment for this process is a mile away, but is not visible from the house. The house is on well water from a shallow aquifer, separate from the lower aquifer the natural gas is being recovered from. This process is expected to go on for five years. Except for this issue, the neighborhood is like yours, and the house is very similar to your house.

Results based on 183 responses indicate that 68 respondents (about 37%) bid on the property described in this scenario, meaning that the corresponding reduction in market demand would be 63%. Of the 68 bids (home 1 mile from the drilling site out of view), the prices offered were discounted by amounts between 0% (that is, no discount, or full price) and nearly 100%. The average bid discount (i.e., value loss) for the property was 41%. The market-clearing bids in the top half of the market were an average loss of 17%, and in the top quarter of the market it was a 6% discount. Thus, for this fracking light scenario, for Floridians, the reported discounts were about ten percentage points lower than for the fracking heavy scenario, ¾ mile closer, and in view of the drilling site. Exhibit 4 shows the results of the residential survey.

ANALYSIS OF THE RESIDENTIAL CV SURVEY

The results demonstrate the relative undesirability of residences in fracking areas. Based on the contingent valuation survey results, only 26%–37% of prospective buyers with the information stated in the fact paragraph would bid to buy a home situated similarly to those in the fracking scenarios, and many of those that do bid would discount their offers so much that many sellers would probably refuse them, at least within a normal, reasonable marketing period. And perhaps permanently, in light of the stated reduction in market demand revealed in this survey. The expected loss on this example residential property near fracking sites would be 5% to 15% in a robust real estate market. If the market is weaker (fewer sales, mortgage foreclosure issues, etc.), losses could increase by another 10%. Texan homebuyers are less risk averse than Floridians (also by about 10%) and being within close proximity and view of the drilling site would likewise indicate a 10% greater discount than further away. This reduction in bid value is a way to measure the reduction in housing services, the flow of enjoyment from owner-occupied housing. It also typically assumes more complete information than is often the case among actual buyers and sellers of homes.

Conclusion

The oil and gas industry has accelerated efforts to extract because of improved technology. This field as an area of study is very new and the ability to confirm information and data is difficult with non-standardized industry practices. Case studies show a lack of coordination and disclosure of potential effects to the quite enjoyment of property. The short- and long-term effects are contested as interests aligned with economic benefits in contrast to health and property concerns. There is a need for impartial and uninfluenced review and input, which is hard to come by.

Survey results for markets in Texas and Florida evaluating the effects of fracking on residential property values show single-digit discounts in strong markets of what is perceived as petroleum-friendly places. In contrast, low double-digit discounts in places unfamiliar with petroleum extraction, illustrate the effect of a potential stigma and how the new lexicon ''fracking'' can influence public opinion.

There is an emerging focus on reducing the environmental impact of exploration for oil and gas. The questions for future research include the long-term implications of chemicals left underground, the air quality implications, the storage solution to flow-back materials such as toxic fracking fluids and radioactive materials, and health and safety concerns of nearby people.

There is a need to share best or improved practices in connection with fracking operations. These include site development or shrinkage, post reclamation, reuse and disposal practices for frack fluid, cutting the emissions from drilling operations, and the public review process. These reactions to the industry, policy changes, and effects on operations and real estate are for further study.

Endnotes

1. http://money.cnn.com/data/markets/. Last visited 5/3/13. Oil at the same date was $95.61 a barrel.
2. 1 million BTU's of energy is approximately 1 million cubic feet of gas.
3. http://www.bls.gov/news.release/pdf/laus.pdf. Last visited 8/18/12.
4. http://fracfocus.org/hydraulic-fracturing-how-it-works/history-hydraulic-fracturing.
5. http://fracfocus.org/hydraulic-fracturing-how-it-works/hydraulic-fracturing-process.
6. Directional and Horizontal Drilling, Natural Gas. http://www.naturalgas.org/naturalgas/extraction_directional.asp.
7. Information on Hydraulic Fracking, State of Colorado Oil and Gas Conservation Commission, Colorado Department of Natural Resources, http://cogcc.state.co.us/General/HydraulicFracturingInfoSheet.pdf.
8. Committee on Energy and Commerce, Chemicals used in hydraulic fracturing. Available at: http://democrats.energycommerce.house.gov/.
9. Chemicals Used in Hydraulic Fracturing (Report). Committee on Energy and Commerce U.S. House of Representatives. April 18, 2011. http://democrats.energycommerce.house.gov/sites/default/files/documents/Hydraulic%20Fracturing%20Report%204.18.11.pdf.
10. A legislative proposal in the U.S. Congress to define hydraulic fracturing as a federally regulated activity under the Safe Drinking Water Act.
11. EPA, Achievable Air Pollution Standards for Oil and Natural Gas/Half of fractured wells already deploy technologies in line with final standards, which slash harmful emissions while reducing cost of compliance, *EPA Issues Updated*, April 18, 2012.
12. Study: No 'significant health threats' from natural gas sites in Fort Worth. *Fort Worth Star-Telegram* July 15, 2011.
13. They include such substances as benzene, ethyl benzene, toluene, boric acid, monoethanolamine, xylene, diesel-range organics, methanol, formaldehyde, hydrochloric acid, ammonium bisulfite, 2-butoxyethanol, and 5-chloro-2-methyl-4-isothiazotin-3-one. Recently, in congressional testimony, drilling companies have confirmed the presence of many of these chemicals.
14. Http://www.epa.gov/hfstudy/.
15. Colorado Oil and Gas Conservation Commission Rules, Definitions (100 Series), as of April 1, 2012.
16. The bundle of rights also has a vertical spatial component. Surface rights are the most widely understood, and include the right to use the surface of the property subject to zoning,

building codes, covenants, and easements. The real estate bundle of rights is usually thought to apply most directly to the surface of the land. If someone deposits contamination on your soil without your permission, you have lost control of this part of your real estate rights. There are also subsurface rights which include the water, groundwater, and mineral rights under the property. In some rural areas mining and water rights are valuable. If someone allows hazardous material from their property to encroach on subsurface water or air pockets underneath your property, without your permission, it is toxic trespass. In some urban areas, this hazardous material may get into a basement and present a fire hazard. It would also be of concern to a lender, and make it less likely that a buyer could get a mortgage secured by the real estate. In rural areas, where property owners obtain their drinking water from private wells, the same issues apply, but the added risk of contamination of the drinking water means the health risk, through the drinking water pathway, is an issue. In addition the air rights above your land or building, extending at least up to the legal building limit or height, and in some cases beyond that. When someone allows hazardous substances or nuisance odors from their property to disperse into the air above your property, it is also a form of trespass. Where the airborne substances include hazardous or potentially noxious compounds, there is an associated health risk issue, through the breathing pathway. Where nuisance odors foul the air on your property, there is a loss in value related to the reduction in use and enjoyment of the property's outdoor features, and sometimes to the additional cost incurred to keep the nuisance odors from encroaching into the dwelling itself.

17. http://articles.marketwatch.com/2012-04-3/general/31335058_1_marcellus-shale-oil-rich-region-horizontal-drilling.
18. Ohio Department of Employment Services, 2012.
19. http://www.csuohio.edu/news/releases/2011/09/14931.html.
20. www.nofrackohio.com.
21. http://www.msetc.org/docs/EconomicImpactFINALAugust28.pdf.
22. http://extension.psu.edu/naturalgas/publications/economic-impact-study-in-5-counties/economic-impacts-of-marcellus-shale-in-susquehanna-county-employment-and-income-in-2010/view.
23. http://www.nofrackohio.com/quick-facts-on-fracking/.
24. ProPublica and *Vanity Fair*.
25. The Split Estate, Documentary film by Debra Anderson, 2009.
26. Study shows air emissions near fracking sites may have serious health impacts. @theForefront. Colorado School of Public Health. March 19, 2012. http://attheforefront.ucdenver.edu/?p=2546. Retrieved 25 April 2012.
27. As a research methodology, CV has well-documented limitations. If survey participants had a financial stake in the outcome of a specific case, they could bias their responses to questions to get money. Other survey participants could have issues with the polluter, and may give responses based on this instead of the facts presented to them. To avoid these threats, we did not name polluters, and there is no fracking litigation involved.

    Other respondents may be tempted to give certain answers to ‘‘please’’ the surveyors. This issue has been minimized by having the surveyors stick to a prearranged script. Also, some respondents may give answers that may not reflect their actions in real life because there are no consequences to providing responses to hypothetical questions (Rowe, d'Arge, and Brookshire 1980; and Mathews and Desvousges, 2002). This has been associated with a discrepancy between stated and revealed preferences (Jackson, in Kinnard, 2003).

Hypothetical bias is a validity threat that can include potential overbidding (resulting in smaller losses than might be expected), and potential underbidding, which could lead to bigger-than-expected losses. Some bidders facing this situation could overbid, and because of their lack of familiarity with environmental situations, trivialize the perceived risks, and artificial nature of the survey (compared to an actual transaction). This may underestimate the discount because an upper bid could in actuality pull out, whereas in a hypothetical situation they state that they would bid full value. The underbidding component is addressed by removing unreasonably low bids from the analysis, focusing instead on bids closer to full value, which would be more likely to be accepted by a seller. This top-of-the market approach employs marginal bids (as opposed to the average bid approach, which averages all bids). Two studies have compared revealed (actual sales) and stated preferences (surveys) for contaminated real estate. They found that stated (survey) techniques generate higher losses than actual sales outcomes, in the range of mid-single digits (Simons and Winson-Geideman, 2005; Simons and Saginor, 2006). This range gives an indication as to the potential order and magnitude of hypothetical bias. Therefore, while hypothetical bias is still a potential validity threat to CV research, we believe its effects are manageable.

28. The technique is also similar to that summarized in Simons (2006), and set forth in Simons, Saginor, Karam and Baloyi (2008), who used personal interviews but the same tabulation approach, and Simons and Saginor (2010), who applied the CV technique to commercial property.

29. For the business park scenario, 75%–82% of the respondents bid some amount, indicating only a modest reduction in market demand. The business park had little effect on the bid amount for the top quarter of bidders (those closest to full value), from a small premium of 2% to a slight loss of 3%. These results are used to calibrate the survey instrument to zero. For the gas station LUST scenario, the reduction in demand was substantial. Between 65% and 80% refused to offer a bid at all, with Florida respondents slightly less likely to bid. Among those that did bid on the LUST scenario, the extent of losses was between 15% and 25% for the top quarter of bidders, with Texas bidders closer to 15% and Florida bidders closer to a 25% discount. This is consistent with published survey results set forth in Simons and Winson-Geideman (2005), and is used to benchmark these survey results to the peer-reviewed literature. The detailed results are shown on Exhibit 4.

30. The bidding scale was designed to include negative values in part because the authors wanted respondents to consider the negative and positive aspects of housing characteristics. It was also used to separate those respondents who were paying attention and could also understand negative numbers in two initial ''tripwire'' (screening) questions. The authors are unaware of any potential behavioral biases that were induced by using this scale, which has been part of previous published literature of real estate damages.

31. While the number of participants may well decline, the intensity of the search may increase for bargain hunters, thus altering the dynamics of the marketplace and ultimately the equilibrium price and transactions volume levels.

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The impact of oil and natural gas facilities on rural residential property values: a spatial hedonic analysis

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Abstract

This paper examines the impact of oil and gas facilities on rural residential property values using data from Central Alberta, Canada. The influences are evaluated using two groups of variables characterizing hazard effects and amenity effects. A spatial error model was employed to capture the spatial dependence between neighbouring properties. The results show that property values are negatively correlated with the number of sour gas wells and flaring oil batteries within 4 km of the property. Indices reflecting health hazards associated with potential rates of H_2S release (based on information from Emergency Response Plans and Zones) also have a significant negative association with property prices. The findings suggest that oil and sour gas facilities located within 4 km of rural residential properties significantly affect their sale price.

JEL classification: Q32; Q49

Keywords: Sour gas; Hedonic prices; Property value impacts

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1. Introduction

The oil and gas sector is large, important and ubiquitous in the Alberta economy. In particular, the natural gas sector has grown in importance with production doubling since the mid-1980s. Almost a third of the natural gas output is ''sour'' gas; that is, contains levels of hydrogen sulphide (H_2S) that imposes potential health risks. Because, with the exception of the tar sands, oil and gas activity is concentrated in the populated regions of the province, the industry must co-exist with other industries, largely agriculture, and with neighbouring communities. Amenity and, in the case of sour gas, health and safety considerations are often concerns of those located near industry facilities. The expansion of natural gas production has heightened those concerns. Surprisingly, relatively little is known of the impacts of industry proximity. For example, examinations into the health implications of long-term exposure to low-level H_2S are ongoing. Also, unlike for many other activities (e.g., airports, power plants and lines, hog operations, air pollution, schools and parks), investigations into the impact of oil and gas industry activity on the values of neighbouring properties seem rare. The purpose of this study is to contribute towards correcting this deficiency by studying the effects of the presence of sour gas and other oil and gas facilities on the values of rural residential properties in the vicinity of the City of Calgary, Alberta.

The paper begins with a section elaborating upon the industry–community interface and the risks associated with sour gas. The data employed in this study are then reviewed. The fourth section outlines the hedonic model and the spatial econometric analysis. This part is followed by presentation and discussion of the empirical results. A brief conclusion completes the paper.

2. The industry–community interface

2.1. Scope of the sector

The oil and gas sector in Alberta represents a major component of the provincial economy. Although the contribution in any year varies considerably with prices, the oil and natural gas industry (exploration, production, transport and processing) represents 20–25 percent of provincial output and contributes a similar share to provincial government revenues directly in the form of royalties and lease revenues from Crown-owned resources. Alberta currently supplies about 12% of the natural gas consumption in the US, over 50% of Canadian consumption, and gas is an input into a provincial petrochemical industry servicing domestic and export markets. The industry has become important and has grown rapidly over the last 50 years. This expansion has been paralleled by a substantial growth in the Alberta population, particularly in and around the urban centres in the province. The rapid expansion of the oil and gas sector (both primary and downstream processing and manufacturing), the expanding urban regions, and the importance of agriculture to the provincial economy has set the stage for conflict between the oil and gas industry and rural residents.

2.2. Sour gas and associated concerns

Although disagreements involve a number of issues, a major concern in the province is the production of sour gas. Sour gas is a natural gas that contains hydrogen sulphide, a colourless flammable compound that has an unpleasant smell similar to that emitted by rotten eggs and that is hazardous to humans and animals in relatively low concentrations.[1] Gas containing at least 1% H_2S is considered ''sour'' and gas with less than 1% H_2S is considered ''sweet.'' While some H_2S can be released due to accidents and equipment failures at sour gas facilities, the industry converts about 97% of the H_2S in the gas to elemental sulphur that is used in the manufacturing of fertilisers, pharmaceuticals, plastics and other products (Petroleum Communication Foundation, 2000). The remaining H_2S is usually burned in flares or incinerators that results in the conversion of H_2S to sulphur dioxide (SO_2), small quantities of other toxic compounds such as carbonyl sulphide (COS) and carbon disulphide (CS_2), nitrogen oxides (NOx) and volatile organic compounds (VOCs).

The production of sour gas has naturally led to concerns over the health effects of the various compounds found in the gas, as well as general air and water quality (Marr-Laing and Severson-Baker, 1999). These concerns have been expressed in various public forums and in public advisory groups established by the industry and government to address and study them (Provincial Advisory Committee on Public Safety and Sour Gas, 2000; Nikiforuk, 2002a). The scientific studies conducted in the province to date have neither found adverse effects of emissions on lakes or rivers, nor have researchers found convincing evidence of impacts of low levels of exposure to H_2S on the health of humans or livestock. This is, however, a topic of ongoing research. Despite the limited evidence, some people hold strong opinions about possible negative effects and, in a few cases, there have been widely publicized conflicts between the industry and persons neighbouring sour gas facilities (Nikiforuk, 2002a, 2002b). While sour gas occurrences have diminished in recent years due to increased care and regulation, there has been several larger scale sour gas events involving well blow-outs or uncontrolled releases in the province and fatal accidents involving industry workers overcome by H_2S. However, there have been no casualties among the general public.

About 30% of Alberta's natural gas production is sour gas and much of that is found near populated areas (Nikiforuk, 2002a). Furthermore, the rising demand for natural gas has expanded its exploration and production and has increased the number of Alberta residents facing actual or proposed sour gas developments in their communities. Naturally, residents neighbouring proposed and existing sour gas developments are concerned about the possible health risks and other potential negative impacts. It is expected that those concerns may have a negative effect on property values. This paper examines the impacts of sour

[1] H_2S can be detected by the human olfactory system in concentrations of 0.01–0.03 ppm. Levels of 1–5 ppm can cause nausea and headaches; concentrations of 50–250 ppm result in olfactory paralysis; and imminent threat to life can occur when concentrations reach 300–500 ppm (Gephart, 1997). The human olfactory system is deadened with concentrations above 100 ppm, giving a false sense of security that no danger is present (Marr-Laing and Severson-Baker, 1999).

natural gas facilities, and of other oil and gas developments, on property values of residential acreages in selected areas around the City of Calgary, Alberta.

Health and safety risks are a clear concern associated with sour gas facilities because they represent a special hazard. This situation is recognized to an extent in regulations requiring minimum setback distances between sour gas and oil facilities and the nearest residence, business, or occupied area (such as campgrounds and recreational areas). The setback distance varies according to the level of the hazard represented by the facility. In addition to setbacks, emergency plan response zones (EPZs) are established around all facilities that have the potential to affect public safety. For sour natural gas facilities, the size of these zones can range up to several kilometres and the size is related to the maximum potential volumes or rates of release of gas. In conjunction with these zones, emergency response plans (ERPs) are established to determine the procedures to notify the relevant members of the affected public in the event of an emergency. The industry is required to conduct regular tests of their emergency response, which includes routine contact with residents living within an EPZ. Also, upon the sale of property within one or more EPZs, the seller is required to inform the buyer of the EPZs affecting the property. Thus, one can expect property values to reflect health and safety considerations.

The presence of industry infrastructure and associated activities may also adversely impact nearby property values for amenity reasons. Industrial structures and activities on what landowners may perceive as natural landscapes can detract from enjoyment of property. Many acreage owners choose to live in rural areas to escape urban and industrial development. Even though regulations require that the land affected by oil and gas wells must be restored to at least the equivalent of its previous condition, a typical well in Alberta exists and produces for about 20 years. In addition, other types of facilities such as pipelines, pumping stations, gas processing plants and oil batteries are typically associated with wells. The presence of such facilities near acreages may further reduce enjoyment of these properties and, thus, could negatively affect their values.

2.3. Assessing the implications for property values

Despite the importance of this issue in Alberta, and likely also in similarly developed jurisdictions in the USA, there have been few studies that examine the effects of oil and gas production facilities on property prices although there are obvious potential hazard and amenity implications. We are aware of only three (all consultant reports commissioned by oil companies operating in Alberta). Those reported little to no impacts of infrastructure on prices of (Deloitte et al., 1988; Lore and Associates Ltd., 1988; Serecon, 1997). The methods employed in these studies, however, have not been the typical techniques employed by economists examining the impacts of environmental amenities and health risks on property values. These studies grouped relatively small samples of properties according to their proximity to infrastructure and compared prices across these groupings (or in pairs of similar properties), or used price regression that included few property or industry variables.

The principle technique used by economists to examine such impacts has been hedonic price analysis (Taylor, 2003). Examples of studies that have uncovered reasonably large effects on residential land prices include the transport of hazardous wastes (Gawande and

Jenkins-Smith, 2001), electricity transmission lines, (Hamilton and Schwann, 1995) changes in water quality (Leggett and Bockstael, 2000) and hog operations (Palmquist et al., 1997). The single hedonic study we uncovered on the effects of oil and gas infrastructure on prices is by Flower and Ragas (1994) who examined the influence of large-scale oil and gas infrastructure in the form of refineries on residential property prices.

This paper reports efforts to determine the impact of proximity to small to medium oil and gas production facilities on rural residential property values. To the extent our data permit, efforts were made to assess the effects of both hazard and amenity considerations. Spatial hedonic methods were explored and ultimately used in this analysis.

3. The data

The data come from areas having significant sour gas activity near the City of Calgary, a city of approximately one million residents in southern Alberta, Canada. The shaded areas in Fig. 1 show the townships comprising the study area. A township is a 6-mile $\times$ 6-mile block. Thirty full townships and parts of six other are included. Oil and gas facilities in the selected townships ranged from sparse to dense. The area spans three rural jurisdictions—the Municipal Districts of Rocky View and Foothills, and Mountain View County.[2] Arm's length sales of ''country residential'' properties in this area during the period January 1994 (when data in electronic form became available) to March 2001 were analyzed.

The initial sample contained information on the sale of 612 residential properties that ranged in size from 1 to 40 acres. The acreage limitation essentially ensured that the property was rural but also residential in that it did not have commercial agricultural value. Furthermore, to minimize the potential influence of a few unusual properties (characterized by abnormally low or high prices), only properties priced from $150,000 to $450,000 were included. This restriction deleted 59 observations. Within this reduced sample, 21 properties had oil and gas facilities located on them. Because the owners at the time of facility establishment are eligible for financial compensation by the companies owning these facilities, and it was not always possible to determine the timing of facility development relative to the property sale, these properties were excluded from the analysis. After these various exclusions a final sample of 532 sales remained.[3]

The model underlying hedonic price analysis is that the price of a residential property is determined by the buyer's appraisal of those characteristics (Taylor, 2003). This appraisal can involve both objective and subjective evaluations. The number of characteristics can be quite extensive, typically including factors such as structural characteristics (e.g., area, number of bedrooms and the presence of a basement or garage), location attributes (e.g., distance to the central business district, proximity to schools and shopping, etc.) and environmental influences (e.g., views, levels of industrial emissions and noise). The basic attributes of the sample properties were gathered from the Multiple Listing Service (MLS)

[2] For our purposes, the distinction between municipal districts and counties is not relevant.

[3] These restrictions deleted about half of the approximately 30 observations considered influential in the various models. The remaining influential observations were not omitted. Failure to do so does not affect our results. In fact, the pattern of the results is robust across the alternative samples (532, 553 and 612 observations).

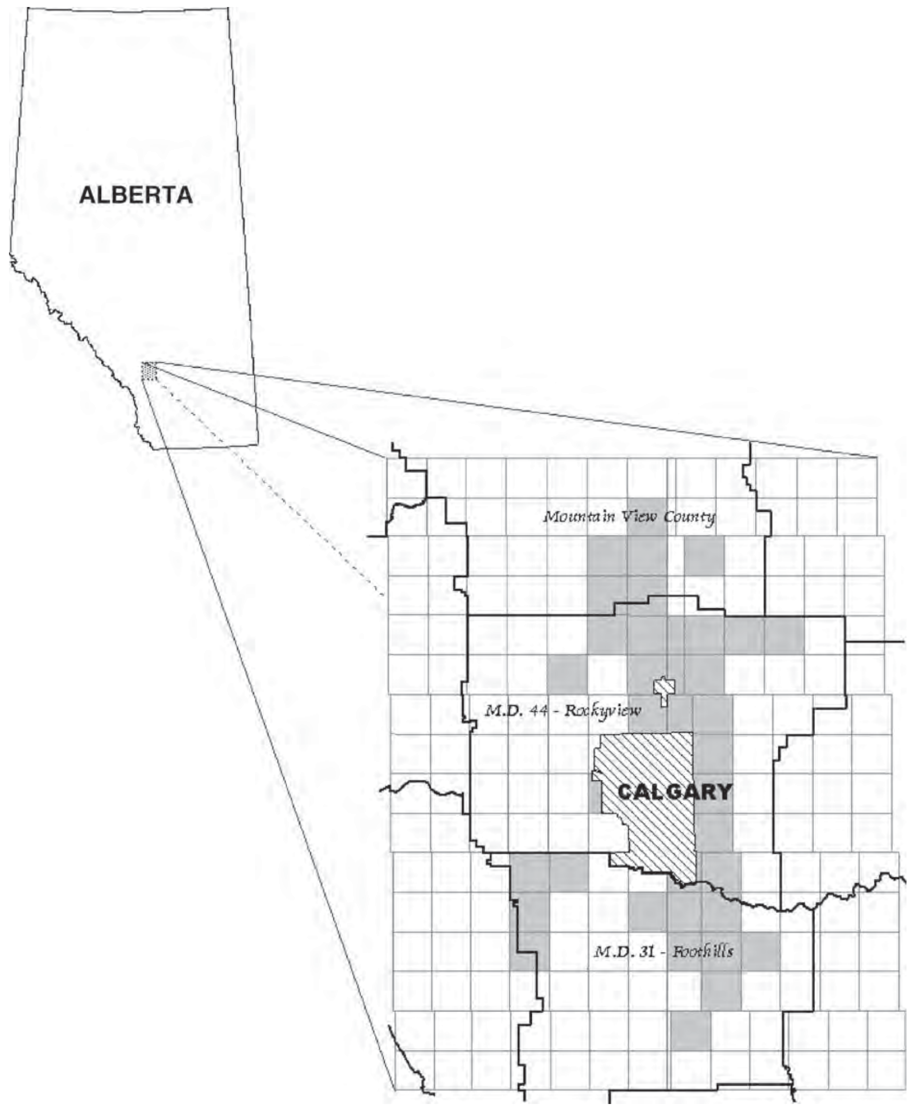

Fig. 1. A map of the study area in Alberta, Canada. Grey areas represent townships in which data on property values and oil and gas infrastructure was collected.

records of the Calgary Real Estate Board. A list and summary statistics of the conventional property attributes are included in Table 1.

Four variables were added that warrant comment. Because many rural residential residents commute to work in Calgary, the distance to downtown Calgary was included. Also, during the 5(+)-year period over which sales data were gathered, house prices in the Calgary market increased considerably. Hence, the real average residential price of property in the City of Calgary (in constant 2000 $CDN) was included to control for the

Table 1
Property attributes from MLS sources[a]

Variable	Description	Mean	S.D.
RPRICE	Sale price of the property (2001 $CDN)	290593.8	69815.48
ACRES	Size of the land associated with the residential structure (acres)	7.15	6.44
AGE	Age of the residential structure at time of sale (years)	10.48	7.94
AREA	Area of the residential structure (m^2)	176.31	63.06
BATH	Number of bathrooms	2.25	0.75
BEDRM	Number of bedrooms	2.91	0.84
CALGARY	Distance from the City of Calgary (km)	31.07	12.23
DECK	Deck or balcony present (DV) [b]	0.67	0.47
NGARAGE	Number of garage spaces for vehicles	2.18	1.09
MUNWATR	Water supplied by municipality (DV)	0.02	0.13
NOBASEMENT	Basement of residential structure is not present (DV)	0.02	0.15
RAVP	Monthly average residential property prices in Calgary (2000 $CDN)	136519.7	9478.30
VMTN	View of the Rocky Mountains	0.40	0.49
ROCKY	Located in Municipal District of Rocky View	0.37	0.48
MOUNTAIN	Located in County of Mountain View	0.05	0.21

[a] Multiple Listing Service.
[b] DV signifies that the variable is a dummy variable (0, 1).

strong housing market in the region. Property values depend partly upon local government taxes and services. Public services are difficult to measure and property tax information was not included in the data. Property taxes are the dominant source of municipal and county government revenue. Hence, dummy variables for the local jurisdiction a property was located in were introduced to capture differences in municipal taxes and services that are reflected in the prices.[4,5] These variables are also described in Table 1.

Numerous other features of the properties were collected and many were initially assessed but ultimately excluded from the final specification. A deficiency of the data was the lack of information on structures beyond the house—that is, out buildings such as stables, barns, corrals and large shops or garages for recreational and utility vehicles.[6] Because horse-back riding is very popular in the area and many properties include significant riding related facilities, this omission is believed to detract from the explanatory power of our regressions.

The principle connections between the presence of oil and gas facilities and residential prices were hypothesized to be visual impacts, noise, traffic, odour and perceived health hazards. Accordingly, additional property attributes were gathered or constructed to

[4] It was not necessary to consider school districts and school financing. While administered by local (district) school boards, schools in Alberta have been fully funded by the province in Alberta since 1995 and a provincial property tax that contributes (about one-third in 2001) to school financing is uniformly levied at a provincial rate. In addition, the school districts match the municipal authorities in the study area.

[5] As reflected in a recent study (Alberta EUB, 2003), the oil and gas industry impacts localities in many ways—for example, direct and indirect jobs, municipal revenues and services. There is no attempt to identify the more obtuse local impacts in this analysis.

[6] The latter may be captured in part by the number of garage spaces variable (Table 1).

Table 2
Oil and gas facility variables

Variable	Description	Mean	S.D.	No. of affected properties in sample
EPZINDEX	Emergency planning zone (EPZ) index (sum of radii of all EPZs a property is located within)	6.83	12.29	246
BATINDEX	Flaring battery index (sum of H_2S released from all batteries within 4 km of property)	49.91	246.83	91
NEAREST	Distance to the nearest operating sour gas plant (km)	16.73	7.01	532
NEPZWELL	Number of well EPZs the property was located within	0.61	2.06	98
NEPZPIPE	Number of pipeline EPZs the property was located within	1.25	2.03	187
FLARING	Number of flaring batteries within 4 km of property	0.31	0.85	91
SWEETWELL	Number of sweet oil and gas wells within 4 km of property	1.94	3.43	250
SOURWELL	Number of sour oil and gas wells within 4 km of property	3.25	3.43	373
ALLWELL	Total number of oil and gas wells (both sweet and sour) within 4 km of property	5.19	4.98	434
ALLPIPE	Total number of pipelines with recorded $H_2S > 0\%$ within 4 km of property	11.31	9.22	495

Source: Alberta Energy and Utilities Board.

characterize the nature, location and extent of any nearby oil and gas facilities. First, each property in the database was located on a Geographical Information System (GIS), and a 4-km buffer was established around each property. The range of 4 km was predetermined by energy experts based on evidence regarding the probable maximum range for impacts that extend from the typical facilities such as wells, pipelines or batteries.

Industry variables were then constructed based upon information held by the Energy Utilities Board. The information used to generate the facility variables came from the Board's GIS databases (accurate to May/June 2001) and information on the EPZs from the emergency response plans submitted by oil and gas companies to the Board. All distance and count measurements were undertaken using the GIS. These variables are described in Table 2.

One group of facility variables was developed to explore the price impacts of the *intensity* of oil and gas developments nearby each property. For each property, the number of natural gas producing facilities within the 4-km buffer of each property was determined. Those included (separately or in combination with oil) sweet gas wells (SWEETWELL), sour gas wells (SOURWELL) and flaring oil batteries (FLARING).

It was expected that property values could be affected by the *proximity* of the various oil and gas facilities. To examine this, the numbers of sour, sweet and oil wells were counted within each of four, 1-km concentric rings around each property. Proximity to sour gas plants was also examined. Plants are few in number and are relatively large processing (versus extraction) facilities. The importance of proximity to the nearest operating sour gas plant (NEAREST) was not limited to the 4 km distance.

In order to focus on the health risk, a second group of variables was selected. Those variables utilized information on the emergency planning zones of the sour gas facilities associated with each property. One measure is the simple counts of the number of EPZs associated with wells (NEPZWELL) or with pipelines (NEPZPIPE) in which a residence is situated.[7] An alternative measure yields a third variable, EPZINDEX, an index of EPZs reflecting the potential volume of escaped H_2S. EPZINDEX was calculated as the sum of the radii (in kilometres) of each of the EPZs overlapping a property. The radius of each EPZ is a function of the potential rate of release of H_2S from the well or pipeline. Thus, a higher EPZINDEX represents a higher potential H_2S exposure intensity or health risk in the event of an emergency.[8] Similarly, the annual volumes of H_2S gas flared at flaring oil batteries within 4 km of a property were summed to construct a flaring battery index (BATINDEX).

Note that pipelines are included in the health risk measures but not the intensity/proximity measures. This distinction was made primarily because data were available only for pipelines carrying natural gas with an H_2S content exceeding 0%. These pipelines are considered sour in this study because they pose some health hazard. Other pipelines, such as those carrying sweet gas and oil, are present but were not included in the data. Pipelines in this area are underground and so are relatively unobtrusive facilities posing minimal amenity problems.

4. The hedonic model and econometric analysis

The hedonic method is one technique in a class of valuation approaches commonly labelled ‘‘indirect’’ valuation. These techniques rely on observable market transactions to obtain values for various characteristics of heterogeneous products. Housing markets are well suited to hedonic methods as the choices of housing location and neighbourhood amenities are observable to researchers. Thus, the choices of properties and their associated prices imply implicit choices of environmental amenities and other characteristics linked to the transacted properties.

In this paper, a first-stage hedonic analysis is reported in which the hedonic price function was estimated using prices and characteristics of a sample of transacted properties. This procedure estimates the implicit prices of the characteristics and reveals information on the underlying preferences for these characteristics. Rosen (1974) suggested the possibility of a second-stage estimation using the implicit prices derived from the hedonic price function and other information to estimate actual household

[7] No EPZ variables were incorporated for sour gas plants directly because the EPZs for gas plants are defined by the zone of the largest volume pipelines serving them. Therefore, the risk of failure for these facilities is described in terms of the pipeline EPZs.

[8] This interpretation of the EPZ index assumes that prospective home-buyers are well informed about the number and size of EPZs in which a property is located. Operators are required to conduct regular tests of their emergency response plan procedures, which include routine contact with residents within a zone and, when a property is sold, it is the obligation of the seller to inform the buyer of the EPZ(s) affecting a property. Thus, property owners should be aware of EPZs and are required to inform potential buyers.

demand for attributes. That step cannot be pursued here because information such as income and household demographics that should be included is lacking.[9]

Three basic issues are involved in constructing a hedonic price model. Two of these, functional form and model specification, are common to all hedonic price analyses. While a range of hedonic price function specifications are possible, this study used the double log specification which was chosen based on preliminary Box–Cox regression procedures and confirmed by LM tests developed by Baltagi and Li (2001) for the specifications reported here. Cropper et al., 1988 have shown that the log–log function is best in terms of measuring marginal prices in the presence of model misspecification relative to linear, linear–log and other quadratic functions. The log–log formulation provided the best fit and allowed construction of price elasticities that aid in the interpretation of the implicit price coefficients. A small constant was added to all non-dummy variables with zero values before logarithmic transformation. Adding a small constant before logarithmic transformation is not uncommon (Antweiler and Frank, 2002; Jacoby, 1992; MaCurdy and Pencavel, 1986).

To determine the specification of the hedonic model, property prices were regressed against both the property (non-industrial) variables and certain combinations of the (industry) facility variables. All facility variables could not be included in the model due to concerns regarding multicollinearity. Final choice of facility variables in the specification involved consideration as to whether the variable likely represented an amenity concern or a health concern. After considerable testing, two health risk specifications and two amenity specifications were chosen. The first health risk model (H1) involved the two index variables, EPZINDEX and BATINDEX and a proximity variable, NEAREST. The second health risk model (H2) included three frequency variables, FLARING, NEPZWELL and NEPZPIPE. Both amenity specifications involved frequency variables; the first (A1) focused on the two types of wells (SOURWELL and SWEETWELL) and the second (A2) used the total number of wells and pipelines (ALLWELL and ALLPIPE).

The third issue involves the treatment of spatial dependencies and whether spatial considerations should be formally considered in the error structure of the model. Spatial dependencies affect hedonic studies from either structural relationships among the observations (lagged dependency) or from the omission of spatially correlated explanatory variables that impact the spatial dependency among the error terms. Researchers have demonstrated the importance of accounting for spatial dependencies in hedonic applications (e.g., spatial lagged dependencies (Can and Megbolugbe, 1997; Gawande and Jenkins-Smith, 2001) and spatially autocorrelated errors (Bell and Bockstael, 2000; Leggett and Bockstael, 2000)).

Anselin (1988) describes spatial regression models that attempt to incorporate these effects. Spatial dependence can be incorporated using a spatial lag model that is defined in the following equation using the double log functional form:

$$\ln Y = \alpha + \rho W \ln Y + \beta \ln \mathrm{X_c} + \delta \mathrm{X_d} + u \qquad (1)$$

[9] The second-stage process is fraught with endogeneity and identification problems that, despite considerable effort and ingenuity (see Taylor, 2003), have led at least one group of analysts to conclude that the method has not yet been used successfully to estimate willingness to pay functions (Deacon et al., 1998).

In this equation, Y represents property prices, X_c are continuously measured property attributes and industry variables, δ is the vector of intercept shifts that correspond to attributes measured using dummy variables X_d, and $u \sim N(0, \Omega)$. The effect of the spatial lag is assessed through the parameter ρ and a spatial weighting matrix W, which defines the spatial relationships among the property prices. Alternatively, the spatial error model suggested by Anselin (1988) with the double log functional form is defined by:

$$\ln Y = \alpha + \beta \ln X_c + \delta X_d + \varepsilon \tag{2}$$

$$\varepsilon = \lambda W \varepsilon + u \tag{3}$$

This model includes a normal disturbance $u \sim N(0, \Omega)$, a spatial weighting matrix (W) and a coefficient (λ) for the spatial autoregressive structure for the disturbance (ε). A non-zero λ-value represents the presence of spatial errors and if present, OLS estimates will be unbiased yet inefficient.

Because the data analyzed in this study were spatial in nature, these spatial issues were examined. A key element in this approach is the determination of the ''spatial weighting matrix'' which involves selecting the properties within a certain range or distance of the given property and determining the relative weight of each on the property of interest. Guided by various specifications in the spatial hedonic literature (e.g., Bell and Bockstael, 2000) a number of specifications of the weighting matrix were examined. A matrix of the inverse distances between properties ($1/d_{ij}$) within 4 km was chosen as the spatial weighting matrix in which the diagonal elements contain zero values:

$$W = \begin{bmatrix} 0 & & & & \\ \frac{1}{d_{1,2}} & 0 & & & \\ \frac{1}{d_{1,3}} & \frac{1}{d_{2,3}} & \ddots & & \\ \vdots & \ddots & \ddots & 0 & \\ \frac{1}{d_{1,N}} & \cdots & \cdots & \frac{1}{d_{N-1,N}} & 0 \end{bmatrix}$$

Specifications using distances of 1, 2 and 10 km were examined; the $(1/d)^2$ form was tried, and weights matrices producing a lattice structure by including only 2, 3 or 5 of the closest neighbours were examined. While these various specifications did not produce results appreciably different than those reported here, intuitively it was felt that properties which are further apart should be given smaller weight due to the minimal impacts they might have on each other. Thus, the distance specifications were preferred over the lattice structure. The 4 km distance was chosen because the 1 km limit (especially) seems rather tight for this data and also because it matches the 4 km cut-off used to study the facility impacts.

A researcher must select a spatial autoregressive model by testing for the presence of a spatial lag ($\rho \neq 0$) or spatial error ($\lambda \neq 0$) through a variety of statistical tests. In addition to the standard Lagrange Multiplier (LM) tests, robust LM tests and Kelejian and Robinson (1999) tests are often performed to provide additional evidence for the spatial error structure. Moran's I-test can be used as a general test of model misspecification when considering the presence of spatial effects. The Kelejian and Robinson test is designed for the same purpose with the additional features of being robust to non-normality of the error terms and non-linear structure in the price equation. While it is possible that independent tests suggest that both a lag and an error model are appropriate, Anselin and Florax (1995) suggest that comparison of the statistical significance of LM tests and robust LM tests will identify the superior specification for capturing spatial dependence.

The results presented below involve models chosen on the basis of the overall fit and statistical significance of the individual parameters. Due to the number of variables assessed in this study, and that the parameters of the property characteristics are of secondary interest and are not sensitive to the inclusion of the facility variables, we present the parameters for the property characteristics and facility variables separately for ease of presentation.

5. Results and discussion

5.1. (Non-industrial) property characteristics

Table 3 presents OLS parameter estimates for the non-industry property characteristics associated with the residence gathered from the standard real estate Multiple Listing Service forms. The characteristics having significant coefficients are AGE, AREA, the number of bedrooms (BEDRM), the number of bathrooms (BATH), the presence of a deck (DECK), the number of garage spaces (NGARAGE), the size of the property (ACRES), a view of the mountains (VMTN), distance from the City of Calgary (CALGARY), the inflation adjusted monthly average price of residential property in Calgary (RAVP) and Municipal District of Rocky View (ROCKY) and the County of Mountain View (MOUNTAIN). Since the local government dummy variables are not significantly different from each other in any of the three models in Table 3 (F-tests; $P > 0.30$), there is a significant difference in prices between similar properties in these two jurisdictions and those in the Municipal District of Foothills.

All of the signs of the parameters are as expected. For example, the larger the area of the residence, the greater its price. Also, the marginal impacts of these variables on price appear to be reasonable (see Appendix A). Note that the impact of an added bedroom is negative but that reflects that the area (and number of bathrooms) in the house remain the same. That is, another bedroom is ‘‘squeezed’’ into the average sized house. Robust t-ratios were also calculated due to the presence of heteroskedasticity indicated by the Breusch–Pagan test results are reported in Table 3. The statistical significance of no variable changed as a result of using the robust t-ratios.

The property characteristics model was then subjected to spatial adjustment and further statistical testing. The results supported the use of the spatial error model over the spatial lag. Inclusion of the jurisdiction dummy variables (ROCKY and MOUNTAIN) removed evidence of spatial lag. However, the spatial error parameter was found to be positive and significant at the 1% level (Table 3; last column). Upon adjustment of the error term, the parameters of the property variables did not change appreciably except for MUNWTR which was found to be statistically significant in the spatial results but not for the non-spatial results.

Table 3
Regression results for the hedonic model of property characteristics on prices

Non-industry Characteristics	OLS (*t*-ratio)	OLS (Robust *t*-ratio)	Spatial error (*t*-ratio)
INTERCEPT	−1.1650 (1.1345)	−1.1650 (1.1399)	−0.1246 (0.1291)
ln(AGE)	−**0.0178**[a] (2.2401)	−**0.0178** (2.3972)	−**0.0185** (2.4734)
ln(AREA)	**0.3884** (17.0194)	**0.3884** (14.0514)	**0.3518** (16.2612)
ln(BEDRM)	−**0.1010** (4.9116)	−**0.1010** (4.6536)	−**0.0765** (4.1461)
ln(BATHRM)	**0.0752** (4.0596)	**0.0752** (3.5506)	**0.0744** (4.4419)
NOBASEMENT	−0.0314 (0.7735)	−0.0314 (0.7437)	−0.0529 (1.4364)
DECK	**0.0324** (2.5111)	**0.0324** (2.4305)	**0.0296** (2.4944)
ln(NGARAGE)	**0.0789** (5.3260)	**0.0789** (4.7299)	**0.0804** (5.7397)
ln(ACRES)	**0.0922** (10.4423)	**0.0922** (10.1550)	**0.0917** (10.1486)
VMTN	**0.0279** (2.2501)	**0.0279** (2.1973)	**0.0276** (2.2475)
MUNWTR	0.0812 (1.7225)	0.0812 (1.9115)	**0.0946** (2.1911)
ln(CALGARY)	−**0.1744** (8.0164)	−**0.1744** (7.4646)	−**0.1734** (5.8598)
ln(RAVP)	**1.0296** (11.8386)	**1.0296** (11.9227)	**0.9553** (11.7621)
ROCKY	−**0.1015** (7.4950)	−**0.1015** (7.5967)	−**0.0983** (5.0629)
MOUNTAIN	−**0.1183** (3.3462)	−**0.1183** (3.1067)	−**0.1119** (2.4953)
λ			**0.4239** (7.6757)
Adjusted R^{2b}	0.6739		0.6811
Multicollinearity condition number	2.7361		
Jarque–Bera test on normality	0.1738		
P-value	0.9167		
Breusch–Pagan test for heteroskedasticity	26.0762		
P-value	0.0253		

[a] Parameter estimates in bold indicate significance at 5% level for a two-tailed test.
[b] The R^2 reported for the spatial error model is the squared correlation between the predicted values and the actual values of the dependent variable.

5.2. (Industrial) facility characteristics

Having chosen a ‘‘base’’ set of property characteristics, combinations of facility variables were added to the hedonic model to arrive at the results presented in Table 4. The property variables in Table 3 were included in these models but since the associated coefficients are not substantially different when facility characteristics are included, the coefficients for these variables are not reported.

The combinations of facility characteristics in each model in Table 4 were chosen based upon consideration of the correlations among the facility variables and whether the combinations represented perceived hazard or amenity effects. The significant Moran's *I*-statistics lend support to consideration of spatial dependencies. Thus, all of these models were spatially adjusted. While both spatial tests were employed, regression diagnostics continued to suggest that when industry characteristics were added, spatial error effects were present in the data as shown by the LM tests and their robust counterparts reported in the bottom of Table 4. In each case, the tests suggest that the spatial error specification be chosen over the spatial lag because the associated LM statistics for the spatial error models were larger and more statistically significant than those from the spatial lag models. The significant Kelejian–Robinson statistics also lend support to the use of spatial error specification. The superiority of the spatial error model holds across all of the hazard and amenity specifications reported below.

Table 4
Spatial error hedonic models for the effects of oil and gas facilities on property prices[a]

Industry variables	Hazard H1 (*t*-ratio)	Hazard H2 (*t*-ratio)	Amenity A1 (*t*-ratio)	Amenity A2 (*t*-ratio)
ln(EPZINDEX)	−**0.0182**[b] (2.5483)			
ln(BATINDEX)	−**0.0113** (2.6011)			
ln(NEAREST)	−0.0036 (0.1560)			
ln(FLARING)		−**0.0541** (2.6715)		
ln(NEPZWELL)		−0.0253 (1.5327)		
ln(NEPZPIPE)		−**0.0319** (2.9037)		
ln(SOURWELL)			−**0.0311** (3.2963)	
ln(SWEETWELL)			−0.0181 (1.5930)	
ln(ALLWELL)				−**0.0410** (3.6722)
ln(ALLPIPE)				0.0104 (1.0933)
λ	**0.3889** (6.7782)	**0.3920** (6.8531)	**0.3577** (6.0409)	**0.3655** (6.2195)
R^2 (Buse)[c]	0.9672	0.9678	0.9613	0.9629
Moran's *I*-test	7.3166	7.7614	6.8661	7.0791
P-value	[0.0000]	[0.0000]	[0.0000]	[0.0000]
LM test (error)	43.5302	49.3745	38.7233	41.3565
P-value	[0.0000]	[0.0000]	[0.0000]	[0.0000]
Robust LM test (error)	42.2604	47.9214	37.5261	39.9373
P-value	[0.0000]	[0.0000]	[0.0000]	[0.0000]
Kelejian–Robinson (error)	121.2155	162.6337	190.1173	208.3861
P-value	[0.0000]	[0.0000]	[0.0000]	[0.0000]
LM test (lag)	4.6055	5.0801	4.6081	5.9726
P-value	[0.0318]	[0.0242]	[0.0318]	[0.0145]
Robust LM test (lag)	3.3357	3.6274	3.4109	4.5534
P-value	[0.0678]	[0.0568]	[0.0648]	[0.0329]

[a] Not reported in this table are the coefficients for the property characteristics found in Table 3 that were also included in each estimated model.
[b] Parameter estimates in bold indicate significance at 5% level for a two-tailed test.
[c] The R^2 reported for the spatial error model is the adjusted R^2 measure adjusted for non-spherical errors (Buse, 1973).

Additional specification tests were conducted on the oil and gas facility models and the results are reported in Table 5. First, LM tests devised by Baltagi and Li (2001) were conducted to simultaneously test for functional form and spatial error. The log–log specification in the presence of spatial errors was supported by the insignificance of the test results (Table 5). Second, the problem of heteroskedasticity was examined using Breusch–Pagan tests. The resulting statistics suggest that this problem may be present, but none of the statistics were significant at the 5% level. The statistic for the H1 model exhibited the level of significance closest to the 5% level.

Hazard model H1 in Table 4 includes the EPZINDEX for wells and pipelines, the annual volume of gas flared from neighbouring batteries (BATINDEX), and the distance to the nearest operating sour gas plant (NEAREST). Both the EPZINDEX and the BATINDEX

Table 5
Specification tests for spatial error hedonic models for the effects of oil and gas facilities on property prices

	Models			
	H1	H2	A1	A2
Test for log–log model and spatial error				
LM test[a]	0.2544	0.6851	0.5825	0.4497
P-value	[0.6139]	[0.4078]	[0.4453]	[0.5024]
Test for heteroskedasticity				
Spatial Breusch–Pagan test	26.4089	24.9566	22.6888	23.5729
P-value	[0.0673]	[0.0956]	[0.1223]	[0.0992]

[a] LM tests from Baltagi and Li (2001) were used to test the null of double log model conditional on the presence of spatial error structure.

parameters were negative and statistically significant, while NEAREST has a negative influence on property value as expected, but was statistically insignificant. The insignificance of the NEAREST coefficient may be partly due to the relatively high, −0.51, correlation with EPZINDEX and the fact that observations nearby plants, and so most likely affected, will also be in EPZ areas. Hazard model H2 included the number of well and pipe EPZs affecting the property (NEPZWELL and NEPZPIPE) and the number of flaring batteries within 4 km (FLARING). All three parameters were negative and those for NEPZPIPE and FLARING are significant, suggesting that these facilities lowered property prices consistent with expectations. The number of well EPZs was statistically insignificant, however, which may be explained by the small number of properties (98) in the sample affected by well EPZs (Table 2).

The amenity models concentrated on the number and proximity of facilities rather than their sour gas content. The numbers of sour and sweet wells within 4 km of each property (SOURWELL and SWEETWELL) were incorporated into amenity model A1. Pipelines, which are less conspicuous, were ignored. The coefficients of both the well variables are negative but that for the number of sour wells was significant at the 5% level while that for the number of sweet wells significant only at the 15% level. The marginal effect of the sour wells on prices is almost twice the size of that from the sweet wells. Because one cannot disentangle the hazard effect of the sour wells from their amenity impact, one should expect a larger impact for the sour wells. Amenity model A2 divided facilities into the total number of wells (both sour and sweet together, ALLWELL) and the total number of sour pipelines (ALLPIPE). (Recall that we have no data on pipelines not carrying sour gas.) The results suggest that it is the total numbers of wells but not the number of sour pipelines that have significant negative impacts on property prices.

A variety of unreported models were also estimated. The general pattern of the results in these is similar to those described above, but some outcomes merit noting. In numerous cases (various specifications and with some variations in the data), the coefficients for sweet and sour wells were both significantly negative. Also, the coefficient for the sweet wells was typically less than or, at most, equal to that for sour wells suggesting an added penalty for sour wells. An effort was made to assess proximity to wells by distinguishing

Table 6
Marginal and mean effects of the presence of oil and gas facility variables on the average property price

Facility variable	Mean level of the variable in the sample (S.D.)	Price effect from 0 to the first unit of the variable	Price effect from 0 to the mean level of the variable	Marginal effect at the mean level of the variable
EPZINDEX**	6.83 (12.29)	−3647.61	−10698.29 (−15470.56)[a]	−676.10 (−263.13)
BATINDEX**	49.91 (246.83)	−2271.38	−12645.85 (−18147.92)	−64.62 (−11.05)
NEAREST	16.73 (7.01)	−717.42	−2904.84 (−3263.85)	−61.94 (−43.86)
FLARING**	0.31 (0.85)	−10702.70	−4174.46 (−11867.57)	−12042.53 (−7282.91)
NEPZWELL	0.61 (2.06)	−5044.35	−3487.41 (−9389.53)	−4552.22 (−2000.53)
NEPZPIPE**	1.25 (2.03)	−6350.31	−7399.44 (−13152.57)	−4124.28 (−2166.31)
SOURWELL**	1.94 (3.43)	−6206.40	−12805.28 (−17881.68)	−2129.64 (−1177.98)
SWEETWELL	3.25 (3.43)	−3621.51	−5614.59 (−9570.23)	−1788.38 (−825.92)
ALLWELL**	5.19 (4.98)	−8148.20	−20942.20 (−27394.35)	−1926.27 (−1067.51)
ALLPIPE	11.31 (9.22)	2110.78	7718.81 (9465.22)	246.40 (140.88)

(**) Refers to the whether the facility variable is significant at the 5% level.
[a] All effects are reported in 2001 Canadian dollars. Numbers in parentheses for the effects refer to the effect with one standard deviation added.

those in successive one kilometre concentric rings on the property (i.e., less than 1 km, 1–2 km, etc., up to 4 km) and employing econometric procedures similar to those used by Palmquist et al. (1997) in their analysis of the effect of hog operations on property values.[10] Other than revealing that wells within one kilometre had the greatest impact on price, the other coefficients did not demonstrate a consistently diminishing effect. Information on whether facilities predated our study period or were built after 1993 provided some interesting insights. The age of wells did not matter. However, ‘‘new’’ post-1993 pipelines typically had a significant negative effect on price; perhaps because the disruption of their construction was still more clearly visible.

5.3. The marginal impacts of industry facilities

Table 6 presents the marginal sale price effects of the oil and gas facility characteristics on the price of the average property in the database in a number of different ways. First, the marginal effect from 0 to 1 represents the impact of the introduction of the first unit of a typical facility on the price of the average property. Second, the mean level effect refers to the effects of the presence of facilities at the average level for that facility type in the sample. Finally, the marginal effect at the variable mean refers to the impact of an additional unit of a facility given that the average property already is impacted by existing facilities of the type under consideration. To demonstrate the pattern over a broader range, the price and marginal effects are also presented at the mean plus one standard deviation.

The price effects in Table 6 indicate that proximity to and H_2S volumes of EPZs and gas flaring batteries as measured by the two index variables EPZINDEX and BATINDEX have significant negative effects on property values. EPZINDEX, which refers to a weighted sum of all EPZ sizes overlaying properties, has a first unit effect of −$3647.61 and a total

[10] Because our data did not include facilities beyond 4 km from a property, it was not possible to explore for potential impacts of more distant facilities.

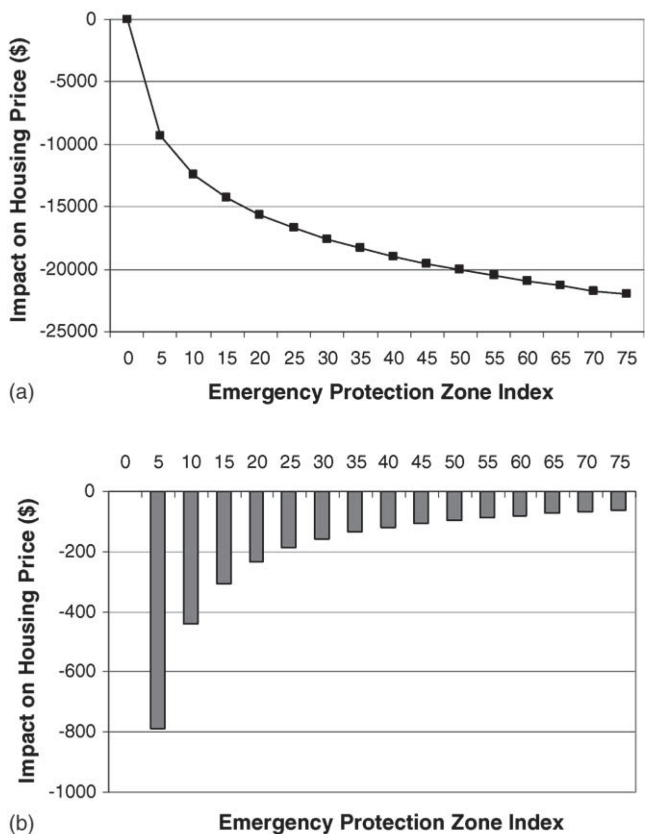

Fig. 2. The effects of increasing the exposure of rural residential properties to sour gas hazards as measured by the emergency planning zones index (EPZINDEX); (a) presents the cumulative effects of additions to the index and (b) presents the marginal effects of increases in the index.

effect at its mean level (6.83) of −$10,698.29 or approximately 3.8% of the value of the average property. The marginal effect on price declines from −$3647.61 to −$676.10 at the mean and to −$263.13 at the mean plus one standard deviation level (19.12). Fig. 2 illustrates further the diminishing effect of additional increments to the EPZINDEX. Fig. 2a shows the total effect on price of the average property as EPZINDEX levels increase and Fig. 2b shows the marginal values at the different levels. A similar conclusion can be made for the flaring battery index (BATINDEX, which represents the weighted sum of the annual volume of flared solution gas in units of m^3) and for which a similar pattern is found. The impact of the first unit is −$2271.38, the mean level effect is −$12,645.85 (which is a decline of approximately 4.3% of the average price) and the marginal value at the mean is −$64.62.

Hazard model H2 gives results similar to those of the two indices reported above. The presence of the first flaring battery within 4 km (FLARING) causes a decline of −$10,702.70 in price. This is the highest first-unit marginal value among the 10 facility variables examined in Table 6. At the mean plus one standard deviation value for

FLARING (1.16 batteries), the total level impact is −\$11,867 and the marginal effect is −\$7283. The number of pipeline EPZs (NEPZPIPE) has a first-unit effect on value of −\$6,350.31 and the price effect at the mean level (1.25 EPZs) is −\$7399. At the mean level, the marginal impact declines to −\$4124. Both hazard models indicate that the presence of oil and gas facilities cause significant negative effects on property values in proximity to the facilities examined.

Turning to the amenity variables, the marginal effects of the presence of wells on price are similarly negative. Sour wells (SOURWELL) have a much higher impact than sweet wells (and recall that the sweet well parameter was significant at the 15% level only). However, the combined effects of both sour and sweet wells (ALLWELL) are also negative and larger in magnitude (Table 4). Introduction of a sour gas well reduces price by \$6206 while the reduction at the mean of 1.94 wells amounts to \$12,805 and the reduction when the number is increased to the mean plus one standard deviation (5.37 wells) is \$17,882. The marginal effects of adding sour wells drops rapidly, from −\$6206 for the first well, to −\$2129.64 at the mean number of wells, and to −\$1178 at the mean plus one S.D. of 5.37 wells. These effects are illustrated further in Fig. 3a and b. The combined effects of both

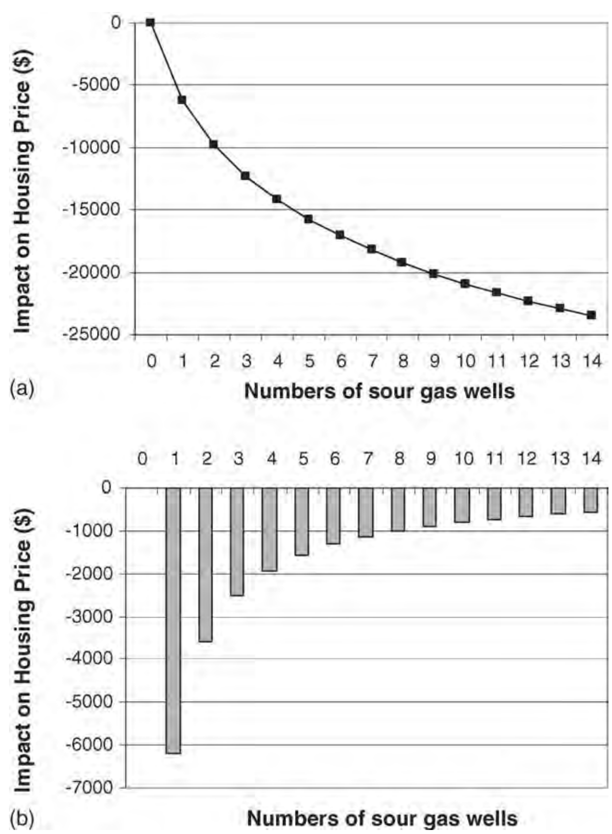

Fig. 3. The effects of increasing the number of sour gas wells within 4 km on the average prices of rural residential properties in Alberta; (a) presents the cumulative effects of additional wells and (b) presents the marginal effects.

sour and sweet wells are also negative. The total number of wells (ALLWELL) is more influential with a first-unit effect of −\$8148.20 and a mean effect (at 5.19 wells) of −\$20,942.20, representing approximately 7% of average property value.

One can employ the amenity model parameters to make some estimates of the hazard effect of wells with H_2S present independent of the amenity effects. Sour wells have both an amenity impact and a hazard impact while sweet wells likely have only an amenity effect on property values. While the magnitude of the hazard is not measured by the SOURWELL variable, these wells are known to have H_2S present and so present some health risk. Similarly, ALLWELL has a sour well component and thus some associated risk. Accepting the SWEETWELL parameter estimate as a valid approximation of the magnitude of the impact of the presence of H_2S risk-free wells on property prices even if significant at only the 15 percent level, allows attribution of the difference between that and the sour well effect caused by the presence of H_2S. For example, the first sweet well reduces the average property's value by \$3621 while the first sour well reduces the value by \$6206. These amounts imply an extra cost to the sour gas well of \$2585. The ALLWELL parameter implies a somewhat higher cost per well; \$8148 for the first well, which would be a combination (0.373:0.626) sweet to sour. Extrapolating from this estimate, the extra cost of the initial well being sour as opposed to sweet is \$4006. At the mean number of 5.19 wells, if all were sour, the market value of the average property would be reduced by \$14,507 while, if all those wells were sweet wells, the reduction would be \$8533. The extra effect of the sour gas is \$5974. Similarly, if the ALLWELL parameter is used, the estimate of the additional impact on price due to the presence of sour gas is \$9359. Hence, it appears that property buyers discount properties neighbouring oil and gas wells and even when relying upon variables that do not account specifically for health hazards, it appears that they discount more heavily those posing a health hazard due to sour gas.

6. Conclusions

The results of this analysis strongly suggest that the presence of oil and gas facilities can have significant negative impacts on the values of neighbouring rural residential properties. These results contrast with those of earlier consulting reports addressing this question in the Alberta context. However, given the relatively extensive (though admittedly not ideal) data and the use of current methodologies—specifically, a double log hedonic model with spatial error adjustment—plus the reasonableness of the magnitudes and behaviour of the estimates, we have confidence in the outcomes presented.

Measures of both hazard and (dis)amenity attributes were found to have negative effects on property values. Hazard characteristics included either volume of hazardous gas indexes or number of hazardous zones measures. Measures of both types had significant coefficients. Number of wells measures or the number of wells and pipelines were variables in the amenity models. The presence of wells, especially sour gas wells, was found to depress property values but the number of pipelines carrying sour gas variable did not have a significant coefficient. At the mean level of industry facilities within 4 km, property values are estimated to be reduced between 4 and 8 percent. The impact can easily be twice that depending upon the level and composition of the nearby industry activities—for example, if all the wells in the 4-km zone were sour gas wells rather than the typical mix of sour gas and other wells.

To our knowledge, this is the first academic study of the implications of oil and gas production facilities upon property values. While, naturally, the results must be considered with some caution (and await further investigation to confirm, refine or refute), they are broadly consistent with studies of the impacts of other industries having potentially detrimental influences on the use and enjoyment of property. As such, we believe the impacts implied by this analysis and the estimates derived will be of interest to and potentially valuable to residents, firms, the oil and gas industry and regulators. For example, the estimates indicate that there are negative economic consequences related to proximity to certain (but not all) types of industry facilities and this evidence may help all to better understand the economic reasons underlying concerns and disagreements. In addition, this work may assist all the players in making better site decisions and regulators, in particular, in mediating disputes and in assessing the merits for compensation should a facility be introduced near existing rural residential property.

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Appendix A

Marginal price effects of the property attributes

Name	Mean	S.D.	Minimum	Maximum	Marginal values at mean	95%C.I. upperbound[a]	95%C.I. lowerbound[a]
AGE**	10.48	7.94	1.00	99.00	−514.27	−106.75	−921.80
AREA**	176.31	63.06	73.10	546.20	579.87	649.77	509.98
BED**	2.91	0.84	1.00	8.00	−7633.09	−4024.65	−11241.52
BATHS**	2.25	0.75	1.00	7.00	9591.16	13823.27	5359.05
NOBASEMENT	0.02	0.15	0.00	1.00	−15376.16		
DECK**	0.67	0.47	0.00	1.00	8602.33		
GARAGE**	2.18	1.09	0.00	6.00	7342.97	9850.44	4835.49
ACRES**	7.15	6.44	1.00	40.00	3727.00	4446.80	3007.21
VMTN**	0.40	0.49	0.00	1.00	8017.92		
MUNWTR**	0.02	0.13	0.00	1.00	27481.89		
CALGARY**	31.07	12.23	9.40	72.20	−1621.48	−1079.12	−2163.84
RAVP**	136519.7	9478.3	118126.9	153993.2	2.03	2.37	1.69
ROCKY**	0.37	0.48	0.00	1.00	−28578.85		
MOUNTAIN**	0.05	0.21	0.00	1.00	−32507.57		

(*) Refers to 10% significance and (**) refers to 5% significance.

[a] Refer to the confidence limits of the mean of the property attribute.

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Is the Shale Energy Boom a Bust for Nearby Residents? Evidence from Housing Values in Pennsylvania

Sathya Gopalakrishnan and H. Allen Klaiber

Profitable extraction of previously inaccessible shale energy reserves has led to the rapid expansion of shale exploration across the United States. We present one of the first empirical studies to measure the impact of early shale exploration on surrounding homeowners using data from Washington County, Pennsylvania, from 2008 to mid 2010. We find that property values are negatively impacted by shale gas exploration activity, but this impact depends on the proximity and intensity of shale activity and is largely transitory. The negative effects are larger for households located close to major highways and sourced with private well water.

Key words: hedonic, housing values, risk, shale gas.

JEL codes: Q33, Q40, Q51, Q53.

Exploration of previously inaccessible sources of energy contained in U.S. shale deposits has the potential to fundamentally change the energy makeup and outlook for the national as well as the global economy. Unlike traditional sources of shale exploration that date back to the 1800s, the recent enthusiasm surrounding shale energy is largely a result of technological advancements that have enabled the profitable extraction of subsurface shale resources. Beginning in 2005 with exploration of the Barnett Shale in Texas, innovations in the use of horizontal drilling and hydrofracturing techniques have ushered in a rapid expansion of shale gas exploration across the United States. In the Northeast United States, extraction of Marcellus Shale gas began in Pennsylvania during the mid 2000s and quickly expanded in the following years (Pennsylvania Department of Environmental Protection, http://www.depweb.state.pa.us).

The U.S Geological Survey estimates that Marcellus Shale alone contains over 84 trillion cubic feet of undiscovered gas deposits (http://energy.usgs.gov). Exploration and development of the natural gas reserves contained in the Marcellus and Utica Shale deposits in Ohio, Pennsylvania, West Virginia, and New York is progressing rapidly and providing substantial private benefits to landowners, with typical lease payments upwards of $6,000 per acre, and royalty payments near 20% (Downing 2013). While the private benefits to landowners and the potential for enhancing state revenues arising from them has resulted in much enthusiasm, there is very little information about the potential private and public costs associated with shale exploration. In particular, the real and perceived environmental impacts associated with drilling techniques required to access this resource is a growing concern, especially among nearby residents.

In the Marcellus Shale region of Pennsylvania, viable deposits of shale gas often occur at depths of one mile or deeper. The use of hydraulic fracturing and horizontal drilling have enabled profitable exploration of this resource, although their use has created considerable controversy stemming from perceived environmental and health risks. The process of fracturing shale and

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releasing natural gas to the surface uses large volumes of water, often between 2 million and 8 million gallons per well, mixed with additional chemicals that are forced into a well under pressure to create fissures that allow natural gas to flow out of the dense shale. A byproduct of the hydraulic fracturing process is the generation of wastewater to the surface of between 10% and 40% of the total water volume used in the process. This water is often laden with heavy metals, salts, hydrofracturing chemicals and other contaminants that pose a serious environmental and health risk if not contained and disposed of properly (Abdalla et al. 2012). Furthermore, concerns over methane leaching into surrounding water supplies and potential health risks associated with nearby water quality have been raised in both the mass media ("Gasland") and academic research (Osborn et al. 2011; Warner et al. 2012).

Shale exploration is likely to produce both winners and losers in a community.[1] Thus, reliable estimates of the economic impacts on surrounding landowners are a necessary first step to better understand the economic impacts of this activity. Potential winners include subsurface mineral rights owners and communities that may benefit from increased tax revenues and the provision of public goods or infrastructure by local authorities. Potential losers include residents who detect or perceive environmental and water quality risks associated with shale gas exploration, or experience more proximate negative impacts in the form of increased noise, traffic, or nighttime lighting (NYSDEC 2011). These negative effects are likely to vary spatially and temporally. We hypothesize that these impacts depend on the proximity of households to gas drilling activity.

In this article we measure the impact of early shale exploration on surrounding homeowners using a Box-Cox hedonic pricing framework for the real estate market of single-family residential homes in Washington County, Pennsylvania. This county typifies the public debate over shale exploration and perceived environmental and health risks. Indeed, many areas of the county have a high density of residents in close proximity to recent Marcellus Shale exploration activity, making it an ideal location to study the impacts of shale exploration on surrounding property values. Over time, this resource boom is likely to result in increased local and state revenues through income and property taxes, as well as direct income to large landowners who have leased land to the oil and gas companies. Our focus on the early stages of activity is intended to limit the potential for positive externalities that could confound econometric estimates.

We find evidence that households are negatively impacted by shale gas exploration activity, although this impact depends on the proximity and intensity of shale activity and diminishes over time, coinciding with the cessation of exploration activity. In particular, shale activity disproportionately impacts households that rely on well water, are located close to major highways, or are located in more agricultural areas. Our analysis shows that households that rely on well water and are located within 0.75 miles of an active well site for which the drilling permit was acquired within 6 months experience a decrease in home values of 21.7%. This large impact mirrors similar findings by Muehlenbachs, Spiller, and Timmins (2012), who find a large negative property value impact of −24% for households sourcing well water. However, we find that this large effect attenuates rapidly, falling to −5.6% at a distance of 1 mile. In both our study and the Muehlenbachs, Spiller, and Timmins (2012) study, a comprehensive database on leased land is unavailable. This suggests that our results potentially include likely "winners" who own and may have leased subsurface mineral rights. To the extent we are unable to isolate these effects, the magnitude of any negative effects we find are likely to be understated and could be viewed as an upper bound.[2]

As shale gas exploration continues to expand, understanding the potential for expansion and the associated impacts on surrounding populations will be a key component of effective policy formulation. To shed light on these issues, we proceed as follows. The next section briefly describes the study setting and shale exploration process

[1] Losers in this context could be residents who are relatively worse off than their surrounding neighbors even when everyone in an area experiences gains. We leave this larger, regional characterization of winners and losers for future research.

[2] The positive effects of leasing would be unlikely to show up in property values if the subsurface mineral rights do not transfer with the sale of property, which should limit this concern. Unfortunately, a comprehensive data set for subsurface mineral rights is not available to explore this issue further.

underlying our identification strategy. Section three discusses the Box-Cox hedonic framework we employ in estimating the impact of shale exploration on nearby housing values. The fourth section describes the data and Marcellus Shale activity in our study area. The fifth section presents results from our econometric analysis, and the sixth section concludes with a discussion of potential policy recommendations.

Shale Exploration and Identification Strategy

It is well established that land and housing markets respond to changes in environmental conditions, with prices adjusting to reflect differences in environmental quality and amenities across space. Since the introduction of the hedonic pricing method by Rosen (1974), hedonic models have become one of the most common tools used by economists to estimate the value (cost) of environmental (dis-)amenities that are capitalized in property values. The hedonic price function decomposes the value of a residential property, itself a bundle of many individual attributes, into housing characteristics that include: property characteristics such as lot size, number of bedrooms and bathrooms, the age of the property, and type of construction; neighborhood characteristics such as quality of the school district, crime rate, and proximity to city services; environmental amenities such as air or water quality (Leggett and Bockstael 2000), amount and quality of open space nearby (Abbott and Klaiber 2011), proximity to beaches and beach quality (Gopalakrishnan et al. 2011); and lastly, disamenities such as proximity to industrial waste disposal (Smith and Desvousges 1986) or agricultural activity (Ready and Abdalla 2005).

Credible identification of the impact of an environmental attribute of concern depends on the ability to control for unobservable factors that may confound the estimates of the treatment effect in a quasi-experimental setting (Kuminoff, Parmeter, and Pope 2010). For example, in our current study we might be concerned about whether potential buyers perceived the presence of shale activity prior to purchasing the home. In what follows, we briefly describe the setting in which buyers and sellers operate before turning our attention to our econometric specification.

Shale exploration activity begins when a shale gas company acquires subsurface mineral rights from a landowner. When horizontal drilling techniques are employed, a typical well pad can hold up to 8 individual wells, extending at least 1 mile underground in each direction. Prior to drilling, mineral rights must be acquired from all owners of the land that a well passes through. Pennsylvania code 58 P.S. § 601.201 requires that drilling operators "must send notice of drilling to the owner of the surface estate upon which drilling is to occur and to surface landowners or water purveyors who have water supplies within 1,000 feet of the proposed well location." This ensures that current owners are aware of pending activity surrounding their property, even if they are not involved in the leasing activities.

After securing leases for all land on which drilling operations are to occur, either at the surface or subsurface in the case of horizontal wells, companies must obtain drilling permits, usually from a state environmental agency, which in Pennsylvania are priced by wellbore length and typically cost under $5,000.[3,4] At this stage, on-site preparations begin, which include constructing or improving access roads, constructing a well pad to hold equipment, assembling retention ponds for water needed for hydraulic fracturing, and ultimately erecting a drilling rig. The final steps include drilling operations, hydraulic fracturing, and ultimately reclaiming the well pad area after the cessation of drilling activities.

To identify shale related impacts on housing values, it is paramount to establish that prospective buyers and sellers were likely aware of pending and ongoing shale activity (Pope 2008). To highlight public awareness of Marcellus Shale activity more generally, a LexisNexis search of "Marcellus Shale" spanning the years 2008 through 2010 found that the two largest newspapers in the Pittsburgh region, the *Pittsburgh Post-Gazette* and *Pittsburgh Tribune-Review*, ran a combined 1,246 articles covering shale-related topics. This high level of visibility in public media is reflective of the widespread interest and awareness of the growing shale exploration

[3] For an example of a lease template in use in the neighboring state of OH and common to the area, please see: http://ohioline.osu.edu/als-fact/pdf/Leasing_Farmland_Oil_Gas.pdf.

[4] Please see: http://www.elibrary.dep.state.pa.us/dsweb/Get/Document-87960/8000-PM-OOGM0001%20Instructions.pdf.

activities in the area. For prospective homebuyers, we hypothesize that awareness of more proximate shale exploration is likely to occur through one of four mechanisms that we detail below.

First, the Pennsylvania Department of Environmental Protection (PA DEP) maintains an online database of locations of shale wells permitted and drilled, which can be accessed by potential homebuyers to determine proximity to wells. Such information is also highlighted in the popular press to increase awareness about ongoing and potential shale activity.[5,6] Second, prior to and during exploration activity, truck traffic in the area is likely to be greatly increased. It is estimated that a horizontal well experiences an average of 230 one-way heavy truck trips, and an additional 230 one-way light truck trips prior to actual drilling (spud date), and an average of 1,145 one-way heavy truck trips and 830 one-way light truck trips by the completion of activity (NYSDCE 2011). A survey of Pennsylvania residents in October 2009 reported that 63% of respondents in areas with high drilling activity reported significantly increased traffic and congestion associated with trucks, compared to just 12% in less impacted areas (Schafft and Glenna 2012).

In addition to truck traffic, the third "visible" aspect of shale exploration is an increase in the associated noise likely to alert existing and prospective homebuyers of nearby activity. Studying various stages of the shale exploration process, NYSDCE found noise levels of 58 decibels at 1,000 feet and 52 decibels at 2,000 feet, the furthest extent reported, during the well pad construction period compared to baseline ambient rural noise levels of approximately 30 decibels at night. During the horizontal well drilling period, which occurs 24 hours a day, decibel levels were 50 and 44 at 1,000 feet and 2,000 feet, respectively. During the fracturing process decibel levels were 78 and 72 at the 1,000 and 2,000-foot range, respectively. Overall, this suggests that in many rural areas the noise associated with shale exploration would be readily apparent up to at least half a mile from an active well pad.

Finally, the visibility of an oil and gas rig is likely to indicate nearby activity, even in the relatively hilly and forested areas of Washington County, Pennsylvania. With heights of up to 150 feet (NYSDCE), drilling rigs are likely to be seen from long distances. Upadhyay and Bu (2010) explore this issue in Bradford County, Pennsylvania, which is similar in terms of hilly and wooded landscape to Washington County, and report good visibility in many cases of up to 1 mile from the well site. These authors also note that the use of horizontally placed lighting at night makes distant sights more visible, particularly in relatively dark rural areas. Taken together, the combination of these measures of visibility to potential homebuyers suggests that this activity is readily apparent if located within 1 mile of a well site during the site preparation and drilling operations stage of exploration.

Hedonic Framework

The hedonic framework represents an individual's utility as a concave function of a bundle of attributes that are capitalized in property values and a composite numeraire commodity:

$$U_{ij}^{k} = U(c, X_i, N_j, Z_{ij}, \alpha^k). \quad (1)$$

Households are assumed to have different preferences, α^k, with the utility of an individual, k, choosing house i in neighborhood j dependent on characteristics of the property (X_i), neighborhood, or location specific characteristics (N_j), environmental attributes that can vary by home and neighborhood (Z_{ij}), and a composite numeraire commodity (c). Households maximize utility subject to a budget constraint and bid prices up or down until an equilibrium price schedule is obtained as a function of preferences, housing, and location attributes as given by:

$$P_{ij} = P_{ij}(\beta, X_i, N_j, Z_{ij}). \quad (2)$$

To estimate the model econometrically, researchers must specify a functional form for equation (2) and assume an error structure. We use a Box-Cox regression to determine the appropriate transformation for the dependent variable—house sale price—as that has been shown to improve the performance of hedonic specifications when combined with spatial fixed effects

[5] Please see: http://www.dep.state.pa.us/dep/deputate/minres/oilgas/2011PermitDrilledmaps.htm.

[6] Please see: http://www.lockhaven.com/page/content.detail/id/525813/Finding-Marcellus-drilling-permits–wells-and-production-information.html?nav=5003.

(Kuminoff, Parmeter, and Pope 2010). The general Box-Cox functional form is given by:

$$(3)\qquad \frac{P_{ij}^{\theta}-1}{\theta}=\beta_0+\beta_1 X_i+\gamma Z_{ij} + \delta_{jt}(N_j * T_t)+\varepsilon_{ij}$$

where θ is the transform parameter, and explanatory variables include property characteristics such as number of rooms, number of stories, built-up area (sq ft.), age of the property, presence of a garage, pool, distance to Pittsburgh, and distance to the nearest road. To distinguish the impact of shale exploration from other confounding unobserved factors that are specific to the area, we include location by sale-year fixed effects ($N_j * T_t$) at the level of municipalities, which correspond closely to census tracts in our study area.[7]

Recent advances in the hedonic method for estimating environmental values have focused on spatial and temporal variation in environmental amenities, and therefore the need to control for the spatial and temporal extent of capitalization of these values (Kuminoff, Parmeter, and Pope 2010). Previous studies have separately explored the spatial extents of capitalization of environmental and land use characteristics (Geoghegan, Waigner, and Bockstael 1997; Paterson and Boyle 2002; Anderson and West 2006; Abbott and Klaiber 2010), and timing of sales relative to the introduction of a hazardous waste site (Michaels and Smith 1990). When considering the impact of shale activity, including spatial-temporal fixed effects enables us to control for unobservable factors that affect housing values within each municipality and sale-year combination. Allowing unobservables to differ from year to year within each municipality ensures that identification of effects associated with shale exploration is not driven by changes in baseline conditions over time that are common across a municipality. Identification comes from differences in shale activity around houses in a municipality sold during the same year (represented by Z_{ij}). Figure 1 provides a map of transactions and municipalities in our study area.

A challenge facing this analysis is that shale exploration is relatively recent and was not widespread until early 2008. In exploring this early effect we are limited by the number of shale gas wells and the small sample of residential properties in close proximity to shale development. In addition, differences in the intensity of development across well pads are important to consider because a single well pad may contain 8 or more horizontal wells due to horizontal drilling (Abdalla et al. 2012). It is likely that the impact of shale activity depends on both the proximity to the drilling site and the intensity of the surrounding activity, as increasing numbers of wells increases the visibility and potential environmental risk to prospective buyers. We therefore include the number of horizontal shale wells within specific distance bands and time windows around each property sale as an explanatory variable. In the hedonic price function, the coefficient γ_1 represents the marginal impact of an additional shale well within a given distance buffer and time window on property values. Box-Cox estimation results shown in table 4 indicate that a square root transformation is most appropriate given our data as revealed by the estimated transformation coefficient of 0.4843. As such, we estimate conditional regressions assuming a transformation coefficient of $\theta = 0.5$ for all subsequent results.[8] Marginal willingness to pay measures associated with shale exploration for the average homeowner in our sample are calculated as:

$$(4)\qquad MWTP(Z_{ij})=\frac{\partial P_{ij}}{\partial Z_{ij}}=\sqrt{\bar{P}}\hat{\gamma}.$$

Data

Marcellus Shale gas exploration began in Southwestern Pennsylvania during the mid 2000s and rapidly expanded by the end of the decade (PA DEP, http://www.depweb.state.pa.us). We use data from Washington County, which is south of Pittsburgh, and exploit the close proximity of housing transactions to shale activity for econometric identification in our analysis (figure 1). In the examined area, widespread shale activity

[7] For robustness, we also conducted the analysis using block-group by sale-year fixed effects, and report those in the appendix. In our study area we observed transactions in 59 census tracks, 63 municipalities, and 162 block groups from 2008 through 2010.

[8] For comparison, we also estimated semi-log models that assume a transformation of theta = 0, a common functional form used in the literature, and found qualitatively similar results.

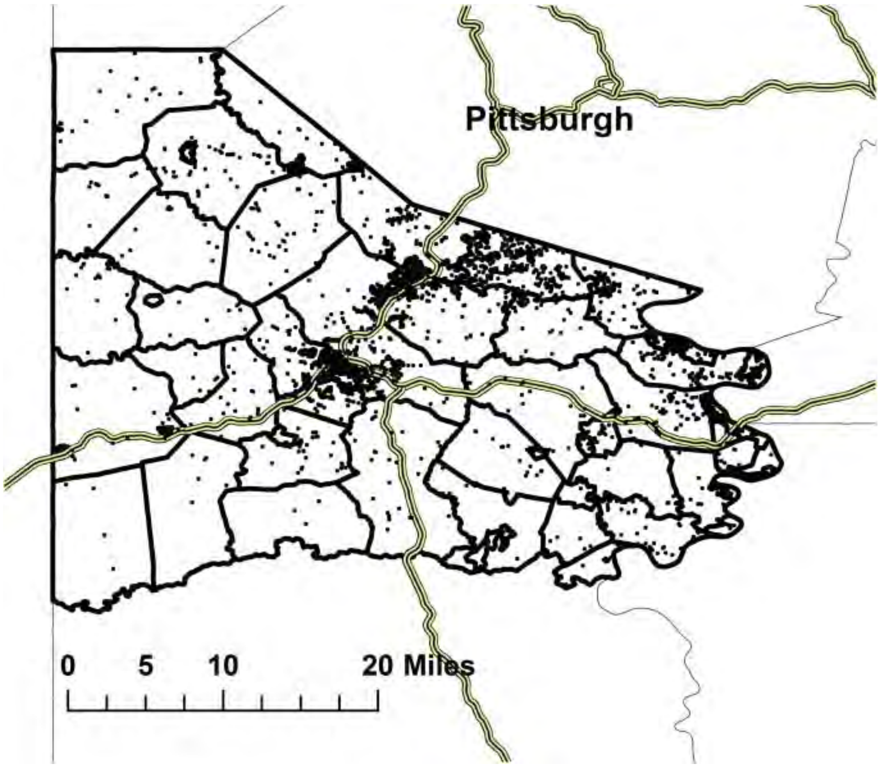

Figure 1. Study area with municipal boundaries and transactions (dots) (for color, please see figure online)

began in 2008, with much of this activity located near residential homes. Our econometric specification requires data on housing transactions, well locations and timing, surrounding land use, as well as additional controls for source of water and municipalities. The following sub-sections describe each of these components.

Housing Transactions

Housing transactions data were purchased from Dataquick, a private data vendor, and spanned January 2008 through October 2010. Unlike much of the country, the Pittsburgh metro area experienced relatively stable prices over this time period. The metro level housing price index was 1.249 in the first quarter of 2008 and rose slightly to 1.299 by the end of 2010 (Davis and Palumbo 2007).[9] The transactions dataset contains a complete set of housing characteristics, sales prices, and sales dates, as well as location and address information for each transaction. Structural characteristics include square footage, lot size, bedrooms, baths, stories, year built, presence of a garage, presence of a fireplace, and presence of a pool. After removing non-arm's length transactions and data with missing attributes or extreme outliers for structural characteristics, our sample consisted of 4,128 housing transactions.

To locate these properties in space, we used the address information included in the transactions data that consisted of street number, street name, municipality, and zip code to geocode each transaction using the publicly available Yahoo geocoding engine.[10] After eliminating 189 transactions that were unable to be geocoded and an additional 293 transactions that were poorly geocoded, that is, did not match street names or addresses and fell outside of the reported zip code in

[9] Their MSA-level data series is updated and maintained at: http://www.lincolninst.edu/subcenters/land-values/metro-area-land-prices.asp.

[10] For comparison, we also used Google's online geocoding tool, which revealed a median difference in location of 125 feet. This difference is largely explained by Yahoo! locating properties at streets, while Google attempts to locate them at parcel centroids. Further manual inspection revealed several large outliers in the Google results, where zip codes were not matched correctly. Yahoo! employs a hierarchical match, which ensures that zip codes match for all of our transactions.

Table 1. Summary Statistics ($N = 3,646$)

Variable	Mean	Std. Dev.	Min.	Max.
Sale price	148,401	117,683	10,150	1,812,812
Square feet (100s)	16.59	7.19	4.52	72.09
Lot size (acres)	0.61	1.10	0.03	28.68
Bedrooms	2.96	0.81	1.00	9.00
Bathrooms	1.68	0.77	1.00	9.00
Stories	1.82	0.88	1.00	5.00
Age	54.38	33.82	1.00	239.00
Garage (0/1)	0.79	0.41	0.00	1.00
Fireplace (0/1)	0.35	0.48	0.00	1.00
Pool (0/1)	0.02	0.13	0.00	1.00
Well water (0/1)	0.09	0.28	0.00	1.00
Inv. Dist to highway (1/meters)	0.26	6.58	0.00	361.75
Dist to Pittsburgh (miles)	19.00	5.00	10.58	39.51
Age sq	4,100.71	4,319.92	1.00	57,121.00
Square feet sq	327.01	329.81	20.43	5,196.97
Lot size sq	1.58	14.91	0.00	822.54
Land Use Buffers (1 mile)				
% Agricultural	0.28	0.24	0.00	1.00
% Forest	0.29	0.15	0.00	0.96
% Residential	0.29	0.17	0.00	0.71
% Water	0.01	0.03	0.00	0.18
% Commercial	0.05	0.06	0.00	0.24
% Industrial	0.02	0.04	0.00	0.14
% Miscellaneous	0.01	0.03	0.00	0.27
Transactions by Sale Year (counts)				
2008	1,324			
2009	1,355			
2010	967			

the assessor data, we obtained a final estimation sample of 3,646 single-family residential transactions. Summary statistics for these are shown in table 1 and largely conform to our prior expectations about the rural/suburban nature of this area. The average home in our data has a price of slightly under $150,000, an average square footage of 1,659, and is located on 0.61 acres of land. The relatively large acreage for the average home reflects the rural/suburban character of much of the county.

The resulting geocoded transactions are shown in figure 2, and are overlaid on municipalities. This figure shows that a large number of transactions are located near the county seat, Washington, at the intersection of Interstates 79 and 70, further north along Interstate 79 in Canonsburg, and along the Allegheny County line in the northeast section of the county. Using the geocoded property locations, we formed several supplemental data elements using ArcGIS, including distance to the nearest highway or interstate and distance to downtown Pittsburgh.

Information on the location of water services and municipality boundaries was obtained from PASDA, a clearing house for spatial data maintained by Pennsylvania State University, which assembles data from local governments across the state. Information on statewide boundaries for public water service providers is provided by the Pennsylvania Department of Environmental Protection (PA DEP, http://www.depweb.state.pa.us). This information was attached to each transaction by overlaying the shapefiles with the geocoded transactions points in ArcGIS. In total, our transactions fall across 67 municipalities and approximately 91% of our transactions are in a water provider's coverage area, shown in figure 3.

Shale Exploration Activity

Data on Marcellus Shale gas activity were obtained from the Pennsylvania Department of Environmental Protection and include information on both permitting of wells and the actual drilling of shale gas wells across

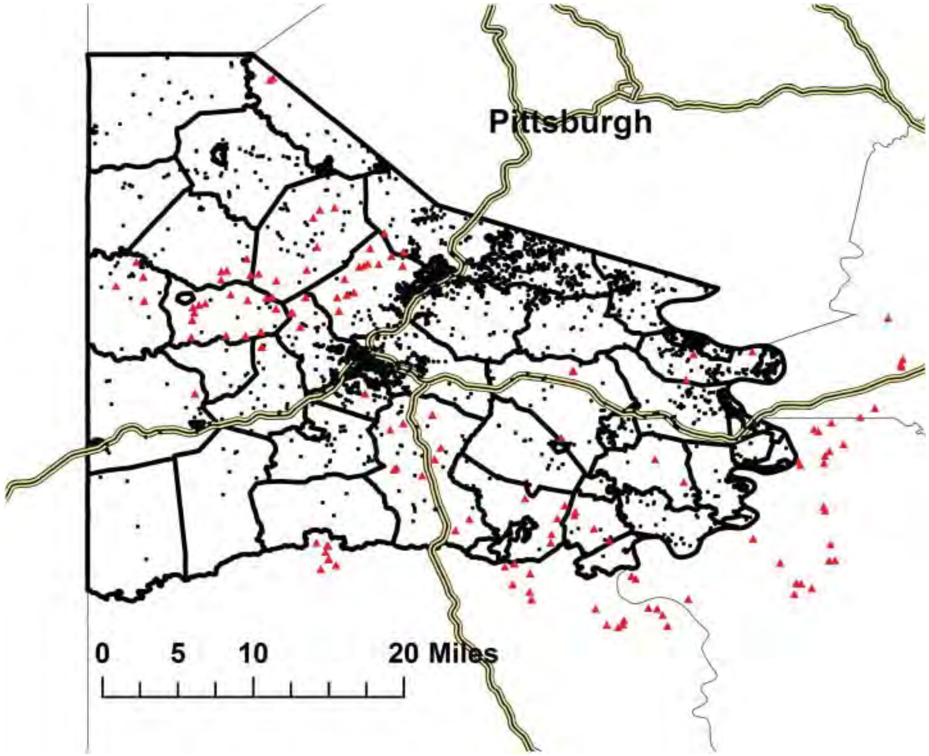

Figure 2. Housing transactions (dots) and shale gas wells (triangles) (for color, please see figure online)

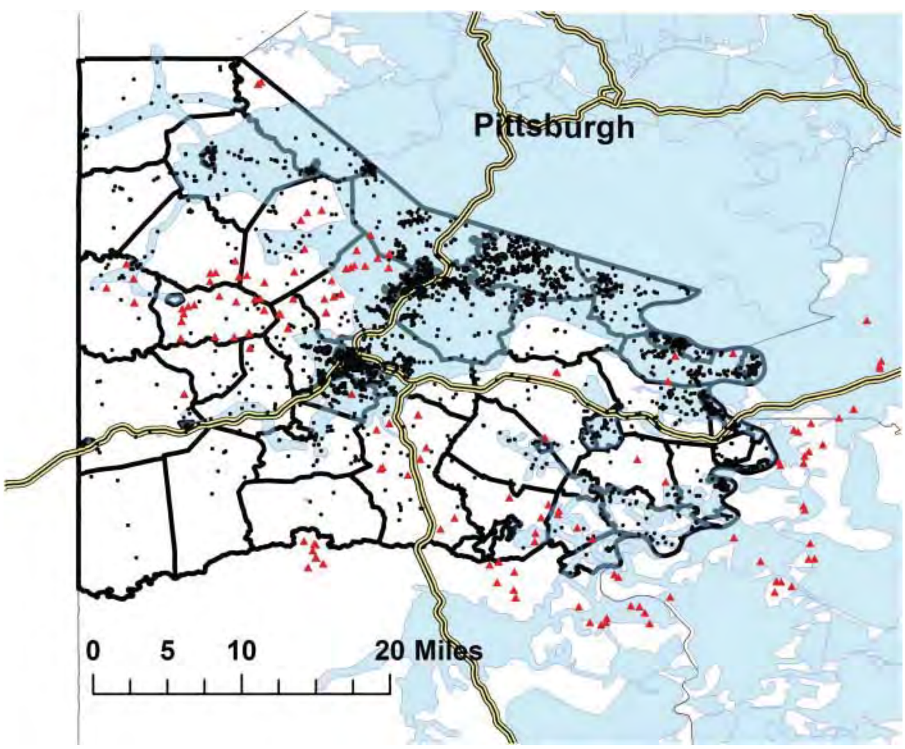

Figure 3. Water provider service areas (for color, please see figure online)

Table 2. Timing of Well Permitting and Drilling

			Permit to Drill Time (months)			
Distance Buffer	Time Window	# Permits	Mean	Std. Dev.	Min.	Max.
0.75	6	48	3.08	1.58	1	8
0.75	12	87	3.29	2.42	1	19
1	6	96	3.34	2.42	1	19
1	12	128	3.48	2.63	1	19
2	6	188	3.51	2.45	1	19
2	12	210	3.76	2.68	1	19

the state (PA DEP). Historically, many oil and gas wells in Pennsylvania were of the "vertical" type, where a single vertical well shaft is drilled to access the resource, usually at shallow depths. In this analysis we focus only on the impacts of horizontal wells for two reasons. First, horizontal drilling has now become the most common technique in Pennsylvania, enabling oil and gas companies to access shale at greater depths and across larger areas. Second, the significant public discourse over health and environmental risks to residents is associated with hydraulic fracturing, which uses horizontal wells. Because a large portion of the visible shale gas activity occurs between permitting and commencement of drilling operations, typically with increased truck traffic over several months, we are interested in identifying the likely time period in which this activity becomes apparent to nearby residents and prospective homebuyers. Using both drilling and permitting data from the Pennsylvania Department of Environmental Protection, we merged each data source to attach the permit date to each drilled well in our study area. In our study area the average time from permit acquisition to the spud date, or the date that drilling begins, is between 3 and 4 months as shown in table 2. Considering that drilling and hydrofracturing activities occur over 6 to 12 weeks, this suggests that the majority of the visible activity associated with shale exploration occurs in a 6-month time window beginning at the permitting date. We use this date in our subsequent analysis.[11]

We also explore a range of spatial and temporal buffers to examine the persistence of our results across space and time. Summary statistics for the number of shale gas wells and the number of residential properties (treated observations) at each time and distance threshold are shown in table 3. Extending the spatial buffer to 2 miles and temporal window to 12 months reveals an average number of shale gas wells of 0.63 across all homes, with a maximum of 19 wells located within those cutoffs for at least one home. This large number of nearby wells drops to a maximum of only 7 wells when using a 0.75-mile cutoff and a 6-month window. The large numbers of wells reflect the horizontal nature of drilling activity. While multiple wells can originate from a single location, as the number of wells increase, the size of the drilling operation and amount of associated traffic and "visibility" to homeowners is likely to increase as well. For this reason, focusing on the total count of wells captures important differences across space and time that would be overlooked if we consider only proximity to activity.

Surrounding Land Use

The final data component consists of land use data obtained from the USGS 2006 National Land Cover Database (NLCD, http://www.mrlc.gov/). Using these data, we calculated percentages of land cover within 1 mile of each residential property in our data for the categories of agriculture, forest, water, commercial, industrial, residential, and miscellaneous. Summary statistics, shown in table 1, reflect the relatively low-density rural nature of much of Washington County, where an average of 27.5% of surrounding land from each home is classified as agriculture and a further 29.5% of surrounding land classified as forested lands.

Shale gas exploration largely occurs in agricultural areas due to easier access and fewer landowners with whom to negotiate

[11] We also conducted the analysis using the spud date, but found that using this date led to a general loss of significance across all models. This loss of significance likely reflects the failure to capture the full effects of shale gas activity on surrounding homes, and led us to instead rely on permit dates. Econometric results using the spud date are shown in the appendix.

Table 3. Number of Horizontal Wells by Distance and Time from Permit Date

Variable	Distance (miles)	Time (months)	Mean	Std. Dev.	Min.	Max.	# Obs. (count >0)
# Horizontal Wells	0.75	6	0.03	0.30	0	7	38
# Horizontal Wells × (Well Water)	0.75	6	0.00	0.13	0	7	5
# Horizontal Wells × (% Ag)	0.75	6	0.01	0.12	0	4	38
# Horizontal Wells	0.75	12	0.05	0.46	0	8	50
# Horizontal Wells × (Well Water)	0.75	12	0.01	0.22	0	8	11
# Horizontal Wells × (% Ag)	0.75	12	0.02	0.26	0	7	50
# Horizontal Wells	1	6	0.07	0.53	0	10	87
# Horizontal Wells × (Well Water)	1	6	0.01	0.25	0	10	13
# Horizontal Wells × (% Ag)	1	6	0.03	0.28	0	8	87
# Horizontal Wells	1	12	0.11	0.76	0	13	107
# Horizontal Wells × (Well Water)	1	12	0.02	0.38	0	10	21
# Horizontal Wells × (% Ag)	1	12	0.05	0.47	0	11	107
# Horizontal Wells	2	6	0.39	1.43	0	14	397
# Horizontal Wells × (Well Water)	2	6	0.06	0.63	0	11	50
# Horizontal Wells × (% Ag)	2	6	0.14	0.83	0	11	397
# Horizontal Wells	2	12	0.64	2.12	0	19	486
# Horizontal Wells × (Well Water)	2	12	0.11	1.04	0	18	65
# Horizontal Wells × (% Ag)	2	12	0.25	1.27	0	16	486

leases. For our econometric analysis, identifying and controlling for surrounding land use is important. In addition to controlling for surrounding land use, the presence of specific land use types may also influence the "visibility" of shale gas activity in this area. In particular, it is likely that high percentages of surrounding agricultural land may make activity more visible and could also influence expectations about the extent and location of future activity.

Results

Using a Box-Cox regression to determine the appropriate functional form, we estimated several versions of the hedonic price function in equation 3. We then use a square root transformation suggested by the Box-Cox regression, and define the dependent variable in all subsequent models shown in table 4 as $(P_{ij}^{0.5} - 1)/0.5$. To establish a baseline model for comparison, all our econometric models include variables describing housing characteristics, surrounding land use, distance to Pittsburgh, and spatial-temporal fixed effects. In addition, we define several explanatory variables associated with shale exploration that are also common to all model specifications and intended to capture the localized effect of shale activity. The first of these variables is a measure of the total number of shale wells within a specified distance and time cutoff from a property. The second variable captures the proximity of households located near shale development to major highways, as highways are likely to be heavily utilized by truck traffic accessing well sites and may indicate greater visibility and potential disruption associated with nearby shale activity. This variable is formed as an interaction between the number of shale wells and the inverse distance to a major highway. Using inverse distance gives this term an interpretation that a negative coefficient reflects a lower willingness to pay associated with more proximate (temporally and spatially) locations.

The baseline models reported in table 4 employ a spatial cutoff of 1 mile between shale wells and surrounding property transactions. We further restrict our attention to shale wells for which a permit had been acquired no more than six months prior to the sale of the property, and that were subsequently drilled. All the housing characteristics have the expected sign, and the land use variables reveal significant and intuitive results for surrounding land use categories relative to the omitted category of residential development. For our main results characterizing shale development, we find a negative coefficient of −3.2608 associated with the count measure of shale wells, which is significant at a 1% level. While proximity to a major road does not have a significant

Table 4. Estimation Results (Spatial Buffer – Distance = 1 mile, Time = 6 months)

Dependent Variable: $(\sqrt{P_{ij}} - 1)/0.5$

Variable	(1) No Land Use Interactions	(2) W/Land Use Interactions
Square feet (100s)	4.651	4.649
	(2.981)	(2.976)
Lot size (acres)	25.523***	25.803***
	(2.695)	(2.739)
Number of bedrooms	6.624	6.911
	(5.357)	(5.486)
Number of baths	13.976***	13.880**
	(5.257)	(5.272)
Stories	−3.640	−3.563
	(2.494)	(2.468)
Age of property	−4.074***	−4.083***
	(0.400)	(0.400)
Garage	58.022***	58.171***
	(8.906)	(9.003)
Fireplace	55.922***	55.757***
	(6.745)	(6.722)
Pool	58.480***	58.930***
	(20.587)	(20.441)
Well water	−27.803	−25.765
	(19.162)	(18.322)
1/Distance to road	0.022	0.0185
	(0.168)	(0.168)
Distance to Pittsburgh	−5.990*	−6.216*
	(3.220)	(3.159)
Age2	0.013***	0.013***
	(0.003)	(0.003)
Square feet2	0.199**	0.198**
	(0.079)	(0.079)
LotSize2	−0.880***	−0.885***
	(0.205)	(0.202)
# Shale wells within 1 mile *(1/ Dist. to road)	−3.266***	−1.010**
	(0.486)	(0.392)
# Shale wells within 1 mile, 6 months	−3.261***	7.586
	(1.102)	(4.893)
Count Shale Wells* Well water		−15.112***
		(4.159)
Count Shale Wells* AgLand		−17.494*
		(9.769)
Landuse – Agriculture	−44.753**	−41.719**
	(18.918)	(18.263)
Landuse – Forest	−30.854	−30.698
	(40.191)	(41.147)
Landuse – Water	−245.470	−256.530
	(203.906)	(195.617)
Landuse – Commercial	−267.751***	−277.792***
	(82.446)	(87.448)
Landuse – Industrial	−541.532**	−516.689**
	(226.117)	(212.954)
Landuse – Other	94.097	93.434
	(160.002)	(159.074)
Constant	762.737***	767.653***
	(98.731)	(95.920)

(*Continued*)

Table 4. Continued.

Dependent Variable: $(\sqrt{P_{ij}} - 1)/0.5$

Variable	(1) No Land Use Interactions	(2) W/Land Use Interactions
Year-Municipality FE	Included	Included
Note: Box-Cox Transformation		
Parameter (theta)	0.4843***	95% CI
	(0.0142)	[0.4564 −0.5123]
Observations	3,646	3,646
R-squared	0.799	0.799

Note: Standard errors clustered by municipality in parenthesis.
$^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$.

impact on an average property in our sample, the negative and significant coefficient of −3.2663 for the interaction of well count with proximity to a major roadway indicates that an increase in the number of active shale wells disproportionately impacts residents located closer to major roadways.

The impact of shale gas activity on particular subsets of the broader housing market is captured by including an interaction between the number of shale wells and the source of water supply to identify the marginal effect of shale activity on a property that uses private well water. To explore the potential risk of lower water quality, we control for the source of drinking water by including an indicator variable for whether the property is provided with public water or private well water.

In addition to potential ground water risks it is likely that the perception of additional future drilling would reasonably be capitalized into housing values. It has been noted in previous research that expectations about future land use patterns can influence the value of open space (Smith, Poulos, and Kim 2002). One might expect that potential future shale exploration activity and the visibility of current activity are both likely enhanced in agricultural areas. We test for heterogenous impacts associated with agricultural land use by including an interaction between the percentage of surrounding agricultural lands and counts of shale gas wells.

Including these interaction terms, the environmental attributes of interest shown in equation (3) are expanded to include $(z_{ij}, (z_{ij} \times L_i^{AG}), (z_{ij} \times X_i^{WATER}))$ in the baseline model, where shale activity is measured within 1 mile from the property and within 6 months from the sale date. Results presented in the second column of table 4 show that the impact of shale activity is largely captured by the interaction effects, with no significant baseline effect remaining. We found a negative and significant effect of additional shale activity on properties that rely on well water (−15.1122) and on properties surrounded by agricultural land (−17.4935). While the average impact of shale activity is small, the effect on rural homes is significant and large.[12] We continue to find a negative and statistically significant impact of roadway proximity interacted with shale well counts (−1.0096), although the magnitude of this effect is smaller.

To allow easier interpretation of these effects, the marginal willingness to pay to avoid additional shale wells is reported in table 8 for all our model specifications.[13] These calculations are based on the average property in our sample, with a sales price of $148,401. For the models including interaction terms shown in column 2 of table 4, the implied marginal effect of an additional shale well depends on both the interaction and level terms. The first row of table 8 presents

[12] In the appendix table A4 we also report results for the inclusion of an interaction between large lots (>5 acres) and well counts. We are unable to include additional interactions in this specification due to high degrees of collinearity.

[13] As shown by Bayer, Ferreira, and McMillan (2007) taste-based sorting suggests that virtually all hedonic estimates are likely to be biased. This sorting bias implies that hedonic estimates recover the average willingness to pay for households choosing to live near (dis-)amenities. In our application, where we expect that close proximity to active shale wells is a disamenity, sorting suggests that our estimates reflect the average willingness to pay for households with the least aversion to shale gas wells as those are the households likely to choose to locate near active wells, all else being equal. As such, our estimates may understate the magnitude of any potential negative impacts and could be viewed as an upper bound.

marginal willingness to pay estimates associated with our baseline specification, and the subsequent rows report these effects for the expanded model including land use and water source interactions with well counts for specified levels of the interaction variables.

Our results reveal that the negative impact of an additional well located within one mile from an average house in our baseline model leads to a loss of $1,256. For the interaction models, the sign and magnitude of this effect depends critically on the location of the home. For homes on public water supplies with little (<20%) surrounding agricultural lands, this effect is a positive $1,576. Moving the same home to a more agricultural area (80%) reveals a negative impact of $−2,467. If that same home in an agricultural region relies on private well water, it will see a loss of $−8,288 while the same home with private well water located in a less agricultural area (20%) will experience a loss of $−4,244. These results highlight the importance of accounting for heterogeneous effects associated with shale development when describing the potential for winners and losers to emerge.

Spatial and Temporal Persistence

To this point, our econometric specifications have focused exclusively on shale wells granted permission within 6 months prior to a house sale and located within one mile of a home. To examine the persistence of these effects across both space and time, we vary the spatial and temporal buffers and analyze the impact of changes in these assumptions on our results. We expect that potential buyers are likely to perceive considerable risks that are capitalized while activity is ongoing, but upon completion of exploration activity the risk perceptions and the associated visibility of nearby wells diminish. If risk perceptions vary over time, as this suggests, we would expect to see any potential negative impacts, transmitted through risk perceptions, attenuate over time. Similarly, as we move farther away from the likely range of perceived risks in space, the effects of shale gas activity as capitalized into housing values are also likely to attenuate.

Table 5 reports results for the baseline model (specification 3), as well as additional specifications with distance ranges of 0.75, 1 mile, and 2 miles, and temporal windows of 6 months and 12 months. We find that the impact of additional wells is largest with a coefficient on well count of −7.8891 for properties that are located within 0.75 miles of the activity, and for which permits were acquired within 6 months from the sale date. This negative impact attenuates across both space and time. The coefficient is insignificant beyond 1 mile regardless of the utilized temporal window, and is insignificant at the 12-month time frame regardless of the spatial buffer. The interaction between shale well count and distance to major roadway remains negative and significant in all models. This may support local policymakers' concerns regarding the degradation of roadways long after shale activity in an area ceases. Table 6 reports the same temporal and spatial permutations and includes the additional heterogeneous interaction effects on well water and surrounding agricultural land as described above. For interactions with well water, we find very large and significant negative effects (−73.3292) for homes located within .75 miles and 6 months of a well, which become insignificant at 12 months, suggesting a relatively short-term impact closely associated with the most active stage of exploration. Interactions with agricultural land are insignificant at the .75 mile range, negative and significant at the 1 mile range (as shown previously) and turn positive and significant at the two mile range. This positive effect at further distances may reflect expectations of potential gains from shale exploration, perhaps associated with the potential for future royalty payments. The implied MWTP values for each of these models are shown in table 8.

Perceptions of Risk

Property values capitalize the perceived risk of living close to a disamenity (such as a hazardous waste site), and this perceived risk increases with proximity to a site with unfavorable attributes (McCluskey and Rausser 2001). In the early shale gas exploration phase, due to the absence of clear scientific evidence about the nature and extent of health and environmental risk, peoples' beliefs about the potential risk from shale exploration likely depend on proximity to the drilling site and the intensity of activity in the region, as we showed previously. We would expect the perceived risk of environmental damage to increase as one is located closer

Table 5. Spatial and Temporal Persistence of Shale Impacts

	Model Specification - Spatial-Temporal Buffers					
Variable	(1) 0.75 Mile 6 Month	(2) 0.75 Mile 12 Month	(3) 1 Mile 6 Month	(4) 1 Mile 12 Month	(5) 2 Mile 6 Month	(6) 2 Mile 12 Month
Square feet (100s)	4.6712	4.6794	4.6516	4.6653	4.6277	4.6391
	(2.984)	(2.991)	(2.981)	(2.990)	(2.974)	(2.979)
Lot size (acres)	25.6175***	25.6697***	25.5230***	25.2998***	25.7109***	25.6458***
	(2.686)	(2.667)	(2.695)	(2.668)	(2.928)	(2.872)
Number of bedrooms	6.7740	6.7741	6.6238	6.6534	6.8633	6.8188
	(5.410)	(5.396)	(5.357)	(5.345)	(5.386)	(5.357)
Number of baths	14.2079***	14.1417***	13.9760***	13.8743**	14.0353***	13.9115**
	(5.219)	(5.203)	(5.257)	(5.269)	(5.235)	(5.255)
Stories	−3.8289	−3.7832	−3.6398	−3.5620	−3.5358	−3.4614
	(2.580)	(2.632)	(2.494)	(2.484)	(2.452)	(2.445)
Age of property	−4.0642***	−4.0680***	−4.0738***	−4.0749***	−4.0611***	−4.0633***
	(0.402)	(0.403)	(0.400)	(0.400)	(0.401)	(0.401)
Garage	58.1647***	58.2155***	58.0216***	58.1277***	58.0368***	58.1147***
	(8.981)	(8.982)	(8.906)	(8.919)	(8.937)	(9.008)
Fireplace	56.0271***	55.9353***	55.9223***	55.7367***	55.5798***	55.5265***
	(6.697)	(6.734)	(6.745)	(6.786)	(6.694)	(6.698)
Pool	63.2366***	62.7562***	58.4804***	57.8452***	57.6582***	57.6123***
	(19.045)	(19.173)	(20.587)	(20.980)	(20.939)	(20.980)
Well water	−27.7398	−27.4814	−27.8026	−27.6991	−28.1764	−28.3729
	(19.179)	(19.136)	(19.162)	(19.171)	(19.142)	(19.317)
1/Distance to road	0.0155	0.0158	0.0219	0.0221	0.0418	0.0405
	(0.162)	(0.162)	(0.168)	(0.167)	(0.178)	(0.175)
Distance to Pittsburgh	−5.8945*	−5.9393*	−5.9901*	−6.0122*	−6.0121*	−6.0554*
	(3.226)	(3.206)	(3.220)	(3.202)	(3.165)	(3.140)
Age2	0.0126***	0.0127***	0.0127***	0.0127***	0.0126***	0.0126***
	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)
Square feet2	0.1978**	0.1976**	0.1985**	0.1985**	0.1988**	0.1987**
	(0.079)	(0.079)	(0.079)	(0.079)	(0.079)	(0.079)
LotSize2	−0.8775***	−0.8797***	−0.8802***	−0.8753***	−0.8881***	−0.8876***
	(0.198)	(0.198)	(0.205)	(0.207)	(0.212)	(0.212)
# Wells *(1/ Dist. to road)	−22.8075***	−25.5194***	−3.2663***	−1.5754***	−1.7733***	−1.2150***
	(2.819)	(3.090)	(0.486)	(0.381)	(0.492)	(0.359)
# Shale wells	−7.8991**	−2.3267	−3.2608***	−0.4168	0.2743	0.6990
	(3.496)	(4.729)	(1.102)	(1.721)	(1.027)	(1.083)
Landuse – Agriculture	−45.7158**	−44.8913**	−44.7526**	−44.5137**	−43.6425**	−43.7651**
	(18.919)	(19.010)	(18.918)	(18.974)	(19.240)	(19.540)
Landuse – Forest	−30.4850	−30.4325	−30.8544	−30.5211	−29.0084	−27.2913
	(40.169)	(40.157)	(40.191)	(40.146)	(40.915)	(41.179)
Landuse – Water	−247.9609	−247.2639	−245.4702	−250.0823	−248.7829	−250.6307
	(205.965)	(203.678)	(203.906)	(201.384)	(199.235)	(197.606)
Landuse – Commercial	−270.0197***	−268.1460***	−267.7508***	−268.1420***	−267.6369***	−265.0781***
	(83.221)	(83.302)	(82.446)	(83.706)	(85.278)	(86.675)
Landuse – Industrial	−543.3444**	−538.1955**	−541.5316**	−535.4750**	−533.1277**	−530.5826**
	(225.661)	(225.909)	(226.117)	(223.251)	(223.286)	(221.611)
Landuse – Other	95.7250	94.4380	94.0965	92.8047	92.5308	90.4115
	(160.541)	(161.153)	(160.002)	(160.463)	(159.805)	(159.388)
Constant	759.7057***	760.4119***	762.7371***	763.2948***	761.4022***	762.1125***
	(99.380)	(99.073)	(98.731)	(98.110)	(96.569)	(96.060)
Year-Municipality FE	Included	Included	Included	Included	Included	Included
Observations	3,646	3,646	3,646	3,646	3,646	3,646
R-squared	0.799	0.799	0.799	0.799	0.799	0.799

Note: Standard errors clustered by municipality in parenthesis. $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$.

to the activity site, and when there are more wells drilled near the property.

To capture the combination of these effects in a single econometric model we create a new variable to explore the impact of perceived risk, measured by the mean inverse distance to wellpads, multiplied by the number of wells located within the spatial

Table 6. Spatial-Temporal Persistence Including Land Use and Water Source Interactions

	Model Specification - Spatial-Temporal Buffers					
Variable	(1) 0.75 Mile 6 Month	(2) 0.75 Mile 12 Month	(3) 1 Mile 6 Month	(4) 1 Mile 12 Month	(5) 2 Mile 6 Month	(6) 2 Mile 12 Month
Square feet (100s)	4.7352	4.6394	4.6490	4.6694	4.5508	4.5940
	(3.021)	(3.018)	(2.976)	(3.007)	(2.947)	(2.958)
Lot size (acres)	25.3614***	25.6315***	25.8031***	25.1591***	25.8173***	25.8343***
	(2.641)	(2.717)	(2.739)	(2.671)	(2.941)	(2.903)
Number of bedrooms	6.6565	6.9558	6.9106	6.7990	6.8842	6.8787
	(5.378)	(5.404)	(5.486)	(5.399)	(5.481)	(5.422)
Number of baths	14.0829***	14.3495***	13.8798**	13.7689**	14.1631***	13.9913***
	(5.240)	(5.265)	(5.272)	(5.335)	(5.225)	(5.213)
Stories	−3.7366	−3.8427	−3.5634	−3.5184	−3.5512	−3.5398
	(2.547)	(2.572)	(2.468)	(2.469)	(2.385)	(2.398)
Age of property	−4.0665***	−4.0751***	−4.0831***	−4.0844***	−4.0546***	−4.0592***
	(0.402)	(0.406)	(0.400)	(0.403)	(0.402)	(0.400)
Garage	58.7264***	57.9756***	58.1713***	58.1691***	57.9402***	58.0861***
	(9.286)	(9.010)	(9.003)	(9.034)	(8.883)	(8.946)
Fireplace	55.9261***	56.1305***	55.7570***	55.7989***	55.4491***	55.4375***
	(6.683)	(6.765)	(6.722)	(6.793)	(6.662)	(6.680)
Pool	63.2028***	62.6848***	58.9298***	57.2782***	58.0861***	57.7715***
	(19.112)	(19.220)	(20.441)	(21.065)	(21.115)	(20.931)
Well water	−25.5278	−29.3010	−25.7648	−28.1295	−28.7315	−31.4377
	(18.383)	(18.214)	(18.322)	(17.596)	(19.372)	(19.209)
1/Distance to road	0.0118	0.0166	0.0185	0.0214	0.0483	0.0489
	(0.161)	(0.160)	(0.168)	(0.165)	(0.177)	(0.174)
Distance to Pittsburgh	−6.0698*	−5.8530*	−6.2155*	−6.0588*	−5.8479*	−5.8797*
	(3.186)	(3.256)	(3.159)	(3.208)	(3.064)	(3.091)
Age2	0.0128***	0.0127***	0.0128***	0.0127***	0.0126***	0.0126***
	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)
Square feet2	0.1969**	0.1977**	0.1981**	0.1983**	0.2001**	0.1992**
	(0.080)	(0.080)	(0.079)	(0.079)	(0.079)	(0.079)
LotSize2	−0.8661***	−0.8775***	−0.8848***	−0.8700***	−0.8930***	−0.8957***
	(0.194)	(0.200)	(0.202)	(0.207)	(0.213)	(0.214)
# Shale wells within 1 mile * (1/ Dist. to road)	18.2717**	−34.6445***	−1.0096**	−1.7208	−1.9479***	−1.4251***
	(7.429)	(9.398)	(0.392)	(1.371)	(0.505)	(0.386)
# Shale wells	−3.5545	−0.4511	7.5857	3.8731	−3.4767	−1.4252
	(7.943)	(4.616)	(4.893)	(2.639)	(2.452)	(0.928)
Count shale wells * Well water	−73.3292***	23.3776	−15.1122***	4.3982	0.1648	2.0747
	(22.495)	(16.832)	(4.159)	(8.588)	(2.131)	(2.048)
Count shale wells * AgLand	−8.3825	−13.9250	−17.4935*	−10.2687**	7.9185**	3.4083*
	(26.751)	(10.808)	(9.769)	(4.970)	(3.762)	(1.724)
Constant	762.1840***	759.8818***	767.6529***	764.9372***	759.9020***	761.0478***
	(98.217)	(100.150)	(95.920)	(97.622)	(96.244)	(96.551)
Year-Municipality FE	Included	Included	Included	Included	Included	Included
Observations	3,646	3,646	3,646	3,646	3,646	3,646
R-squared	0.800	0.799	0.799	0.799	0.799	0.799

Notes: Standard errors clustered by municipality in parenthesis. Land use categories included but not shown here.
***$p < 0.01$, **$p < 0.05$, *$p < 0.1$.

buffer.[14] This house-specific risk measure is given by:

$$(5) \qquad R_{ij} = \frac{z_{ij}}{D_{ij}}; \quad \frac{\partial R_{ij}}{\partial z_{ij}} > 0; \quad \frac{\partial R_{ij}}{\partial D_{ij}} < 0$$

where z_{ij} is the number of shale gas wells near a property, and D_{ij} is the average distance to all wellpads located within the distance buffer from the property.[15] The

[14] For consistency with our other specifications, we set inverse distance to 0 for wells beyond a spatial threshold. This is equivalent to assuming an infinite distance.

[15] This specification is similar in spirit to the introduction of risk perceptions employed by McClusky and Rausser (2001), but due to limited data we are unable to fully replicate their model.

modified hedonic price equation is:

$$(6)\qquad \frac{\sqrt{P_{ij}}-1}{0.5}=\beta_0+\beta_1 X_i+\gamma R_{ij}+\delta_{jt}(N_j * T_t)+\varepsilon_{ij}.$$

In this model, the estimated coefficient γ measures the marginal impact of increased risk from shale activity, which can then be decomposed into a proximity risk effect (holding number of wells constant) and an intensity effect (holding distance constant):

$$(7)\qquad R_{ij}=\frac{z_{ij}}{D_{ij}} \Rightarrow dR_{ij}=-\frac{\bar{z}}{D_{ij}^2}dD_{ij}+\frac{1}{\bar{D}_{ij}}dz_{ij}.$$

The MWTP associated with our measure of risk from shale activity is:

$$(8)\qquad MWTP=\sqrt{\bar{P}}\gamma\left(\frac{\bar{z}}{\bar{D}_{ij}^2}dD_{ij}+\frac{1}{D}dZ_{ij}\right)$$

where $\bar{P}$ ($148,401) is the average property value in the sample, $\bar{z}$ (3.88) is the mean number of shale wells within a mile, and $\bar{D}$ (3740 ft) is the average distance to a wellpad for properties within one mile from a wellpad. The MWTP for proximity risk can then be measured as:[16]

$$(9)\qquad MWTP_{\mathrm{Pr}}=\sqrt{\bar{P}}\gamma\left(\frac{\bar{z}}{\bar{D}_{ij}^2}dD_{ij}\right).$$

Similarly, the MWTP associated with an increase in quantity of wells located within a mile from an average property in the sample can be measured as:

$$(10)\qquad MWTP_{Count}=\sqrt{\bar{P}}\gamma\left(\frac{1}{\bar{D}}dz_{ij}\right).$$

In addition to this measure of risk, we also include interaction effects between risk and water source and the portion of agricultural land around the property as in our previous models. We estimate the hedonic price function in equation (3) using the new explanatory variable, R_{ij}, rather than the well count alone for comparison to our earlier specifications. Results shown in table 7 are consistent with earlier specifications, indicating an overall negative impact of additional risk (coefficient of −345.431). Including interaction effects, we find a heterogeneous impact on properties that rely on well water (−436.528) and properties that are predominantly surrounded by agricultural land (−719.709). The MWTP associated with increased risk, decomposed into proximity and intensity risk measures, are also shown in table 8.

Decomposing the risk effect provides further evidence that, conditional on being located near a wellpad, the intensity effect dominates the proximity effect. A marginal increase in intensity of shale activity (an additional shale well within one mile of the property) results in a negative willingness to pay of $−3,596, and an increase in proximity to shale activity (a property located 100ft closer to a wellpad) will result in a negative willingness to pay of $−377.

Robustness Specifications

We present three robustness checks in the appendix. The first replaces the municipality by year fixed effects, with smaller block-group by year fixed effects in table A1. These results largely mirror those presented thus far, although with some loss of significance due to sparse sales in many rural block group and year combinations with this more stringent set of fixed effects. Nevertheless, in a model without interactions we find a negative and significant impact of shale exploration (−9.4086), and find qualitatively similar, although not significant, magnitudes and signs for interactions with agricultural land and well-water.

Our second robustness specification replaces the permit date with the spud (drill) date to gauge the sensitivity of the assumption that impacts are likely to begin around the time of permit date due to the increased visibility of activity between well permitting and drilling. We hypothesized that substantial activity begins prior to the actual drilling period, and that this activity is important when considering the potential impacts of shale development on surrounding homeowners. Therefore, we would expect that omitting the period of time between permitting and drilling would result in an attenuation of our results. Results presented

[16] We are measuring the risk of being located 100ft closer to the shale activity. The negative change in D_{ij} reverses the sign of $\frac{\bar{z}}{\bar{D}_{ij}^2}$.

Table 7. Estimation Results with Constructed Risk Perception Measure

Dependent Variable: $(\sqrt{P_{ij}} - 1)/0.5$

Variable	(1) No Land Use Interactions	(2) W/Land Use Interactions
Square feet (100s)	4.6648	4.6651
	(2.985)	(2.981)
Lot size (acres)	25.4977***	25.6953***
	(2.688)	(2.703)
Number of bedrooms	6.4909	6.7308
	(5.304)	(5.421)
Number of baths	14.0231***	13.8884**
	(5.276)	(5.296)
Stories	−3.7058	−3.6143
	(2.524)	(2.485)
Age of property	−4.0691***	−4.0765***
	(0.401)	(0.400)
Garage	58.0919***	58.3437***
	(8.994)	(9.141)
Fireplace	55.9825***	55.9254***
	(6.794)	(6.783)
Pool	59.1614***	59.5071***
	(20.079)	(20.141)
Well water	−27.3069	−25.5820
	(18.866)	(18.198)
1/Distance to road	0.0196	0.0164
	(0.167)	(0.166)
Distance to Pittsburgh	−6.0107*	−6.1729*
	(3.203)	(3.162)
Age2	0.0127***	0.0128***
	(0.003)	(0.003)
Square feet2	0.1985**	0.1981**
	(0.079)	(0.079)
LotSize2	−0.8774***	−0.8806***
	(0.203)	(0.200)
# Shale wells within 1 mile *(1/ Dist. to road)	−2.6974***	−1.2098***
	(0.420)	(0.355)
Risk	−345.4305***	83.9191
	(35.830)	(155.508)
Risk * Well water		−436.5284**
		(172.794)
Risk * AgLand		−719.7087*
		(394.464)
Landuse – Agriculture	−44.5880**	−42.0804**
	(18.733)	(18.103)
Landuse – Forest	−31.0126	−30.2647
	(40.121)	(40.638)
Landuse – Water	−242.3662	−248.2973
	(205.754)	(201.956)
Landuse – Commercial	−269.1082***	−274.1509***
	(82.054)	(83.521)
Landuse – Industrial	−545.5344**	−529.5074**
	(226.923)	(219.673)
Landuse – Other	96.2736	95.4046
	(160.556)	(159.710)
Constant	762.9149***	765.7001***
	(98.345)	(96.824)

(Continued)

Table 7. Continued.

Dependent Variable: $(\sqrt{P_{ij}} - 1)/0.5$

Variable	(1) No Land Use Interactions	(2) W/Land Use Interactions
Year-Municipality FE	Included	Included
Observations	3,646	3,646
R-squared	0.799	0.799

Note: Clustered robust standard errors in parentheses.
$^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$.

Table 8. Marginal Willingness to Pay Measures

Model Specification	MWTP ($)	% Change in Property Value
Average Property Value	$148, 400.90	
Baseline Buffer: 1 mile, 6 month		
No land use interaction	−$1, 256.15	−0.8%
No well water, Surrounding Ag land = 20%	$1, 576.05	1.1%
No well water, Surrounding Ag land = 80%	−$2, 467.46	−1.7%
Well water, Surrounding Ag land = 20%	−$4, 244.75	−2.9%
Well water, Surrounding Ag land = 80%	−$8, 288.27	−5.6%
Spatial Buffer: 0.75 mile, 6 month		
No land use interaction	−$3, 042.96	−2.1%
No well water, Surrounding Ag land = 20%	−$2, 013.20	−1.4%
No well water, Surrounding Ag land = 80%	−$3, 950.13	−2.7%
Well water, Surrounding Ag land = 20%	−$30, 262.00	−20.4%
Well water, Surrounding Ag land = 80%	−$32, 198.93	−21.7%
Spatial Buffer: 2 mile, 6 month		
No land use interaction	$105.67	0.1%
No well water, Surrounding Ag land = 20%	$715.75	0.5%
No well water, Surrounding Ag land = 80%	$2, 546.01	1.7%
Well water, Surrounding Ag land = 20%	$779.24	0.5%
Well water, Surrounding Ag land = 80%	$2, 609.50	1.8%
Risk Measure: 1 mile, 6 month		
Mean distance to wellpad within buffer (in 100s ft)	37.488	
Mean number wells within buffer	3.88	
Overall risk	−$3, 973.61	−2.7%
Intensity risk (one additional shale well within 1 mile)	−$3, 596.47	−2.4%
Proximity risk (locating 100ft closer to wellpad)	−$377.14	−0.3%

in appendix table A2 support this hypothesis, and show qualitatively similar findings to those reported previously, albeit with less significance, as expected.

Our third robustness specification includes nearest wellpad fixed effects to control for potentially unobservable determinants of drilling activity in an area, and maintains the municipality by year fixed effects used in our previous models. This specification identifies the impact of increasing numbers of wells over time within a 1 mile buffer of each well site to directly gauge the importance of measuring the well count rather than the well pads in our specifications. We report our findings in table A3 and find qualitatively similar and statistically significant results to those reported previously, suggesting that our treatment of well counts is appropriate and that households are responding to well activity conditional on the presence or location of well pads.[17] Overall, these robustness specifications provide additional confirmation of our main findings, and suggest that our results

[17] We would like to thank an anonymous referee for this suggestion.

are not overly sensitive to assumptions on unobservables given the use of spatial-temporal fixed effects at the municipality and sale year level.

Discussion

The recent expansion of shale gas development across large regions of the United States has led to copious public discourse over perceived health and environmental risks associated with its expansion. Despite widespread public debate, there is surprisingly little applied research examining the direct impacts on surrounding populations. This lack of empirical research is likely due to the relatively recent expansion of this activity, which often occurs in regions with isolated and sparse populations, thus making econometric identification challenging. In this article we have assembled a dataset that allows us to examine the early impact of shale gas activity on surrounding homeowners in a relatively populated area of Pennsylvania, Washington County.

We find clear evidence that housing markets respond to shale exploration, with impacts dependent both on proximity and intensity of shale activity. Our findings show a strong negative impact associated with the early stages of shale exploration, but these impacts are highly heterogeneous, suggesting that a uniform characterization of the impact of shale development on surrounding homeowners is not suitable for policy decisions.

Since shale activity is rapidly expanding, for example Ohio is currently experiencing the early stages of expansion into the Utica shale, our findings are of immediate policy relevance to local and state officials in Pennsylvania and surrounding states. For policymakers seeking to both reassure and alleviate any potential negative impacts from shale development, our results provide several key insights. First, while we find significant negative impacts to surrounding homeowners, these impacts are largely short-term and occur in close proximity to shale activity. This suggests that perceptions of risk may drive much of these relatively temporary losses. Second, we find that these impacts are heterogeneous and any negative effects disproportionately fall on rural households that rely on private well water. Finally, we find that households in close proximity to major roadways, which are often heavily used for shale activity, experience negative impacts that persist both across time and for longer periods.

To address the potential negative impacts from shale energy development, many states are considering or have adopted impact fees associated with shale activity. In 2012, Pennsylvania passed Act 13 to amend the existing Oil and Gas Act of 1984 to address issues associated with unconventional (Marcellus and Utica) shale development. One component of this new legislation is the establishment of a fee associated with unconventional shale exploration designed to compensate local communities for any damages, and to establish a fund to hold a portion of gas revenues to cover potential damages (PA DEP, http://www.depweb.state.pa.us). How best to use these new revenues is a key policy concern, particularly as this law is implemented and funds are disbursed to local communities.

Our results have direct implications for the disbursement of these monies. First, our findings of significant negative impacts that persist over time associated with proximity to major roadways, suggest that more oversight and expenditure on repair and upkeep may be needed. Further restrictions tied to routing truck traffic to the wellpads may also alleviate some of these concerns, as municipalities may choose routes to avoid close proximity to households, to the extent possible, even if this routing is slightly more expensive. Second, the large losses associated with households in close proximity to ongoing shale development and who are reliant on well water suggests that more formal regulations surrounding water testing and potential remediation may help alleviate perceived risks. Both baseline testing before shale activity begins and testing after shale activity is completed may help to address any potential impacts, although this alone is unlikely to fully reduce the risks that households may perceive. One step towards reducing these perceived risks could be through additional monies being set aside specifically to address water quality issues and to develop contingency plans in the event of water quality problems. Finally, the large impacts on homes near surrounding agricultural lands suggests that efforts to reduce visibility such as new regulations on nighttime lighting or deliberate siting of well pads in more inconspicuous locations may help to alleviate these effects.

Moving forward, the econometric identification of impacts from shale gas activity will continue to face challenges, stemming in large part from the potential for localized housing price inflation due to an increased demand for housing from new workers, as well as the influx of additional royalty and lease payments to rural areas. Future work to unbundle these competing affects will likely need to obtain information on land leasing and royalty data, which to date has not been readily accessible to researchers in many areas where shale activity is ongoing. While our results provide convincing evidence of relative winners and losers within Washington County, Pennsylvania, they do not inform us as to whether there are larger price dynamics that have the potential to make people across a region better or worse off. Additional research is therefore needed to understand the regional implications of shale gas exploration.

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Appendix: Additional Robustness Results

Table A1. Estimation Results with Block Group by Year Fixed Effects

Variable	(1) No Land Use Interactions	(2) W/Land Use Interactions
Square feet (100s)	4.567**	4.535**
	(2.269)	(2.266)
Lot size (acres)	25.392***	25.811***
	(4.892)	(5.013)
Number of bedrooms	7.838*	8.036*
	(4.714)	(4.708)
Number of baths	13.183**	13.13**
	(5.670)	(5.675)
Stories	−1.781	−1.80
	(2.874)	(2.871)

(*Continued*)

Table A1. Continued.

Variable	(1) No Land Use Interactions	(2) W/Land Use Interactions
Age of property	−4.511***	−4.519***
	(0.406)	(0.407)
Garage	51.59***	51.850***
	(7.995)	(7.993)
Fireplace	46.898***	46.811***
	(5.792)	(5.818)
Pool	54.154***	54.70***
	(18.926)	(19.001)
Well water	−33.806**	−32.544**
	(13.951)	(13.845)
1/Distance to road	0.110	0.108
	(0.219)	(0.219)
Distance to Pittsburgh	−4.135	−4.449
	(5.987)	(6.105)
Age2	0.017***	0.017***
	(0.003)	(0.003)
Square feet2	0.181***	0.181***
	(0.060)	(0.060)
LotSize2	−0.771***	−0.781***
	(0.213)	(0.213)
# Wells within 1m *(1/ Dist. to road)	−1.728	0.074
	(2.506)	(2.332)
# Shale wells within 1 mile, 6 mo	−9.409*	2.879
	(5.631)	(9.406)
Count Shale Wells * Well water		−14.965
		(9.591)
Count Shale Wells * AgLand		−13.812
		(13.108)
Landuse – Ag	−27.709	−27.538
	(51.997)	(52.189)
Landuse – Forest	−60.074	−59.236
	(62.183)	(62.366)
Landuse – Water	−419.419	−416.144
	(370.528)	(369.661)
Landuse – Comm.	−128.954	−125.925
	(175.076)	(174.951)
Landuse – Industrial	−174.276	−164.401
	(418.331)	(417.653)
Landuse – Other	−166.611	−170.281
	(235.590)	(235.999)
Constant	758.54***	764.852***
	(144.750)	(147.392)
Year-Block group FE	Included	Included
Observations	3,646	3,646
R-squared	0.83	0.83

Note: Standard errors clustered by block group in parentheses; ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$.

Table A2. Estimation Using Well-drilled Dates

Variable	(1) No Land Use Interactions	(2) W/Land Use Interactions
Square feet (100s)	4.6710	4.6765
	(2.992)	(3.000)
Lot size (acres)	25.3537***	25.2287***
	(2.686)	(2.678)
Number of bedrooms	6.5936	6.6750
	(5.300)	(5.375)
Number of baths	13.9079**	13.8243**
	(5.264)	(5.343)
Stories	−3.6570	−3.6879
	(2.544)	(2.513)
Age of property	−4.0730***	−4.0774***
	(0.401)	(0.402)
Garage	58.1519***	58.1390***
	(8.954)	(9.022)
Fireplace	55.8294***	55.9651***
	(6.796)	(6.860)
Pool	57.9499***	57.5554***
	(20.802)	(20.788)
Well water	−27.5449	−28.2325
	(18.990)	(17.731)
1/Distance to road	0.0198	0.0195
	(0.165)	(0.164)
Distance to Pittsburgh	−6.0167*	−6.0052*
	(3.213)	(3.217)
Age2	0.0127***	0.0127***
	(0.003)	(0.003)
Square feet2	0.1985**	0.1983**
	(0.079)	(0.079)
LotSize2	−0.8768***	−0.8730***
	(0.207)	(0.208)
# Shale wells within 1 mile *(1/ Dist. to road)	−1.4048**	−1.6899
	(0.530)	(1.306)
# Shale wells within 1 mile, 6 mo	−2.9734	0.3419
	(3.349)	(1.876)
Count Shale Wells * Well water		7.8052
		(10.188)
Count Shale Wells * AgLand		−11.7408*
		(5.980)
Landuse – Agriculture	−44.2650**	−43.4009**
	(18.808)	(18.277)
Landuse – Forest	−30.8842	−31.9095
	(40.200)	(40.357)
Landuse – Water	−247.0652	−249.8944
	(203.273)	(202.928)
Landuse – Commercial	−267.913***	−270.3866***
	(83.175)	(83.449)
Landuse – Industrial	−538.15**	−534.8394**
	(225.369)	(221.917)
Landuse – Other	94.5195	96.2322
	(160.893)	(161.938)

(*Continued*)

Table A2. Continued.

Variable	(1) No Land Use Interactions	(2) W/Land Use Interactions
Constant	763.212***	763.3719***
	(98.209)	(98.267)
Year-Municipality FE	Included	Included
Observations	3,646	3,646
R-squared	0.799	0.799

Note: Standard errors clustered by municipality in parentheses; $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$.

Table A3. Estimation Results Including Wellpad Fixed Effects

Variable	(1) No Land Use Interactions	(2) W/Land Use Interactions
Square feet (100s)	4.6575	4.6589
	(3.122)	(3.117)
Lot size (acres)	25.7549***	26.0024***
	(2.709)	(2.722)
Number of bedrooms	6.7203	7.0052
	(4.898)	(5.016)
Number of baths	13.7984***	13.7517***
	(5.122)	(5.118)
Stories	−3.2663	−3.1952
	(2.561)	(2.542)
Age of property	−4.0492***	−4.0630***
	(0.378)	(0.377)
Garage	58.1540***	58.2777***
	(8.923)	(8.984)
Fireplace	52.9948***	52.9431***
	(6.902)	(6.894)
Pool	57.3414***	57.6403***
	(20.442)	(20.177)
Well water	−35.1062*	−33.1527*
	(19.270)	(18.525)
1/Distance to road	0.0197	0.0196
	(0.156)	(0.159)
Distance to Pittsburgh	−6.3944**	−6.5567**
	(2.673)	(2.724)
Age2	0.0129***	0.0130***
	(0.003)	(0.003)
Square feet2	0.1936**	0.1931**
	(0.085)	(0.085)
LotSize2	−0.9017***	−0.9057***
	(0.201)	(0.198)
# Shale wells within 1 mile *(1/ Dist. to road)	−2.1597***	−0.1117
	(0.398)	(0.358)
# Shale wells within 1 mile, 6 mo	−3.477***	7.688***
	(0.824)	(2.853)

(*Continued*)

Table A3. Continued.

Variable	(1) No Land Use Interactions	(2) W/Land Use Interactions
Count Shale Wells * Well water		−12.364***
		(3.364)
Count Shale Wells * AgLand		−19.864***
		(5.662)
Landuse – Agriculture	−57.069***	−54.789***
	(18.353)	(18.361)
Landuse – Forest	−29.4316	−30.321
	(42.745)	(43.295)
Landuse – Water	−272.660	−285.941
	(222.931)	(213.169)
Landuse – Commercial	−261.835**	−268.508**
	(113.062)	(117.151)
Landuse – Industrial	−642.574**	−617.807**
	(242.856)	(234.130)
Landuse – Other	58.1985	53.393
	(170.389)	(169.935)
Constant	529.638***	537.355***
	(100.290)	(99.995)
Year-Municipality FE	Included	Included
Wellpad Fixed Effects	Included	Included
Observations	3,646	3,646
R-squared	0.806	0.806

Note: Standard errors clustered by municipality in parentheses; $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$.

Table A4. Estimation Including Well count Interaction with Large Lots (>5acres)

Dependent Variable: $(\sqrt{P_{ij}} - 1)/0.5$

Variable	(1) No Land Use Interactions	(2) W/Land Use Interactions
Square feet (100s)	4.6516	4.6106
	(2.981)	(2.952)
Lot size (acres)	25.5230***	26.2021***
	(2.695)	(2.835)
Number of bedrooms	6.6238	6.9018
	(5.357)	(5.519)
Number of baths	13.9760***	13.9321**
	(5.257)	(5.258)
Stories	−3.6398	−3.6209
	(2.494)	(2.486)
Age of property	−4.0738***	−4.0785***
	(0.400)	(0.398)
Garage	58.0216***	58.1541***
	(8.906)	(8.970)

(*Continued*)

Table A4. Continued.

Dependent Variable: $(\sqrt{P_{ij}} - 1)/0.5$

Variable	(1) No Land Use Interactions	(2) W/Land Use Interactions
Fireplace	55.9223***	55.4737***
	(6.745)	(6.756)
Pool	58.4804***	60.1845***
	(20.587)	(19.973)
Well water	−27.8026	−26.8200
	(19.162)	(18.855)
1/Distance to road	0.0219	0.0209
	(0.168)	(0.169)
Distance to Pittsburgh	−5.9901*	−6.0461*
	(3.220)	(3.181)
Age2	0.0127***	0.0127***
	(0.003)	(0.003)
Square feet2	0.1985**	0.1988**
	(0.079)	(0.079)
LotSize2	−0.8802***	−0.8982***
	(0.205)	(0.205)
# Shale wells within 1 mile *(1/ Dist. to road)	−3.2663***	0.0101
	(0.486)	(0.312)
# Shale wells within 1 mile, 6 mo	−3.2608***	0.7675
	(1.102)	(2.357)

(*Continued*)

Table A4. Continued.

Dependent Variable: $(\sqrt{P_{ij}} - 1)/0.5$

Variable	(1) No Land Use Interactions	(2) W/Land Use Interactions
Count Shale Wells * Large Lot		−27.1307***
		(2.481)
Landuse – Agriculture	−44.7526**	−44.8938**
	(18.918)	(19.096)
Landuse – Forest	−30.8544	−30.1849
	(40.191)	(40.385)
Landuse – Water	−245.4702	−249.1741
	(203.906)	(199.151)
Landuse – Commercial	−267.7508***	−269.9076***
	(82.446)	(84.133)
Landuse – Industrial	−541.5316**	−531.9391**
	(226.117)	(218.657)
Landuse – Other	94.0965	92.74
	(160.002)	(159.090)
Constant	762.7371***	763.8412***
	(98.731)	(97.151)
Year-Municipality FE	Included	Included
Observations	3,646	3,646
R-squared	0.799	0.799

Note: Clustered robust standard errors in parentheses: ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$.

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Unconventional Shale Gas Development and Real Estate Valuation Issues

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Abstract: This article provides an overview of the real estate valuation issues related to unconventional shale gas activities, particularly those related to hydraulic fracturing or "fracking." With the research on this topic in its infancy, we focus more on the valuation issues that *can* arise as opposed to those that *have* arisen. Central to this discussion are the factors associated with fracking activities that could alter the existing risk context of real estate valuation in communities and the role that information plays in developing risk perceptions. As current examples of these issues, we discuss some specific legal and regulatory changes that have arisen in Pennsylvania.

Keywords: unconventional shale gas, hydraulic fracturing, valuation
JEL Codes: R21, R31, Q38

1. INTRODUCTION

Unconventional natural gas is most broadly described as gas that is more difficult or less economical to extract (NaturalGas.org). According to the U.S. Government Accountability Office (2012), unconventional shale gas extraction has become more prevalent since its first use in the 1940s. Hydraulic fracturing or "fracking" is one part of the larger unconventional shale gas development process. Fracking is the process by which natural gas (usually methane) or petroleum is extracted from shale formations when high-pressure fluids are injected into cracks in the rocks, forcing them to open farther. Several activities associated with shale gas development are relatively more permanent (pipelines, roads and related infrastructure, pad area, any chemicals remaining in the groundwater or soil, gas seepage into drinking water) while others are relatively more temporary (local truck traffic, potential odors, earthquakes). We contend that the more permanent features of unconventional shale gas development are likely to affect property values and that the relatively temporary features are more likely to affect residents' use and enjoyment of the affected real estate.

In addition to physical impacts from direct development, shale gas development leads to new legal and regulatory challenges for real estate valuation. How local, state, and federal governments choose to regulate shale gas development will impact real estate values. These impacts are not trivial to individuals and families for whom real estate is a large value asset. Further, property values vary depending on the type of ownership and with the existing local

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laws regarding shale gas rights.[1] Local real estate markets in shale gas development areas include four different groups: those who own both surface and mineral rights, those who own only surface rights, those who own only mineral rights, and those that own neither. Shale gas development affects the value of their properties/rights differently. This paper describes the related issues that affect each group, from property rights to environmental concerns. These issues can be used to guide policy makers toward holistic policy design for legal and regulatory changes or updates.

The organization of the paper is as follows: we first present a brief literature review that discusses traditional real estate valuation methods and how shale gas development activities fit in the general context of property valuation. Second, we discuss the relationship between property value and the property owner's shale gas rights. Third, we present surface estate valuation issues related to direct shale gas development for both residential and commercial properties. Fourth, we present information about legal and regulatory changes and developments in Pennsylvania, due to shale gas development, and their impacts on property valuation. This includes a brief discussion of Pennsylvania's Act 13 and a pending Pennsylvania Supreme Court case on shale gas rights. Finally, we conclude with policy recommendations and potential avenues of future research related to real estate valuation and unconventional gas development.

2. LITERATURE REVIEW

Traditionally, the impact of amenities and disamenities on property values has been demonstrated using revealed preference and stated preference approaches. The behavioral process that underlies arguably the most commonly used revealed preference approach, the hedonic price method, was initially set forth by Rosen (1974). As described by Taylor (2008, p. 16-17), if consumer utility is defined over two goods, Z and X, where Z represents a housing bundle with characteristics $Z = z_1, z_2, \ldots, z_n$ and X is a composite numeraire good, then consumer j with α^j demographic characteristics has utility defined by $U^j (X, z_1, z_2, \ldots, z_n; \alpha^j)$. If we further assume that the consumer purchases only one unit of housing, the budget constraint is given by $y^j = X + P(Z)$. Then, the Lagrangian formulation of the utility maximization model is differentiated with respect to each argument in the utility function as well as the shadow prices to yield the first-order conditions. Rearranging the first-order conditions yields the Marshallian demands, which are used to derive the general indirect utility function v[P(X), P(Z), y]. By choosing X and each element of Z so that the marginal rate of substitution conditions are satisfied for each z_i, the consumer maximizes utility.

The empirical translation of the theory presented above is a hedonic pricing model, which is a revealed preference method that typically expresses the price of a good as a function of the characteristics of a good. Boxall, Chan, and McMillan (2005) found a negative impact on residential property value from proximity to traditional oil and gas facilities. However, as of this writing, there is very little literature on the effects of shale gas development activities on property values. An exception is Gopalakrishnan and Klaiber (2012), whose research used the hedonic pricing method to study the effects of shale gas exploration on property values in Washington County, Pennsylvania. Their results indicated that properties are adversely affected by proximate gas exploration sites/wells and that this effect dissipates with time and distance (the effect seems to disappear at 2 miles from a gas exploration site). One of their more interesting

[1]Here, we use "mineral rights" as the general term describing all subsurface rights. It varies from state to state whether natural gas rights and shale gas rights are listed separately.

results was that the effect on property values was worse (-3.8%) for properties that had well water as a source of drinking water; if these properties were surrounded by agricultural lands, the effect was even larger (-7.2%). While their study provides a variety of results using various econometric models, the overall conclusions indicate that the impact on property values due to gas exploration activities diminishes over time and distance, is larger for properties with well water as their main drinking water source, and is larger for properties near agricultural land, which is likely due to the concern of increased activity on surrounding properties.

Similarly, Muehlenbachs, Spiller, and Timmins (2012) utilize a hedonic model to determine if proximity to both vertical and horizontal gas wells creates a difference in property values through water supply. Their results indicate that property values increased for houses with "piped water" (i.e. public water) due to the positive economic impacts of natural gas wells. However, for those houses with "groundwater" (i.e. private wells) the presence of gas wells created a net decrease in housing values. Their research suggests differences in the consequences of gas wells on housing values that may be associated with the perceived risk of groundwater contamination.

Throupe, Simons, and Huo (2012) conducted contingent valuation surveys in Texas and Florida to test for any risk aversion differences to fracking activities. Contingent valuation (CV) is a stated preference method that is based on survey research. Typically, surveys are used to quantify respondents' willingness-to-pay or willingness-to-accept payments. These authors find that property value diminution will range from 5 to 15 percent in a robust real estate market and up to 25 percent in a weaker market, which is defined as having fewer sales and mortgage foreclosure issues.

The overall effect of shale gas extraction on property values is unknown and what is known is limited. The results of the above studies indicate that shale gas development can change the valuation of the existing real estate. However, a few studies cannot provide definitive answers to questions regarding the complex effects of shale gas development activities on property values. Future research is necessary to analyze the role of the economic impacts of shale gas development such as job creation, increased incomes, or population on real estate valuation. It must be understood that effects are different from, and co-exist with issues associated with environmental concerns, stigma, loss of use and enjoyment, the role of lease and/or royalty payments to owners of subsurface rights. The relationship between real estate valuation and shale gas development relates is further complicated by possible structural change and household migration. We expect these changes in housing demand to manifest differently in rural and urban areas. As such, the next section focuses on the valuation issues related to homeowners' shale gas rights and then discusses implications for both rural and urban areas.

3. SHALE GAS RIGHTS AND PROPERTY VALUE

Whether or not a property owner holds the surface and the mineral rights leads to a different market value. Property value is derived from the ownership of real property rights. To understand the impact of shale gas development on property values, we start with understanding the role of shale gas rights as a type of property right. Several issues that we discuss below complicate the relationship between property rights and property value in the shale gas context. First, homeowners may own the surface rights, but not own the mineral rights; this situation is called a split estate. Second, urban and rural residents have different considerations even if they own both the surface and mineral rights. Third, shale gas development is a relative new phenomenon. Local and state laws often do not have a specific description about shale gas rights, which makes the situation prone to disputes. The answers to the above issues are closely connected to property valuation at the time of resale, routine appraisal, and local assessment.[2]

According to Jaffe and Louziotis (1996), the most traditional economic models of property ownership identify three categories of property rights:

1) Right of use
2) Right of exclusion
3) Right of transfer

These rights are applicable to what is known as **fee simple estate** (also known as fee simple interest), which is the "absolute ownership unencumbered by any other interest or estate, subject only to the limitations imposed by the governmental powers of taxation, eminent domain, police power, and escheat" (Appraisal Institute, 2010). By contrast, the **leasehold interest** is "the tenant's possessory interest created by a lease" (Ibid.).

A typical homeowner has a fee simple interest, but with shale gas development leases these rights may become encumbered. For example, a property owner granting a shale gas development lease would share the *right of use* with the shale gas development company and associated parties; in doing so, they lose the *right to exclude* these parties from their property. In addition, they may lose the *right to transfer* (or sell) the property due to these leases, or they may only be able transfer (or sell) certain parts of the property depending on the various terms of the contract/lease. Further, current owners may find it difficult for potential buyers to obtain a mortgage if shale gas development leases are in place. We discuss this topic in more depth in a later section on mortgageability.

3.1 Land versus Mineral Rights

Understanding the traditional relationship between land and mineral rights is the key to understanding the unconventional shale gas rights attached to a property. In some states, property owners with fee simple interest can own the land rights, mineral rights, air rights, and even water rights to a property. In other states, an owner has the rights to only parts of these various media, and the municipality, for instance, owns the rest. It is important for property owners and policymakers to understand what can and cannot be owned and/or leased. Typically, the more rights a property owner owns the higher the value of the property. No matter how different the local mineral right regulations are, shale gas rights are a type of subsurface right.

One important note regarding land and mineral rights is that research indicates that underground changes (e.g. underground contaminants) have a direct and measurable impact on both *fee simple* values as well as the value of the surface rights taken alone. As a result, even though a lease or easement may only grant subsurface rights, an environmental condition in the subsurface may actually impair the value of the entire property. Lipscomb and Kimball (2012) provided an overview of the valuation issues and appraisal processes used to value subsurface rights. They note that appraisers must be careful to indicate what interests are being appraised, whether that be the "mineral estate" (the subsurface rights) or the "surface estate" (surface rights). The market value of the subsurface and surface rights cannot simply be added together

[2] Homeowners can trade mineral rights and surface rights separately if they own both of them.

to create a total value. Additional complexity arises because the laws and regulations regarding these different interests vary by state.

Generally, most states in the U.S. adopt common law, which considers mineral rights as the dominant estate. Thus, homeowners, especially those who only have surface rights, cannot stop mineral right owners from exercising the right to drill on their properties. Homeowner compensation for access varies across states. For example, according to the Pennsylvania Department of Environmental Protection (2010), the Commonwealth of Pennsylvania requires surface owners to provide "reasonable access for development and production" for mineral right owners. For surface right owners, activities such as legal consultation, pre-drill documentation, and well-site negotiation with drillers can be costly and time consuming; but they serve a vital purpose in protecting property rights pre/post lease. This may be the main way that homeowners can protect their property interests if related public policies gravitate toward more favorable policies for drilling companies.

3.2 Rural versus Urban Considerations

The valuation issues associated with shale gas development vary across rural and urban areas. Homeowners and prospective buyers of properties from rural and urban areas have different considerations of shale gas rights that are related to the usage and value of property.

Drilling on rural lands potentially poses the risk of making the lands less accessible for livestock and agriculture, and makes agricultural land planning for an entire property more difficult. At the time of a resale, the presence of gas wells on large rural tracts may restrict a property owner's ability to subdivide his/her property if drilling pads, containment ponds, access roads, and other building structures occupy certain portions of the property. Property value may suffer from decreased accessibility, difficulty of subdividing, and loss of acreage.[3] Local municipalities rarely reassess a property after a gas well is drilled unless property owners file a request to dispute the existing property assessment. In rural areas, homeowners rely on well water more often than municipal water, and the effects on property values from shale gas development activities may be stronger (e.g., Gopalakrishnan and Klaiber, 2012). For rural residents without access to municipal water, the quality of well water is essential for daily living and is a key driver of property value. Any actual risk or perceived risk related to water can affect property value.[4]

A final concern for rural residents who have mineral rights is that they may face restricted choices if they want to avoid shale gas development. Many oil and natural gas rich states have certain kinds of oil and gas conservation laws that describe the specific conditions for compulsory pooling.[5] This is where neighboring owners of potential oil and gas deposits join their lands together for exploration either voluntarily or under compulsory orders from state or local governments. If the pooling is voluntary, we assume that property owners are rational and are seeking to maximize their economic benefits. However, if pooling is mandatory, the law is

[3] According to Range Resources, one of the largest Marcellus Shale gas companies, it can take from several months to two years to drill a well. http://www.myrangeresources.com/Drilling/learn_drilling.aspx (retrieved on November 7, 2012)

[4] Fraser (2012) shows that 82.6 percent of residents from 31 shale drilling counties across Pennsylvania, Ohio, West Virginia, and Maryland think there is some environmental risk from Marcellus Shale development: http://www.pittsburghtoday.org/specialreports/MarcellusShaleWashingtonCounty.pdf (retrieved on November 22, 2012).

[5] Please refer to the following links of pooling of properties for oil and gas production from Pennsylvania and Michigan for further details: http://www.portal.state.pa.us/portal/server.pt/community/marcellus_shale/20296; http://www.michigan.gov/documents/deq/ogs-oilandgas-pooling_257974_7.pdf.

designed largely from the perspective of mineral rights owners and may not fully protect (surface) property values. This is an area where property values and potential environmental risks should be evaluated in policy creation and design.

Unconventional shale gas development in urban areas might affect property values, but is different from shale gas development in rural areas for several reasons. In urban areas, houses are more densely located. Drilling in urbanized communities and near public facilities brings additional uncertainty for homebuyers and for drilling companies. Urban home sites are typically much smaller than sites in rural areas. This suggests that the percentage of urban land required for shale gas development, assuming the footprint of a shale gas well site is held constant, is higher than the percentage of rural land required for shale gas development. Cady (2009), suggests that, for urban homeowners who control both the surface and mineral rights, the perceived costs of having gas wells in their backyards are greater than the perceived benefits (royalties).

As a side note, average annual royalty payments can be on a per-acre or per-well basis. On a per-acre basis, royalty payments range from several hundred to several thousand dollars per acre in early years of drilling, and decreases over time following the decline of well production.[6] Payments vary based on the size of a property and the market price of natural gas. For example, on a per-well basis, Encana, a Canadian company that operates 140 gas wells near Pavillion, Wyoming, pays property owners $1,321 on average for each year of access to their land (Drajem, 2012).

Urban drilling has some associated environmental impacts; these include the disposal of waste water, air pollution, noise, and fresh water usage (Cady, 2009). In the later section on legal and regulatory issues, we will discuss more about urban drilling issues based on the highly debated Pennsylvania Act 13.

From the above discussions, it seems that owners of large land parcels who control both the surface and mineral rights may benefit the most from shale gas development. Of course, the extent of shale gas development "winners" and "losers" has to be determined on a case-by-case basis and depends on how much surface activity interruption occurs due to unconventional shale gas development, royalty amounts, and fiscal policy pursued by state and local governments.

4. DIRECT SHALE GAS DEVELOPMENT AND VALUATION OF THE SURFACE ESTATE

In a previous section we discussed shale gas rights and royalty payments. In this section we focus on the potential impacts of direct shale gas development on valuation of the surface estate. We briefly mentioned this issue in the last section as it pertains to urban and rural homeowners. In this section we discuss the potential positive and negative impacts of direct shale gas development and how these impacts may affect commercial (income-producing) properties.

From a positive perspective, shale gas development may stimulate demand in local housing markets. According to a joint survey released in November 2012 from the University of Pittsburgh and *Pittsburgh TODAY* for 31 counties with Marcellus Shale gas development across

[6] Links to royalty calculators for Pennsylvania and Texas are: http://gomarcellusshale.com/royalty-calculator and http://southlakedrillingfacts.com/SouthlakeDrillingFacts.com/Facts_about_Royalties.html (retrieved on November 7, 2012).

Pennsylvania, Ohio, West Virginia, and Maryland, fully 90 percent of respondents believe that, to certain degree, "Marcellus Shale represents an economic opportunity;" and 74.9 percent residents either support or do not oppose shale gas extraction. It is uncertain whether the anticipated opportunities will occur and how local real estate markets will be influenced. If economic growth promotes population growth in the local areas as in-migration exceeds out-migration, it is expected, c*eteris paribus*, that increases in housing demand drive up regional housing values (Fraser, 2012). Likewise, anecdotal evidence suggests that property values may reflect capitalization of the subsurface rights/interests.

Alternatively, property value diminution may result, for example, from a violation of the bundle of rights as a result of environmental contamination or due to stigma from how real estate market participants perceive the real estate risks associated with shale gas development, especially for properties close to the shale gas development sites. For an overview of perceived risk (a type of stigma) as it relates to property values, see McCluskey and Rausser (2001). For an overview of stigma as it relates to property values, see Mundy (1992).

Other factors in property value diminution may occur if the habitability decreases (also related to use and enjoyment of that property); the ability to finance, refinance, or mortgage the property decreases; the ability to rent a property decreases; the risk perceptions of property owners change; or the risk of physical endangerment increases (also related to use and enjoyment). With the environmental uncertainties associated with unconventional shale gas activities, each of these outcomes is possible.[7] Appraisers measure the market value of real estate, as well as the diminution in value, using comparable market data. If reliable market data are not available, an alternative way to measure the changes to marketability, habitability, financing, and perceived and actual risks is to use survey research. Lipscomb (2011) provides an example of the use of survey research to measure the potential prospective impacts of a new biomass facility on surrounding property values. Certainly this kind of survey research would be applicable to a broader regional scale (instead of the local level) if theory suggests that the impact of unconventional shale gas activities would be capitalized into the regional housing market.

Environmental risk is one of the major factors that concerns local residents and influences property values. According to the same joint survey noted above, 82.6 percent of residents believe that there is some environmental risk from shale gas development. Chemicals involved in the shale gas development process, such as the fracking fluid itself, benzene, and methane, may enter the environment through various media. Also, noise from the truck traffic associated with shale gas development activities may be related to one's use and enjoyment of their property. Next we discuss how the environmental risks potentially related to shale gas development affect property value through four media: noise, air, water, and soil.

4.1 Noise

Shale gas development exploration and drilling often comes with increased activity (and noise) in small geographic areas. Increases in noise can cause areas that are not typically

[7] As of this writing, we are aware of at least one situation that may involve nearby fracking activities near a private home in Texas that resulted in the death of the owners' entire cattle herd and health impact on family members (*Lisa Parr and Robert Parr v. Aruba Petroleum, Inc. et al.*, Cause No. CC-11-01650-E, In the County Court at Law No. 5, Dallas County, Texas). We are also aware that in December 2011 the U.S. Environmental Protection Agency issued a preliminary report citing the Pavillion, Wyoming area as the only place in the nation where fracking activities are causing water contamination. These kinds of situations likely will not be noticed in regional hedonic property value models.

proximate to industrial activities and associated noise to be disturbed. Rural areas may be affected even more from increased noise impacts due to the already quiet natural surroundings and low background noise levels. Various studies have indicated that noise from traffic negatively affects property values (e.g., Wilhelmsson, 2000).

4.2 Air

Environmental impacts to air may occur due to shale gas development activities. Various news articles in recent years have indicated that dust (and whatever may be in that dust) as well as methane can move through the air near shale gas development sites. Further, diesel fumes from drilling engines and fracking pumps have been noted in various other news media as well as fumes from increased truck traffic (and associated noise). According to a June 12, 2012 article in *The New York Times* the World Health Organization declared that diesel fumes cause lung cancer, adding it to its list of carcinogens (McNeil, 2012).

With a variety of chemicals used in shale gas development activities, there could be other concerns related to air exposure, but these chemicals vary by site and by company and are not monitored in most states at this time. Regulations are slowly changing and various states require disclosures of these chemicals as well as the amounts used.

4.3 Water

According to Armstrong (2011), at least two potential environmental risks result from shale gas development: the additional demand on water resources required to perform hydraulic fracturing and the “potential release of hydraulic fracturing chemicals into the environment.” In a recent *Appraisal Journal* article (Huso, 2012), one appraiser interviewed for the article indicated that “land without water has no value.” His concern stemmed from an actual lack of water supply due to vast amounts of water being used in the fracking process. Current water supplies and the water required for shale gas development activities could become a real issue, which could affect the value of leases on lands used for shale gas development activities.

Abdalla et al. (2012) provided a description of the paths that shale gas development waters take and indicated that 60 to 90 percent of fracking fluids may remain below the surface. With the various components of fracking fluids as well as the naturally occurring elements (for instance methane) that are relocated due to shale gas development, groundwater can potentially be affected. From a valuation perspective, water quality affects property values.

Lunz (1989) noted that owners with contaminated groundwater underlying their properties have had their bundle of rights diminished. As a result, the properties lose both their preservation and value creation potential. For owners of properties with groundwater contamination, the bundle of rights is reduced to the single right of owner occupancy. Given some of the research on unconventional shale gas development and property values (e.g., Gopalakrishnan and Klaiber, 2012), it is not surprising that these effects are exacerbated if the primary source of water is a private well.

4.4 Soil

For soil, spills from “flowback” water can potentially cause both surface and subsurface soil contamination, which some experts indicate may be slightly radioactive according to Bernstein, Kinnaman, and Wu (2013). It is possible that environmentally affected soil correlates to property value diminution, though the impact likely will vary by contaminant, exposure pathways, and quantity (though quantity may not be relevant in all cases).

4.5 Environmental Concerns for Income-Producing Properties

Up to this point, we have focused on environmental contamination media and how they may impact residential properties. But, it is possible that income-producing properties may be impacted by shale gas development. Kilpatrick and Mundy (2003) discussed four factors that affect the value of income-producing property due to contamination:

1. Reduction in net operating income. This can be due to increased vacancy rates when finding a tenant to lease the space or finding a replacement tenant due to turnover takes longer than typical (assuming no contamination or stigma). With an increase in vacancy rates, an increase in property maintenance expenses typically follows. Typical pass-through charges to the tenant, such as utilities and yard maintenance, would be the responsibility of the landlord during periods of vacancy. Increased vacancy rates and maintenance expenses reduce net operating income.
2. Actual cost-to-cure. The costs for any on-site remediation could be borne by the landlord/owner, further reducing net operating income.
3. Ongoing increases in maintenance.
4. Stigma, which frequently results in increased capitalization (cap) rates, which are highly sensitive to risk or risk perception.

In Mundy's model, slight increases in cap rates can overwhelm the other three factors as a component of value diminution or loss. The author concluded that, in some circumstances, stigma effects are actually the greater portion of value losses to income-producing property owners. Therefore, commercial (income-producing) properties share some similar issues with residential properties (e.g. cost-to-cure, maintenance, and stigma) with respect to shale gas development that must be considered in discussion of public policy.

5. LEGAL AND REGULATORY ISSUES AND PROPERTY VALUE

As we have discussed, unconventional shale gas development can affect property values across property types (e.g. residential and commercial). Two of the major concerns related to property values and shale gas development are mortgageability and insurance. We present these items first, followed by a discussion of the relationship between legal and regulatory issues related to shale gas development and property values. As a case study, we present a brief discussion of Pennsylvania's Act 13 and a pending Pennsylvania Supreme Court case on shale gas rights.

5.1 Mortgageability Concerns

Mortgageability concerns stem from the potential environmental hazards and risks that may occur from shale gas development activities. If environmental contamination or risk is present (e.g. if drilling activities are present on a property), some banks will not originate mortgage loans on those residential properties. In a New York Bar Association article, Radow (2011) indicated that Wells Fargo is one of the banks that will not originate a loan on a residential property with drilling activities. For homeowners hoping to sell their home in the future, there is cause for concern that shale gas development activity may affect their ability to sell due to a potential buyer's inability to originate a mortgage on the property. Perhaps a greater concern is the situation of *improper* shale gas development activities, which would have its own set of environmental concerns. In essence, having drilling activities on one's property could affect the mortgageability of that property and should be researched in advance of signing any type subsurface lease. The compensation outlined in the lease may not be greater than or equal to the diminution in value of the property.

At the federal level, the *Selling Guide: Fannie Mae Single Family* (2009) provides some guidance on conditions that Fannie Mae considers unacceptable for federally subsidized loans. Also, the U.S. Department of Housing and Urban Development (U.S. HUD) has at least two documents that provide valuation guidelines and details on unacceptable sites and hazards: the *Valuation Analysis for Single Family One- to Four-Unit Dwellings* (U.S. HUD, 2007) and the *Multi-Family Accelerated Processing* (U.S. HUD, 2009) guide. U.S. HUD's environmental requirements include that the lender in a potential transaction must provide an environmental report that identifies any significant environmental issues to U.S. HUD. This environmental report may include a U.S. Environmental Protection Agency Phase I (an administrative review) and/or Phase II (which involves environmental sampling) site assessment.

The lack of mortgageability of a property is likely to be of concern to single-family real estate values. If lenders are reluctant to lend money to potential buyers, then housing transactions may be delayed or may not consummate at all. This would affect all parties (e.g. buyers, sellers, agents, and brokers) involved in real estate transactions. Certainly there can be a stigma associated with properties on which lenders are not willing to lend. As Robinson and Lucas (1998) suggest, stigma may result from "mortgage discrimination."

5.2 Insurance Concerns

Another concern related to real estate valuation is the lack of insurance coverage for any potential claims that might result from improper shale gas development activities on or near one's property. On July 13, 2012, Nationwide Mutual Insurance Company (2012) issued a press release that said the company did not have a comfort level with the unique risks associated with shale gas development and that they could not insure against problems from fracking activities for a reasonable price. This decision by Nationwide suggests that property owners should consult with their insurance company and possibly an attorney to determine the possible outcomes in case of an adverse event related to shale gas development activities. Since a property owner may not be able to insure against potential damage from shale gas development, s/he could potentially include a clause in the lease agreement requiring the lessee to return the property to its previous condition when the drilling activities are completed. Insurance coverage limitations or increased premiums could affect the amount that homebuyers are able to pay for housing, as overall households costs could increase. From a regional perspective, this is not dissimilar from the change in insurance carriers' coverage in Florida after a particularly damaging series of hurricanes in that state. It will be interesting to see if similar withdrawals of coverage occur as a result of shale gas development activities.

5.3 Act 13 and the Dunham Rule: The Case of Pennsylvania

Shale gas rich areas are experiencing significant changes in certain legal requirements to either better accommodate or monitor the development of shale gas. Protecting local residents and their properties is one of the motivations for these changes, which will have major impacts on real estate markets generally as well as individual properties. If legal requirements are too strict, then shale gas development may be stifled and property values will experience no impact, *ceteris paribus*. If legal requirements have a lack of specificity, then this will cause confusion, disputes, and even abuse of the legal and regulatory system. We use Pennsylvania Act 13 and a pending Pennsylvania Supreme Court case as examples to demonstrate the depth of changes, the degree of potential disputes, and eventually the strong impact on property values.

The Marcellus Shale formation covers about 60 percent of Pennsylvania. The boom in shale gas development activities comes with new regulations and controversies. Act 13 of 2012 is a new Pennsylvania statute that regulates conventional and unconventional oil and gas development (House Bill No. 1950). It amends the Pennsylvania Oil and Gas Act of 1984. The Act consists of six major chapters that address different aspects of the regulatory issues. These include:

1) establishment of an "unconventional gas well fee" to mitigate uncompensated impacts to communities by natural gas development
2) establishment of an "oil and gas lease fund"
3) establishment of a "natural gas energy development program"
4) enforcement procedures to protect health and safety of related parties and public and private interests related to the environment and natural resources
5) "local ordinances relating to oil and gas operation," and
6) "responsibility for fee."

One of the controversial parts of Act 13 is the chapter related to local ordinances. It requires the "uniformity of local ordinances," which means that "all local ordinances regulating oil and gas operations" have to allow for the "reasonable development of oil and gas resources." The Act makes it potentially possible to drill oil and gas wells anywhere in local communities in Pennsylvania, no matter what the prior zoning ordinances stipulate. Several municipalities, together with other entities, filed a lawsuit in the Commonwealth Court challenging this provision on the grounds that its requirement of uniformity divests municipalities of the ability to use their local zoning authority to protect their communities. In *Robinson Township, et al. v. Commonwealth of Pennsylvania Public Utility Commission, et al.*, the Commonwealth Court issued an opinion on July 26, 2012, voiding the relevant provisions of Act 13. The plaintiff agencies filed an appeal with the Pennsylvania Supreme Court. The case status is pending. The final ruling of this case is likely to have a profound effect on oil and gas development and affect property values in Pennsylvania.

Besides the controversial regulatory statute, the Pennsylvania Supreme Court is reviewing another case related to complicated mineral rights that may shake the foundations of the historic Dunham rule, which originated from *Dunham v. Kirkpatrick*, 101 Pa. 36 (1882). According to the Dunham rule, without specific mention, the reservations of minerals stated in a deed do not include oil and natural gas. In other words, mineral rights owners may not own the rights to oil and natural gas. However, in the case of *Butlers v. Powers*, the lower court ruling based on the Dunham rule was reversed by the Pennsylvania Superior Court. It focused on the "unconventional" nature of Marcellus Shale gas that is locked in the rock formation and different from traditional natural gas. The case was appealed to the Pennsylvania Supreme Court. In April 2012, the Pennsylvania Supreme Court agreed to take the case, which is currently pending. If the Dunham rule cannot be applied to Marcellus Shale, shale gas can be treated like coal bed gas, which belongs to the mineral rights owner and would complicate the existing and future shale gas leases. Needless to say, the property valuation issues related to these leases would be complicated.

5.4 General Policy Issues

Zoning has been used as a method of preserving property values. Industrial activities typically are not allowed in residential or even rural zones. As such, industrial properties require their own zoning under listings such as light or heavy industrial. Shale gas development is different because of the overlapping jurisdictions between states and local municipalities. Some states (e.g., New York and Pennsylvania) have state laws focusing on the regulation of oil and gas development and local laws focusing on land use. In the case of New York and Pennsylvania, both have state laws with provisions that supersede the local laws, which create difficulty for local zoning laws to work as intended when contradictions arise. A consistent legal framework in a state is crucial in order to have effective policies on shale gas development that create more certainty in local real estate markets.

It is common, in shale gas development areas, to find properties in a non-drilling township that experience impacts from activities taking place in an adjacent or nearby township that allows drilling. The possibility of externalities across communities also poses challenges for property valuation. Furthermore, according to the Appraisal Institute, appraisers usually use the sales comparison approach for residential property valuation, which requires data from prior transactions of similar properties. Since shale gas development is a relatively new consideration for appraisers generally, the techniques for making adjustments for “external obsolescence” in a non-drilling community due to the proximity to drilling communities have not been fully developed and codified. This adds another layer of complexity to property valuation in regions with shale gas development.

Policymakers must be aware of the potential spillovers that may occur in nearby communities if a shale gas development site is approved. An “external factors” consideration in the site approval process could be included, which would require shale gas developers to provide data to policy makers on the type and magnitude of potential spillovers to other communities, such as increased truck traffic (road infrastructure), increased water usage (aquifer supply), and increased dust (air quality). Further, additional scientific research could inform policies that specify a “safe” distance to the nearest drinking water source, or perhaps a “safe” distance from a residential area.

6. CONCLUSIONS

We have discussed a range of possible impacts on property values that may be associated with shale gas development. With the research on this topic in its infancy, the scholarly community will continue to learn as time passes. Particularly important will be the science that is needed to indicate an appropriate distance a shale gas well should be, for example, from residential properties and drinking water sources (such as rivers and private wells). It is necessary to obtain objectively measurable estimates of the environmental impacts. Then, once the scientific evidence has been determined, it is necessary to express these impacts on real estate valuation. Broadly speaking, changes in real estate valuation can be measured using revealed preference (e.g. hedonic pricing) or stated preference (e.g. contingent valuation) methods. Revealed preference methods are based on rents, incomes, and prices observed in the marketplace; stated preference methods are based on survey research, which can be used to quantify respondents’ willingness-to-pay or willingness-to-accept payments in contingent valuation (CV) scenarios.

The role of information about the science of shale gas development activities and how that information is used to create perceptions in the marketplace is critical. Sanders (1996) noted that geotechnical issues are among the most complex for market participants to understand. As a result, markets may be slow or inefficient to incorporate information about shale gas development into sales prices. In situations such as this, “stated preference” methods such as contingent valuation are often preferred over other “revealed preference” valuation methods because the former often provide more salient information about impacts to property *values* instead of sales *prices*. That is why we might expect there to be situations where the value impacts for individual properties may differ from the general *average* results one might find from regional econometric models.

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