Spring 2009: Volume 8, Number 1

Western Economics Forum

A Journal of the
Western Agricultural Economics
Association

Farm & Ranch Management

Marketing & Agribusiness

Natural Resources & the Environment

Policy & Institutions

Regional & Community Development

Western Economics Forum

Volume VIII, Number 1

SPRING 2009

Table of Contents

The Western Economics Forum

A peer-reviewed publication from the Western Agricultural Economics Association

Purpose

One of the consequences of regional associations nationalizing their journals is that professional agricultural economists in each region have lost one of their best forums for exchanging ideas unique to their area of the country. The purpose of this publication is to provide a forum for western issues.

Audience

The target audience is professional agricultural economists with a Masters degree, Ph.D. or equivalent understanding of the field that are working on agricultural and resource economic, business or policy issues in the West.

Subject

This publication is specifically targeted at informing professionals in the West about issues, methods, data, or other content addressing the following objectives:

- Summarize knowledge about issues of interest to western professionals
- To convey ideas and analysis techniques to non-academic, professional economists working on agricultural or resource issues
- To demonstrate methods and applications that can be adapted across fields in economics
- To facilitate open debate on western issues

Structure and Distribution

The *Western Economics Forum* is a peer reviewed publication. It usually contains three to five articles per issue, with approximately 2,500 words each (maximum 3,000), and as much diversity as possible across the following areas:

- Farm/ranch management and production
- Marketing and agribusiness
- Natural resources and the environment
- Institutions and policy
- Regional and community development

There are two issues of the *Western Economics Forum* per year (Spring and Fall).

Send submissions to:

Dr. Donald McLeod
Editor, Western Economics Forum
Dept. of Ag & Applied Economics
University of Wyoming
Dept. 3354 1000 E. University Avenue
Laramie, WY 82071
Phone: 307-766-3116
Fax: 307-766-5544
email: dmcleod@uwyo.edu

Biofuel policy for the pursuit of multiple goals: The case of Washington State

Ana Espinola-Arredondo, Philip Wandschneider, and Jonathan Yoder[1]

Introduction

The Washington State Legislature in April 2007 passed E2SHB 1303, an "act relating to providing for the means to encourage the use of cleaner energy." The legislation calls for recommendations about appropriate market incentives as well as research and development directions -- which are to focus on three basic goals: the development of a viable in-state biofuel and biofuel feedstock industry; the reduction of carbon emissions; and a reduction in petroleum dependency.

This paper provides a synopsis of a set of policy recommendations developed in Yoder, et al. (2008). The recommendations are discussed in the context of biofuel policy developments occurring now in Western North America and particularly in the Pacific coast states and British Columbia. The analysis draws on the rapidly growing economic literature on biofuel and global warming policy as well as the broader literature on policy design and implementation.

The result of the analysis is a unique policy suite designed to provide cost-effective incentives for the development of motor fuel markets that reduce both dependence on foreign oil and greenhouse gas emissions, in Washington and the Western states more generally. The analysis and policy recommendations highlight the differences between western states and the Midwest in terms of comparative advantages in current and potential future biomass based biofuel markets.

Biofuel markets in Washington and the West

Agricultural feedstocks for biofuel including oilseeds, sugar beets, and field corn are likely to account for only a very small fraction of Washington's agricultural production and state fuel needs. Current production of oilseeds and sugar beets in Washington is small. The projected breakeven prices for Washington farmers to produce these crops for biofuels profitably exceed current and projected prices. The few large ethanol and biodiesel processors in the region import nearly all of their virgin feedstocks from other regions. Washington State does not yet commercially produce any ethanol, though there is some production in neighboring Oregon.

This market outcome is partly due to the particular agronomic conditions of Washington. Overall Washington is very competitive in markets for myriad other high-value crops, which implies a high opportunity cost for switching land to biofuel feedstocks. This is not to say that new crops and cultivars will not emerge. To date, many potential biofuel feedstocks have received little research for variety development in Washington State relative to traditional crops

[1] The authors are Post Doctoral Fellow (anaespinola@wsu.edu), Associate Professor (yoder@wsu.edu), and Professor (pwandschneider@wsu.edu), School of Economic Sciences, Washington State University. This research was funded by the State of Washington, mandated and funded via H2SB 1303, section 402. Additional funding and support was provided by the Washington Agricultural Research Center under project number WNP00539.

like wheat, apples, and potatoes. New cultivars and agronomic techniques with high biofuel potential may be developed in the future.

In comparison to crop biofuel feedstocks, the long-run potential for biofuel production from lignocellulosic biomass in Washington State is more promising. Washington ranked fourth after California, Texas, and Oregon among 19 western states in available biomass (Western Governors Association 2008). The lack of maturity in the technology for producing biofuel from lignocellulosic biomass precludes a reliable estimate of the biofuel fraction at this point. It appears that ongoing research has potential to solve the engineering, biochemical, and logistics barriers to utilization of Washington's abundant lignocellulosic biofuel feedstock sources.

The Federal Energy Policy Act of 2005 and The Energy Security and Independence act of 2007 together mandate consumption requirements for biofuels. The requirements increase to 36 billion gallons by 2022. The corn ethanol contribution to the RFS is capped at 15 billion gallons per year beginning in 2015, with the remainder being *advanced* biofuels, such as biomass-based fuels. In the 2008 Farm Bill (H.R. 2419: Food, Conservation, and Energy Act of 2008), tax credits for corn-based ethanol are reduced from 51 cents to 45 cents per gallon (section 15331), while the tax credits for cellulosic are $1.01 per gallon (section 15321). These and other federal programs will likely provide Washington State and Western states an improved relative long-run position in future biofuel markets.

The State of Washington biofuel policy currently includes minor tax incentives for biofuel sales, limited funding for infrastructure development, and a renewable fuel standard (RFS) that was intended to build the percentage of renewable fuels. The actual implementation of the RFS was designed to be conditional on a certain amount of in-state biofuel production, which for biodiesel in particular, has not occurred. In contrast, last year, market-based ethanol sales (all from out-of-state sources) have satisfied the targeted 2 percent average blend rate.

Recommendations for market incentives

If the state wishes to address the three stated goals of biofuel market development, reduction of greenhouse gas emissions and petroleum dependence in a cost-effective manner, then the state should explicitly target greenhouse gas emissions. In addition, there is a trend nationally, regionally, and within some key government organizations in Washington, to move climate change policy toward a regional carbon cap and trade program. The recommendation offered here is that the state focus on price instruments such as carbon taxes to address greenhouse gas emissions and petroleum dependence, and utilize tightly associated tax credits and investment incentives based on net carbon emissions to promote an in-state low-carbon fuel industry. These tax incentives or grants should *not* be funded by general state funds. These and ancillary conclusions are motivated below.

The carbon tax is the centerpiece of the proposed program, but how the resulting revenues are used is integral to the cost effectiveness of the program. The carbon-emissions taxes can be used to develop a "renewable energy fund" which can be used in one (or all) of three ways:

1. to fund tax credits for low emission fuels produced in the State;
2. to support tax credits and research and development for low carbon fuels; and.
3. to reduce other taxes such as sales taxes and Business and Occupation taxes.

Support for a carbon-based policy approach

No state or federal policy in the United States has yet to target carbon emissions directly or explicitly. GHG emissions can be directly targeted for biofuel policy for several reasons. First, targeting greenhouse gases (GHGs) is the most effective way to address all three policy goals. Biofuels are highly variable in the amount of greenhouse gas emissions reduction, and can vary due to differences in feedstock efficiencies, in production processes, and in combustion characteristics. British Columbia recently adopted a carbon tax on nonrenewable energy sources (including motor fuels), but renewable fuels are exempt **(British Columbia Ministry of Small Business and Revenue 2008).** Although British Columbia's design strengthens incentives for renewable fuels over nonrenewable fuels, it does not provide differential incentives for the development of low-carbon *biofuels* over higher-carbon *biofuels*, despite the importance of doing so to insure an emphasis in this direction for biofuel technology development and adoption.

Focusing policy directly on the net contribution of (all) fuels to carbon emissions reduction will provide a foundation for motor fuel diversification and will encourage motor fuel development of the most environmentally benign fuels (renewable and nonrenewable), in both the short- and long- run, reducing the external cost associated with motor fuel.[2] It will spur further development of low carbon fuels on both demand and supply sides. This policy incentivizes a state energy industry that continues to be shaped by the issues of increasing energy scarcity and mitigation of global warming.

Importantly, advanced biofuels and biomass-based fuels show more environmental and economic promise in the long run than do the first generation biofuels (though it is likely that even these first generation fuels can improve their environmental performance if firms are given tangible incentives to do so). Moreover, Washington State has a better potential market position for biomass-based fuels relative to current starch and even oilseed based biofuels. Implementing a carbon-based policy approach will work in favor of Washington's comparative advantage in lignocellulosic feedstocks, especially in the context of developing regional, national, or global carbon policies.

Adoption of a carbon-based policy, though, does not come without additional regulatory and compliance complications, costs and weaknesses. Estimating net carbon emissions over the life of fuels is a complicated problem, especially for biofuels. The analysis entails consideration of the direct combustion emissions, emissions due to the production and distribution of the biofuels and feedstocks, and to the emissions changes in ancillary activities (Searchinger 2008, Fargione 2008). Measuring, standardizing, and applying carbon accounting is administratively costly, and the extent to which a carbon-emission based policy helps reduce carbon emissions cost-effectively depends on how accuracy of carbon emissions estimates.

Pitfalls exist for relying on life-cycle carbon emission estimates as a foundation for policy incentives, especially in the short run. Early integration of carbon intensity measurement and tracking into policy will spur accelerated improvements in carbon intensity measurement and

[2] There are several categories of substantial external costs associated with fuel use and vehicle miles traveled. Parry and Small (2005) find that externality costs related to traffic congestion, traffic related accidents and local air pollution are important external cost related to transportation fuels. However, our focus here is on greenhouse gas emissions.

tracking. Methodological improvements will come faster if they are relied upon in the context of a policy that provides incentives for improving these methods.

Support for a price-based policy approach

With a focus on greenhouse gas emissions as the foundation for policy, there remains a fundamental choice between price incentives (e.g. carbon taxes) versus quantity-based based instruments (such as standards and cap and trade programs). Stavins (2007, pp. 50-53) provides a useful and concise summary of the relative strengths and weaknesses of these approaches. In summary, the potential strengths of carbon emissions taxes over cap and trade include the following: 1) simplicity in implementation for regulators and firms; 2) reduction in political difficulties of allocating allowances; 3) ability to use tax revenues elsewhere in the economy; and 4) avoidance of carbon price volatility (which is introduced by a cap and trade). The potential disadvantages of taxes relative to cap and trade programs are as follows: 1) political resistance to new taxes; 2) potential increased cost to firms compared to traditional cap-and-trade programs without credit auctioning (which is the traditional method, though recent work and proposals tend to favor auctions); 3) compared to taxes, a cap and trade program avoids requests and battles for tax exemptions that might reduce the effectiveness of a tax system; 4) cap and trade programs provide more certainty over carbon emissions; and 5) a new cap and trade systems is easier to harmonize with other cap and trade programs.

A rapidly growing literature on the economic dynamics of climate change and mitigation is shedding light on the relative efficacy of quantity versus price instruments. For instance, Hoel and Karp (2002) and Newell and Pizer (2003) extend Weitzman (1974) to include the stock effects of GHG accumulation, but are based on several different assumptions about the characteristics of uncertainty and policy adjustment. Despite their differences, both find that taxes tend to dominate standards for controlling greenhouse gases. Newell and Pizer (2003) in particular find that the net benefits of using emissions taxes are several times larger than for standards, and that the dominance of taxes over standards is very robust over a reasonable range of parameter values. Karp and Zhang (2008) argue that price instruments are likely to outperform quantity restrictions for three reasons: a) rapidly changing markets and rapidly changing (endogenous) policy targets tends to favor the use of taxes; b) given that GHGs are a stock pollutant, the relative magnitude of the slope of the damage function would have to be implausibly large to favor quotas over taxes. (Hoel and Karp 2002); and c) market investment in abatement capital in response to both market conditions and policy instruments favors price instruments (taxes on GHGs) further. Finally, Pizer (2002), finds that expected welfare gains from an optimal price policy are five times that of an optimal quantity-based policy for mitigating climate change using a stochastic computable general equilibrium model. This literature review is neither exhaustive nor is the existing literature globally decisive in favor of one approach over the other. However, the recent literature suggests increasing support for the use of price instruments such as carbon emissions taxes for GHGs mitigation over quantity instruments such as standards and cap and trade regimes.[3]

[3] In addition to Cap and Trade programs under discussion, The Low Carbon Fuel Standard (LCFS) under development in California is receiving a lot of attention as a policy alternative for biofuels. The LCSF is basically a carbon based renewable fuel standard with credit trading, that restricts the average carbon “intensity” per gallon of fuel, but it does not address changes in total fuel production or consumption. As a result, the findings of Holland, Knittel and Hughes (2007) suggest that a Low Carbon Fuel Standard is not as cost effective as even a carbon cap and trade program.

Subsidies and the importance of revenue source

Along with renewable fuel standards, subsidies are the most common instruments for promoting biofuel markets. Subsidies are costly in two ways (the two terms *tax credit* and *subsidy* are used interchangeably). The direct costs are taxes on the citizens to fund the subsidy. Providing subsidies for fuel blendstocks such as ethanol also may alter the blend rate of blended fuels in favor of biofuels, but they also make blended fuels less expensive than they otherwise would be. This results in higher quantities demanded of blended fuels, reducing the effectiveness of this approach for reducing petroleum dependence and greenhouse gas emissions reduction.[4] It is possible for a subsidized blended fuel program to lead to a net *increase* in the use of fossil fuels.

Despite the weaknesses of tax credits (subsidies), providing tax credits for biofuels produced in the state may still be the most effective way to promote in-state production of biofuels and feedstocks, and this is often an objective of state governments (as is the case of Washington).[5] The *combination* of carbon tax and biofuel tax credit may be more effective in promoting state goals, than either alone. When carbon taxes are used to fund tax credits for low carbon fuels, the taxes increase the price of high carbon fuels relative to low carbon fuels and all other goods. Hence the taxes tend to reduce or reverse the price increase of blended fuel that a subsidy alone creates. The combination mitigates the incentive to increase blended fuel use, and will therefore more effectively support the goals of reducing carbon emissions cost-effectively and increasing the relative competitiveness of low carbon alternative fuels. Financing the subsidy programs from a fund generated by the carbon emission tax revenue avoids creating additional demand on general revenue funds that could lead to either higher general taxes or reprioritization of state spending.

Given that most or all fuels are net positive (lifecycle) carbon emitters, a carbon tax/subsidy combination amounts to a "shifted" carbon tax. This modified carbon tax would be zero for some fuel type with intermediate carbon intensity. It would be positive for high-carbon fuels, and negative -- a tax credit for fuels with lower carbon intensity – all proportionate to carbon emission intensity. The subsidies could be funded by the fuel taxes so that the policy mix could be more or less revenue neutral in the long run.[6]

There are interesting dynamics for the short run. A fixed carbon tax rate would generate relatively high revenues in the beginning due to the dominance of petroleum-based fuels. Since biofuel production is currently small, a revenue fund could build up a large endowment based on relatively low percentage taxes on the high carbon fuels. Given that Washington produces small amounts of biofuel now and likely in the foreseeable future, carbon tax revenues might initially go mostly unclaimed as tax credits, and the fund could accumulate. Even if the tax credits are little used initially, they would provide a long-term promise of tax credits for low-

---

[4] A series of recent working papers by de Gorter and Just (2007, 2008a, 2008b, 2008c, 2008d) highlight some of the incentive effects of subsidies, including some surprising problems when using subsidies from general tax funds in conjunction with a renewable fuel standard, as the federal government is doing.

[5] Federal biofuel subsidies provide incentives to increase biofuel production, but are not explicitly targeted toward specific states. Those states that have a comparative advantage for producing biofuels benefit most from these subsidies. Washington is not currently one of them.

[6] Galinato and Yoder (2008) develop a theoretical model of a revenue-neutral carbon tax/subsidy combination.

carbon fuels that would create an incentive for private investment in low-carbon fuel production in the State.

Further, early fuel tax revenues could be invested in R&D and infrastructure needs to complement private investment in the State's nascent biofuel industry. As the industry develops and low-carbon fuel production increases in the State, revenues from carbon taxes could increasingly move away from R&D toward tax credits for low-carbon fuels. Ultimately, perhaps, the marginal tax credits might go entirely for in-state low-carbon fuel production.

Using carbon tax revenues on high carbon fuels to support low carbon fuels is reminiscent of a related literature on *revenue recycling*: using environmental tax revenues to offset other taxes such as income, payroll, and sales taxes (Fullerton and Metcalf 2001, Parry 1995, Parry 1997, Bovenberg and Mooji 1994). An example is British Columbia's carbon tax, the revenues from which are targeted for reducing other provincial taxes (British Columbia Ministry of Small Business and Revenue. 2008). The basic argument of this literature is the following. Traditional taxes such as income taxes and payroll taxes reduce after tax returns to labor and business investments, reducing incentives for capital and labor investment. Environmental taxes, on the other hand, are traditionally prescribed to correct a market failure. So, if environmental tax revenues (which in principle improve welfare) can be recycled to reduce other traditional "distortionary" taxes, then this combination provides "double dividends," and if applied appropriately, can improve social welfare relative to traditional revenue-raising taxes.

Were it not for the State goal of supporting the development of a biofuel industry, a more typical revenue recycling approach would likely be an effective approach for reducing greenhouse gas emissions. However, in pursuing all three stated goals, directing at least some of the revenues from the modified carbon tax for incentives to promote in-state biofuel industry will likely reduce the costs of pursuing this last goal relative to tax credits/subsidies that are funded in some other way.

Conclusion

To promote the development of a biofuel industry while facilitating the reduction in state greenhouse gas emissions and reducing petroleum dependence, we propose an integrated biofuel policy approach that includes modified carbon taxes on motor fuels, the revenues from which can be used to fund incentives for low-carbon renewable fuel development and production. In the current market and technological environment, this approach has the capacity to provide incentives to reduce petroleum consumption and greenhouse gas emissions in the short and the long run, while providing a foundation for long run development of a biofuel industry that may have the capacity to be more competitive in advanced biofuel markets than it is today.

References

Bovenberg, A. Lans and Sjak Smulders. 1995. "Environmental quality and pollution-augmenting technological change in a two-sector endogenous growth model." *Journal of Public Economics*, 57(3): 369-391. http://www.sciencedirect.com/science/article/B6V76-46BMT4G-2/2/797a0f542ac48108a13ce59ad644c46b

British Columbia Ministry of Small Business and Revenue. 2008. “British Columbia Carbon Tax Update.” British Columbia Government. http://www.sbr.gov.bc.ca/documents_library/notices/BC_Carbon_Tax_Update.pdf

Climate Action Team. 2008. Leading the Way: Implementing Practical Solutions to the Climate Change Challenge. November. http://www.ecy.wa.gov/climatechange/2008CATdocs/ltw_app_v2.pdf

de Gorter, Harry and Just, David R. 2007. The economics of a biofuel consumption mandate and excise-tax exemption: An empirical example of U.S. ethanol policy. MPRA Working Paper No. 5503, . http://mpra.ub.uni-muenchen.de/5503/1/MPRA_paper_5503.pdf

de Gorter, Harry and Just, David R. 2008a. The Welfare Economics of an Excise-Tax Exemption for Biofuels and the Interaction Effects with Farm Subsidies. *Social Science Research Network,* Working Paper No. 2007-13, http://ssrn.com/abstract=1015542.

de Gorter, Harry and Just, David R. 2008b. "'Water' in the U.S. Ethanol Tax Credit and Mandate: Implications for Rectangular Deadweight Costs and the Corn-Oil Price Relationship.". *Social Science Research Network,* , http://ssrn.com/abstract=1071067.

de Gorter, Harry and Just, David R. 2008c. "The Law of Unintended Consequences: How the U.S. Biofuel Tax Credit with a Mandate Subsidizes Oil Consumption and Has No Impact on Ethanol Consumption." *Social Science Research Network,* Working Paper No. 2007-20, http://ssrn.com/abstract=1024525.

de Gorter, Harry and Just, David R. 2008d. The social cost and benefits of U.S. biofuel policies. Paper presented at the National Agricultural Biotechnology Council 20, Reshaping American agriculture to meet its biofuel and biopolymer roles, , Columbus, OH. http://video.google.com/videosearch?q=de+gorter%2C+harry&emb=0&aq=f#q=de%20gorter%2C%20harry&emb=0 (accessed November 6, 2008).

Fargione, Joseph, Jason Hill, David Tilman, Stephen Polasky, and Peter Hawthorne. 2008. “Land Clearing and the Biofuel Carbon Debt.” *Science* 29, 319, (5867): 1235 - 1238 . http://www.sciencemag.org/cgi/content/abstract/1152747

Fullerton, Don and Gilbert E. Metcalf. 2001. “Environmental controls, scarcity rents, and pre-existing distortions.” *Journal of Public Economics,* 80(2): 249 - 267. http://www.sciencedirect.com/science/article/B6V76-42T4F1V-4/2/50f0cb01c8a933779213f11773a6751f

Galinato, Gregmar and Jonathan Yoder. 2008. Revenue-Neutral Tax-Subsidy Policy for Carbon Emission Reduction. Washington State University School of Economic Sciences Working Paper WP 2008-22. http://www.ses.wsu.edu/PDFFiles/WorkingPapers/Yoder/WP2008-22-Galinato-Yoder-TaxCarbonEmis.pdf

Hoel, Michael and Larry Karp. 2002. Taxes versus quotas for a stock pollutant. *Resource and Energy Economics*, 24 (4): 367 - 384. http://www.sciencedirect.com/science/article/B6VFJ-46RKR3H-1/2/a519fb0c97d49d9aa37e2e58d0c755d9

Holland, Stephen P., Christopher R. Knittel, and Jonathan E. Hughes. 2007. . Greenhouse Gas Reductions under Low Carbon Fuel Standards?. Institute of Transportation Studies, University of California, Davis, Research Report UCD-ITS-RR-08-01. http://pubs.its.ucdavis.edu/publication_detail.php?id=1128

Karp, Larry and Jiangfeng Zhang. 2008. Taxes Versus Quantities for a Stock Pollutant with Endogenous Abatement Costs and Asymmetric Information. CUDARE Working Papers 1064. http://purl.umn.edu/42877

Newell, Richard G. and William A. Pizer. 2003. "Regulating Stock Externalities Under Uncertainty." *Journal of Environmental Economics and Management*, 45 (2): 416 - 432. http://www.sciencedirect.com/science/article/B6WJ6-47YY389-2/2/65e6ab338464718a5d87d565d3f28b0b

Parry Ian W. H. 1995. “Pollution Taxes and Revenue Recycling.” *Journal of Environmental Economics and Management*, 29 (3): S64 - S77. http://www.sciencedirect.com/science/article/B6WJ6-45S92WM-16/2/ea5ee19f7891079bc1ff3ecb601e96e7

Parry Ian W. H. 1997. Revenue Recycling and the Costs of Reducing Carbon Emissions". Climate Issues Brief No. 2. Resource for the Future. http://www.rff.org/rff/Documents/RFF-CCIB-02.pdf (accessed November 7, 2008).

Parry Ian W. H. and Kenneth A. Small. 2005. “Does Britain or the United States Have the Right Gasoline Tax?” *American Economic Review,* 95 (4): 1276-1289.

Pizer, William A. 2002. “Combining price and quantity controls to mitigate global climate change.” *Journal of Public Economics*, 85 (3): 409 - 434. http://www.sciencedirect.com/science/article/B6V76-4679PR4-5/2/d1d67c0d68ec28e7664504ef60997dc1

Searchinger, Timothy, Ralph Heimlich, R. A. Houghton, Fengxia Dong, Amani Elobeid, Jacinto Fabiosa, Simla Tokgoz, Dermot Hayes, and Tun-Hsiang Yu. 2008. “Use of U.S. Croplands for Biofuels Increases Greenhouse Gases Through Emissions from Land-Use Change.” *Science*, 319 (5867): 1238 - 1240. http://www.sciencemag.org/cgi/content/abstract/1151861

Stavins, Robert N. "A U.S. Cap-and-Trade System to Address Global Climate Change." Working Paper RWP07-052, Cambridge, Mass.: John F. Kennedy School of Government, Harvard University, October 2007. http://belfercenter.ksg.harvard.edu/publication/17657/us_capandtrade_system_to_address_global_climate_change.html.

Western Governors’ Association (WGA) with Kansas State University and the U.S. Forest Service. 2008. Strategic Assessment of Bioenergy Development in the West: Biomass Resource Assessment and Supply Analysis for the WGA Region: Final Report, September 1. http://www.westgov.org/wga/initiatives/transfuels/Task%204.pdf

Yoder, J., C. R. Shumway, P. Wandschneider, D. Young, H. Chouinard, A. Espinola-Arredondo, S. Galinato, C. Frear, D. Holland, E. Jessup, J. LaFrance, K. Lyons, M. McCullough, K. Painter, L. Stodick. 2008. *Biofuel Economics and Policy for Washington State*. A Report to the Washington State Legislature and the Washington State Governor's Office. December. 179 pp. plus appendices. http://www.ses.wsu.edu/research/EnergyEcon.htm .

Western Governors' Association (WGA) with Kansas State University and the U.S. Forest Service. 2008. Strategic Assessment of Bioenergy Development in the West: Biomass Resource Assessment and Supply Analysis for the WGA Region: Final Report, September 1. http://www.westgov.org/wga/initiatives/transfuels/Task%204.pdf

Yoder, J., C. R. Shumway, P. Wandschneider, D. Young, H. Chouinard, A. Espinola-Arredondo, S. Galinato, C. Frear, D. Holland, E. Jessup, J. LaFrance, K. Lyons, M. McCullough, K. Painter, L. Stodick. 2008. *Biofuel Economics and Policy for Washington State*. A Report to the Washington State Legislature and the Washington State Governor's Office. December. 179 pp. plus appendices. http://www.ses.wsu.edu/research/EnergyEcon.htm .

Can Conservation Easements Market Evolve from Emerging to Efficient?

Catherine M. Keske, Dana L. Hoag and Christopher T. Bastian[1]

Introduction

Private lands provide public benefits, such as open space and wildlife habitat, for which landowners are often not compensated (Bergstrom, Dillman, and Stoll, 1985). As a result, traditional land markets do not provide optimal levels of these socially desirable amenities. Economists promote conservation easements as a government facilitated "market based solution" (Anderson, 2004) to provide quasi-public goods. A conservation easement is a voluntary, but legally binding agreement, where the landowner commits to limit development and/or future changes in land use, thereby preserving socially desired amenities. Landowners may sell an easement, donate an easement and receive tax benefits, or engage in a hybrid combination of these two approaches. Landowners typically agree to prohibit future building on the property; limit future buildings to certain areas on the parcel; or restrict land use for which they may receive payment and/or tax benefits[2] subject to IRS regulations. Land under conservation easement remains privately owned and can be transferred, although the agreed upon development rights are extinguished[3].

Conservation easements address market failures, but implementation problems abound (Cheever, 1996). As they provide quasi-public goods, conservation easement programs are chronically underfunded. Most private landowners do not have the income or wealth to utilize all of the potential tax benefits. There is not enough compensation to fully eliminate deadweight losses resulting from the positive externality incurred by private landowners whose lands provide social benefits. Furthermore, appraisal practices have contributed to high profile, contentious IRS audits (Stephens and Ottaway, 2003; Ozarski, 2008). The issue is whether the conservation easement market flourish (become complete), vanish or remain perpetually incomplete.

The purpose here is to examine and discuss whether the emerging conservation easement market will ever operate efficiently. Answers are sought in the substantial literature characterizing emerging markets, though not traditionally applied to conservation goods, or partial interests in property rights, like conservation easements. Criteria is compiled to define an

[1] Assistant Professor, Agricultural and Resource Economics/Dept. of Soil and Crop Sciences, Associate Director, Institute for Livestock and the Environment, Colorado State University; Professor, Dept. of Agricultural and Resource Economics, Colorado State University; and Assistant Professor, Department of Agricultural and Applied Economics, University of Wyoming, respectively

Acknowledgements: This research was supported by the U. S. Department of Agriculture, CSREES NRICGP grant 2005-35401-16008. Views expressed herein are those of the authors and do not necessarily reflect the views of USDA CSREES.

[2] For a summary of these benefits, see Hoag et al., 2005.

[3] For readability, we use the terms "market for private land protection" and "market for conservation easements" interchangeably to refer to private lands encumbered with conservation easements

efficient market in order to characterize the conservation easement market as "emerging" and to describe where it is still lacking. Lessons are learned about market formation to suggest policies that can be implemented to improve efficiency in the conservation easement market and markets for other privately traded quasi-public goods.

Characterizing Conservation Easements as an Emerging Market

Based on the literature, three criteria are presented that must exist if conservation easement markets are to evolve to efficiency. These criteria include a *well-defined scope, consistent price signals, and absence of market failures*.

1) Well-defined scope

According to Buzzell (1999), the first step of defining a market is to finely specify the scope of the good around which the market is forming. In the case of conservation easements, the associated amenities being preserved can make the scope of the good difficult to succinctly define. The United States Internal Revenue Service, which effectively regulates tax payer financial benefits that result from donated conservation easements, is clear that the conservation easement MUST exhibit at least one of the following conservation values, as outlined in Section 170 (A)(2)(d) of the U.S. IRS Tax Code:

1) Public outdoor recreation and education

2) Significant wildlife habitat

3) Qualifying open space (including protection of agricultural land where there is a strong state or local government policy for protecting such land) or scenic views

4) Historic property

In the specific example for the market for private land protection where a conservation easement is involved, the tax code works toward defining the goods in a way that promotes efficiency. Interestingly, the government was recently forced to become more involved because the IRS needed to assure that the tax write-offs were legitimate. Due to the large role tax incentives play, IRS rules became an important contributor toward evolving the market.

2) Consistent price signals

Economic theory indicates that price effectively serves as a signal for both sides of the market (Smith, 1776; Friedman and Friedman, 1962, 1990). A well-documented stream of literature indicates that a fully developed market will present consistent price signals and provide information to market participants (Innes, 1990; Forsyth and Lundholm, 1990; Grossman, 1995; Marin and Rahi, 2000). So long as there is no interference with price communication, markets will operate seamlessly.

Suppose that the price information is inconsistent or counterintuitive to economic theory. This would probably be a sign that a market is incomplete, or new and not fully formed (Innes and Rausser, 1989; Lundholm, 1991; Marin and Rahi, 2000). Inconsistent price signals indicate that there is a need for market characterization as described in Coase (1988). Coase states that market characterization is an important, but often overlooked, step towards improving efficiency. Coase advocates for government regulations that minimize transactions costs in order to bolster greater trade volume —actions that will yield consistent price information.

Inconsistent price signals are a hallmark of the conservation easement market. Brown (1976) found that inconsistent prices affect wetland conservation easement programs in North and South Dakota and Minnesota. An econometric study by Plantinga and Miller (2001) found that land encumbered with conservation easements is difficult to value with traditional appraisal practices, although the authors suggested that the value of development rights is a monotonic relationship between distance from a city and a property in most cases. Anderson and Weinhold (2005) asserted that properties encumbered with conservation easements do not necessarily show a decrease in resale price when compared to properties that are identical in all respects except for the conservation easement. Nickerson and Lynch (2001) also found a statistically insignificant relationship between property price and a conservation easement.

Inconsistent price information is clearly linked to the presence of market failures, which will be discussed momentarily. However, another consideration is that CEs are often placed on unique, signature parcels of land described as protecting a community's "sense of place", which may be considered "priceless" to protecting community identity (Keske, 2008). The heterogeneity of such parcels may impede any kind of broad-scale price discovery – because "priceless" is in the eyes of the beholders, in this case, the parties involved in individual transactions.

3) Absence of Market Failures

An efficient market should be absent of market failures. There are at least three market failures that contribute to an incomplete market: thin markets, uncertainty, and information failures. Thin markets are defined as markets in which there are few buyers or sellers, and the sparse amount of transactions leads to market failure because there are not enough transactions to generate consistent price information, and transactions costs may be high (Carey and Sunding, 2001; Rosenzweig et al, 2002; Coase, 1988). It is well established that comparable sales for properties encumbered with conservation easements are limited for conservation easement appraisers and will take some time to develop (Plantinga and Miller, 2001; Keske and Hoag, 2006), but comparative sales data are increasingly becoming available for encumbered properties (McLaughlin, 2004).

Uncertainty is characteristic of an incomplete market, particularly in the study of financial and securities markets. The market for private land preservation presents uncertainty due to speculation on the conservation values that exist on the property. From a land trust's perspective, there is some uncertainty associated with verifying and protecting conservation values of the land for perpetuity, especially in the event of an IRS audit, which have become increasingly more common (Land Trust Alliance, 2009). From the landowner's perspective, conservation in perpetuity extinguishes option values (Boyd, Caballero, and Simpson, 2000), which may preclude future farm-saving measures or wealth transfers to heirs.

Information failures encompass incomplete or asymmetric information, where at least one side of the market lacks knowledge about market issues associated with risks or price information, yielding market inefficiency (Wang, 1994; Roth, Sönmez, and Ümar 2005). In the case of water markets, Carey and Sunding (2001) and Carey, Sunding, and Zilberman (2002) found that information asymmetry and lack of price information prevented emerging water markets from fully succeeding. Information asymmetry abounds in the conservation easement market. Landowners have better information about the amenities that exist on their land. Land trusts may have more experience and therefore more information about the values they place on similar conservation easements. Given that these transactions are privately negotiated one trade at a time, the market yields little information to help participants negotiating a trade.

Discussion: Policy Implications

By facilitating conservation easement markets and providing regulations to enforce tax policies, the government has, on one hand, created a market solution for private lands that provide public conservation values. On the other hand, despite the fact that financial benefits prompted by changes to the 1976 Tax Code invigorated the conservation easement movement, the market remains inefficient 30 years later. Without further government intervention, it is possible that the market may remain perpetually incomplete, as is the case with water markets. In this section policy recommendations are offered to transition the market for private land preservation from an emerging market into a more efficient one. Policies are proposed that reduce market failures (information failures, thin markets, and uncertainty, respectively), and facilitate progressive tax policies.

1) Invest in government communications and research programs that reduce information failures

Investment in research and government programs can reduce information failures on two fronts. First, more information regarding the resale of properties encumbered by conservation easements, perhaps in the form of a national or state-wide database, may yield more accurate, consistent appraisals. Availability of this database may be possible through The Land Trust Alliance, an NGO considered to be the "governing organization" for land trusts that "hold" conservation easements and enforce the land stewardship practices. The Land Trust Alliance has already reduced some information failures by committing resources towards availability of information and branding. For example, the Land Trust Alliance (2009) has developed many educational programs and informational guidelines, which are easily accessible on their website and their large land conservation electronic library. The Land Trust Alliance also recently awarded 12 land trusts with accreditation as part of its inaugural accreditation program to promote branding. With an accepted policy organization in place, appraisal information (and conservation attribute information) can be made available with cooperation from a government partner.

Second, more research is needed to understand and communicate landowners' conservation values and preferences for preserving environmental amenities. The bulk of academic research available focuses on the demand side for conservation easements. However, it is also important to recognize that landowners may be motivated to engage in land protection for non-financial reasons. Several agricultural studies have suggested that landowners receive non-consumptive use rent, referred to by Marshall (2002) and Hoag et al. (2005) as private amenity rent (PAR), which may impact their reservation price for a conservation easement. This may prompt a landowner to accept an easement that does not cover the full appraisal value. McLaughlin (2004) cites a joint effort by the State University of New York and the University of Vermont, noting that landowners enacting a conservation easement were motivated to do so primarily as a result of their "personal attachment to their land, a sense of altruism, and a commitment to the stewardship of their land." Despite the fact that PAR may nudge some landowners into conservation easements, the availability of financial benefits also has a clear influence on landowner willingness to consider conservation easements (Miller et al., 2009).

2) Decrease thin market properties by educating conservation organizations and landowners regarding one another's preferences

Land trusts may be able to reduce some of the information failures by signaling to landowners the weights that the trusts have for specific conservation attributes, such as open space. For example, by including the specific attribute in the organization's name (e.g. Colorado Open Lands), the land trust may make itself more identifiable to the landowner as a better potential match. This "niche branding", commonly used in the marketing field, represents one step of the market evolving from incomplete to emerging, and it indicates to landowners the specific weights that they may place upon these conservation attributes.

Thin markets and the resulting matching risk also present challenges. A trust may be interested in either the wildlife habitat or the open space conservation values of the property, but if the landowner possesses zero PAR for wildlife habitat, the landowner may not even consider approaching a land trust whose mission is to protect wildlife habitat. A landowner may have difficulty finding a land trust that may represent his specific conservation needs, particularly in the case of working or family heritage lands. Thus, due to the information failure, the landowner may end up converting his land to development because he is unable to find a land trust appropriate for his conservation needs. Public information regarding landowners' and land trusts' preferences, perhaps made available through the Land Trust Alliance, could reduce this matching risk problem significantly.

3) Make tax benefits progressive rather than regressive
Paradoxically, tax incentives are regressive in the sense that they are more beneficial to the rich than to the poor. Too little land is preserved because the tax is available but not attainable. According to Marshall, Hoag, and Seidl (2002), the top reason listed by landowners for NOT placing a conservation easement on a family ranch was financial—including insufficient funds available to facilitate transactions costs, and limited benefits from income and estate tax breaks. Thus, a more progressive tax benefit may allow for increased realization of private benefits.

Policies such as a transferable state income tax credit, like that used in Colorado, effectively reduce the amount of uncertainty about whether a tax benefit can be utilized because the landowner is able to receive more (if not all) of compensation for the loss of development rights when he enacts a conservation easement on his property. These tax benefits are progressive, rather than regressive. This occurs because what the landowner does not use against his or her income taxes can be transferred, or sold, to a third party, who pays the landowner $0.80 on the dollar for the tax credit. The third party may then utilize $1 of tax credit against his or her state income taxes. This tax program reduces the uncertainty that is associated with fluctuations in income and wealth that is experienced by many working farmers and ranchers. For example, the transferability of the Colorado tax credit may also provide the necessary infusion of cash that may be needed to expand an operation. However, as has been shown in Colorado, progressive tax policies also present potential for abuse (Simpson, 2004; Ozarski, 2008), and adequate enforcement will be required to mitigate these potential abuses.

4) Reduce uncertainty with respect to future earning power
There is considerable uncertainty with respect to a landowner's future income when he enacts a conservation easement on his land. First and foremost, in order to receive full financial benefits, conservation easements are required to be perpetual, which limits potential future income. This leaves the landowner with significant uncertainty about how they are affecting future land management and their heirs' inheritances. There will likely be opportunities in the future to make income from natural resources, but a binding conservation easement restricts the landowner from engaging in many of these opportunities. Expanding the availability of conservation lease programs that require landowner commitment for a finite, rather than perpetual, length of time can reduce income uncertainty for landowners, although these conveniences will need to be balanced with the priority of providing sustainable public benefits.

Summary and Conclusions

Questions remain as to whether the emerging conservation easement market will rise to the level of a complete market. The conclusion here is that some government intervention will make it more likely. Overall, government intervention facilitates more transactions and reduces transactions costs. Policy intervention following the suggestions from the previous section may transition the market for private land preservation from emerging toward a complete and efficient one because price signals may be more consistent.
It is important to note that it can be difficult to recognize when the market has reached efficiency, and without a crystal ball, no one knows for certain what the outcome from government intervention really will be. However, when comparing the market for private land preservation to other incomplete markets, the market for private land preservation shows signs that it is advancing through several development stages and that it could blossom into a mature market on its own with minimal government intervention. Although the market may "self-correct", this self correction will require a substantial increase in the number of private land conservation transactions. However, the opportunity cost related to non-intervention may be considerable while the market undergoes self-correction. Therefore, government intervention is necessary in order for the market for land preservation to evolve into an efficient and complete market in a timely manner. At a minimum such intervention will likely be a Pareto improvement.

References

Anderson, T. L. 2004. Viewing Land Conservation Through Coase-Colored Glasses. Natural Resources Journal, 44(2): 361-382.

Anderson, K.G., and D. Weinhold. 2005. Do Conservation Easements Reduce Land Prices? The Case of South Central Wisconsin. Dept. of Agr. and Applied Econ, Staff Paper 484, June 2005, University of Wisconsin-Madison, Staff Paper Series.

Bergstrom, J.C., B.L. Dillman, and J.R. Stoll. 1985. Public Environmental Amenity Benefits of Private Land: The Case of Prime Agricultural Land. Southern Journal of Agricultural Economics, July 1985: 139-149.

Boyd, J., K. Caballero, and R.D. Simpson. 2000. The Law and Economics of Habitat Conservation: Lessons from an Analysis of Easement Acquisitions. Stanford Economic Law Journal, 19: 209-254.

Brown, R.J. 1976. A Study on the Impact of the Wetlands Easement Program on Agricultural Land Values. Land Economics, 52(4): 509-517.

Buzzell, R.D. 1999. Market Functions and Market Evolution. Journal of Marketing, 63 (Special Issue 1999): 61-63.

Carey, J.M., D.L. Sunding, and D. Zilberman. 2002. Transactions Cost and Trading Behavior in an Immature Water Market. Environment and Development Economics, 7: 733-750.

Carey, J. M. and D. L. Sunding. 2001. Emerging Markets in Water: A Comparative Analysis of the Central Valley and Colorado-Big Thompson Projects. Natural Resources Journal, 14: 283-328.

Cheever, F. 1996. Public Good and Private Magic in the Law of Land Trusts and Conservation Easements: A Happy Present and a Troubled Future. Denver University Law Review 73: 1077-1102.

Coase, R.H. 1988. The Firm, the Market, and the Law. Chicago: The University of Chicago Press.

Forsyth, R. and R. Lundholm. 1990. Information Aggregation in an Experimental Market. Econometrica, 58: 309-348.

Friedman, M. (with the assistance of R.D. Friedman). 1962. Capitalism and Freedom. Chicago, IL: University of Chicago Press.

Friedman, M. and R. D. Friedman. 1990. Free to Choose: A Personal Statement. Orlando, FL: Harcourt.

Grossman, S.J. 1995. Dynamic Asset Allocation and the Informational Inefficiency of Markets. The Journal of Finance, 50(3): 773-787.

Hoag, D., C. Bastian, C. Keske-Handley, D. McLeod and A. Marshall. 2005. Evolving Conservation Easement Markets in the West: Western Economics Forum, May 2005: 7-14.

Innes, R.D. 1990. Government Target Price Intervention in Economies with Incomplete Markets. The Quarterly Journal of Economics, 105(4): 1035-1052.

Innes, R.D. and G.C. Rausser. 1989. Incomplete Markets and Government Agricultural Policy. American Journal of Agricultural Economics, 71(4): 915-931.

Internal Revenue Service Tax Code Section 170 Section 170 (A)(2)(d).

Keske, C.M. 2008. Rents, Efficiency, and Incomplete Markets: The Emerging Market for Private Land Preservation and Conservation Easements. VDM, Verlag Dr. Müller Aktiengesellschaft & Co. Publishers.

Keske, C.M. and D.L. Hoag. 2006. A Market Perspective. Exchange: The National Journal of Land Conservation, 25(4): 24-27.

Land Trust Alliance. 2009. Private Land Conservation in U.S. Soars. (Wyerman, J. 2006) www.landtrustalliance.org. Last accessed April 20, 2009.

Lundholm, R.J. 1991. What Affects the Efficiency of a Market? Some Answers from the Laboratory. The Accounting Review, 66(3): 486-515.

Marin, J.M. and R. Rahi. 2000. Information Revelation and Market Incompleteness. The Review of Economic Studies, 67(3): 563-579.

Marshall, A.B. 2002. "Investigating Agricultural Land Protection: A Theoretical Case Study on Conservation Easement Valuation And Tenure." Ph.D. Dissertation, Department of Agricultural and Resource Economics, Colorado State University.

Marshall, A.B., D.L. Hoag, and Andrew F. Seidl. 2002. "Colorado Landowner Conservation Easement Survey," Department of Agricultural and Resource Economics, 02-3. Colorado Experiment Station, Extension Technical Bulletin, Colorado State University.

McLaughlin, N.A. 2004. Increasing the Tax Incentives for Conservation Easement Donations: A Responsible Approach. Ecology Law Quarterly, 31: 1-115.

Miller, A.D., C.T. Bastian, D.M. McLeod, C.M. Keske, and D.L. Hoag. 2009. Factors Impacting Agricultural Landowners' Willingness to Enter into Conservation Easements: A Case Study. Society and Natural Resources: An International Journal. (Currently in Press).

Nickerson, C.J. and Lynch. 2001. The Effect of Farmland Preservation Programs on Farmland Prices. American Journal of Agricultural Economics, 83(2): 341-351.

Ozarski, J. 2008. Fact Sheet: IRS Audits of Conservation Easements in Colorado. May 2008. Colorado Coalition of Land Trusts.

Plantinga, A.J., and D.J. Miller. 2001. Agricultural Land Values and Rights to Future Land Development. Land Economics, 77(1): 56-67.

Rosenzweig, R., M. Varilek, B. Feldman, R. Kuppalli and J. Janssen. 2002. "The Emerging International Greenhouse Gas Market," Prepared for the Pew Center on Global Climate Change.

Roth, A.E., T. Sönmez, and M. U. Ümar. 2005. A Kidney Exchange Clearing House in New England. Practical Market Design, 95(2): 376-380.

Simpson, K. February 22, 2004. Conservation Efforts Might Lose Ground in Appraisal Flap. Denver Post.

Stephens, J. and Ottaway, D.B. December 21, 2003. Conservation Easements: Developers Find Payoff in Preservation. Donors Reap Tax Incentive By Giving to Land Trusts, but Critics Fear Abuse of System. Washington Post.

Smith, A. 1776. The Wealth of Nations.

Wang, J. 1994. A Model of Competitive Stock Trading Volume. Journal of Political Economy, 102: 127-168.

A Benefit Transfer Estimation of Agro-Ecosystems Services

Jay E. Noel, Eivis Qenani-Petrela, and Thomas Mastin[1]

Introduction

Agricultural land supports not only the production of food and fiber, but a variety of socially valuable non-market goods and services. Examples of those non-market goods and services include aesthetic experiences, wildlife habitat, carbon sequestration, and recreation to name a few. There is a growing awareness of the importance that provision of these non-market services has to the long-run sustainability of agriculture in general, and the sustainability of California agriculture in particular. This awareness has led to an increasing interest in the estimation of the ecosystem functions of non-market goods and services of agriculture.

As the ecosystem services are typically not traded in markets and do not carry an explicit market value, they are improperly quantified and often inadequately considered in policy decisions (Costanza et al.'s 1997). Calculating their actual value is a complex undertaking that requires finding an integrative metric that can link these services to human welfare (Pattanyak and Butry, 2005). Value estimates of the ecosystem goods and services can be obtained by relying on two approaches: a) cost-based methods that price these services according to their provision costs, and b) demand-side valuation methods that generate estimates of the willingness to pay or the consumer surplus related to a change in the provision level of these services (Madureira *et al*, 2007). Table 1 summarizes these methods and gives a short description of each category.

[1] The authors are Professor, Agribusiness Department and Director of the California Institute for the Study of Specialty Crops, Associate Professor, Agribusiness Department, California Polytechnic State University, and Lecturer, BioResource and Engineering Department, California Polytechnic State University.

Table 1: Approaches and Methods for Environmental Economic Valuation

Valuation Approach	Valuation Methods	Description
Cost-side	Replacement Cost	Costs of replacing environmental assets and related goods and services (e.g. replace soil fertility due to soil contamination)
	Restoration Cost	Costs of restoring environmental assets and related goods and services (e.g. restore soil fertility through soil decontamination)
	Relocation Cost	Costs of relocating environmental assets and related goods and services (e.g. moving existing habitats to alternative sites)
	Government Payments	Government payments for the provision of environmental goods and services (e.g. agri-environmental measures)
Demand-side Revealed preference Methods	Travel Cost Method	Estimates the demand for a recreational site using travels costs as a proxy to the individual price for visiting the site
	Hedonic Price Method (HPM)	Estimates the implicit price for environmental attributes through the individuals choices for market goods which incorporate such attributes (e.g. estimate implicit price for air quality in the price of a house)
	Averting Behavior (AB)	Estimates the monetary value for an environmental good or service observing the costs individuals incur to avoid its loss (e.g. buying water filters to assure safe drinking water)

Despite the relevancy of ecosystem evaluation, the existing empirical literature on this topic is scarce. It is limited to a few studies for each type of ecosystem or service (Pattanayak and Butry 2005, Pagiola et al. 2004), as the application of these primary evaluation methods is costly both in terms of time and financial resources. One way to take advantage of the benefits of primary research, while minimizing the use of resources is to rely on the benefit transfer method.

Benefit transfer methodology (BTM) represents a growing area in environmental economics research that has been fueled by the needs and demands of policy makers for estimates of non-market environmental goods benefits. Benefit transfer is a formal process whereby the stock of knowledge, rather than original research, is used to inform decisions (Loomis, 1992). Economic information from one place (a 'study' site where data are collected) and time is used to make inferences about the economic value of environmental goods and services at another place (a 'policy' site with little or no data) and time (Rosenberger and Loomis, 2000).

BTM took form as a separate method once the non-market valuation literature grew large enough to allow comprehensive synthesis and cross-study comparisons. It has matured in the last two decades into a viable approach for estimating the ecosystem benefits. BTM has been used more and more frequently by various bodies and organizations including government agencies to facilitate benefit-cost analysis of public policies and projects affecting natural resources (Bergstrom and DeCivita,1999, Colombo et al., 2007, Wilson and Hoen, 2006).

This paper illustrates the use of BTM for estimating the non-market benefit of goods and services provided by an agro-ecosystem. The site selected for this analysis is Kern County, California. This county was selected due to its geographic diversity and available data sources. Kern County is located in the southern San Joaquin Valley and encompasses an area of about 8,171 square miles or 5,229,440 acres, making it the third-largest county in California. The county is well-endowed with mineral resources and fertile land allowing for agricultural production to be a significant economic activity. Kern County has a population approaching 800,000 and is expected to continue population growth over the next 20 years. This increase in population is expected to exert pressure to convert agricultural land to housing, industrial, and commercial uses. Thus, it becomes increasingly important to determine the benefits of the agro-ecosystem goods and services provided by agricultural land, in order to determine appropriate land use policies. If this is not done, then it is possible that a significant yet, currently unaccountable and non-quantified portion of the total economic benefit of Kern County agricultural land base will not be considered in land use planning.

Benefit Transfer Estimate of Kern County Agro-Ecosystems Goods and Services

The estimation of the Kern County agro-ecosystem goods and services benefits begins with the GIS mapping of various land cover types. Data on the land categories used in this study were obtained from California Spatial Information Library, U.S. Fish and Wildlife's National Wetlands Inventory, and County of Kern Department of Agriculture/Measurement Standards. Table 2 present data on acreage and percentage of 13 land types present in Kern County as determined by the GIS analysis[2]. Figure 1 shows a map of Kern County land typology as developed by the authors of this study.

Table 2: Land Cover Typology for Kern County, California

GIS CODE	Land Type	Area (Acres)	Percentage of Land Type
AGR	Agriculture	1,209,465	23.0
CON	Forest-Conifer	176,688	3.0
DSHB	Desert Shrub	1,338,701	25.0
DWLD	Desert Woodland	7,141	01
FWET	Fresh wetland	52,265	1.0
HDW	Hardwood oak woodland	334,417	6.0
HEB	Herbaceous	1,254,210	24.0
MIX	Mixed hardwood, conifer	61,936	1.0
RIPF	Riparian Forest	151,051	3.0
SHRB	Shrubs	381,174	7.0
URB	Urban and Barren	218,278	4.0
URBG	Urban Green	94,143	2.0
WAT	Open Fresh Water	41,729	1.0

[2] A description of the GIS process used to provide the land type covers necessary to estimate the ecosystem services value associated with each can be obtained directly from the authors.

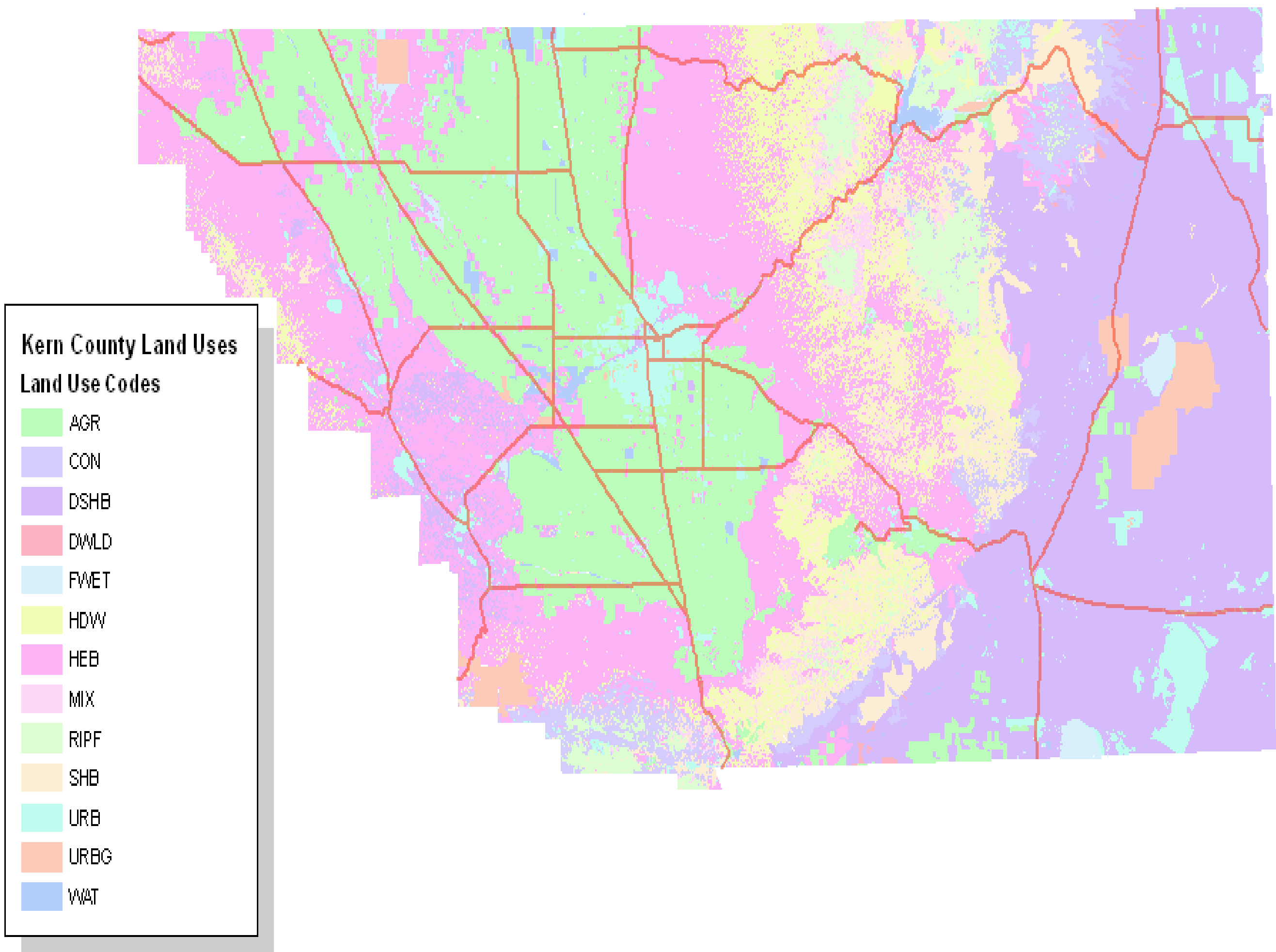


Figure 1. Map of 13 land categories in Kern County, California

Once the mapping of the land types for the study area has been completed, the ecosystem goods and services areas were overlaid on GIS mapping of land types to determine the acreage of each ecosystem good and service associated with each land type. The next step in the estimation of the agro-ecosystem goods and services benefits is the determination of the ecosystem goods and services benefit transfer values. This study uses benefit transfer values generated by Troy and Wilson (2006) and TSS Consulting (2005). These studies provide a set of unique standardized ecosystem service value coefficients broken down by land cover class and service type. The area included in Troy and Wilson study represents rich landscape heterogeneity that is sufficiently representative of most of California's major biomes to allow transferability of results to other parts of the state. To generate these benefit transfer estimates, Troy and Wilson considered preexisting studies published in peer reviewed journals, focused on temperate regions in North America, Canada and/or Europe, and focused primarily on non-consumptive use. They were able to obtain data from 84 viable primary valuation studies using these search criteria,. After coding these data points by temporal (i.e., time of study), spatial (i.e., place where study was done) and methodological (i.e., method used) criteria a lower bound, an upper bound and an average estimate of dollar values for the study site were derived.

Table 3 reports the available estimates by land cover type and ecosystem services that were used by Troy and Wilson to generate benefit transfer value coefficients. The numbers in white cells show that a total of 205 individual ecosystem value estimates were able to be obtained from the peer-reviewed empirical valuation literature for the land cover types included in this study. Areas shaded in grey represent cells where a service is anticipated to be provided by a land cover type, but for which there is currently no empirical research available. Given the aforementioned restrictions and gaps in the available literature, these values should be considered as providing a conservative, baseline economic values for the study area.[3]

Table 3: Gap of Estimates Matrix

ESS\LAND COVER TYPE	AGR	CON	DSHB	DWLD	FWET	HDW	HEB	MIX	RIPF	SHRB	URB	URBG	WAT
Gas & Climate Regulation		1				1		1				3	
Disturbance Prevention									2				
Water Regulation	1				1							1	1
Water Supply					2				5				7
Soil Retention & Formation	1								1				
Nutrient Regulation													
Waste Treatment					3				1				
Pollination	2												
Biological Control													
Refugium Function	1	4			1	4		4	2				
Aesthetic & Recreation	2	12			7	1		12	8			4	17
Cultural& Spiritual	2												

Source: TSS Consulting, 2005

A description of the ecosystems services considered in the estimate of Kern County agro-ecosystem goods and services benefit is provided in Table 4.

[3] The authors were unable to identify additional studies that could be used to augment the Troy and Wilson and TSS Consulting ecosystem services benefit values used in this study.

Table 4: List of Ecosystem Services Included in the Study

Ecosystem Services	Description
Gas and Climate Regulation	Capture and storage of carbon dioxide by forest and other plant cover, reducing global warming
Water Regulation and Supply	Storage, control, and release of water by forests and wetlands, providing local supply of water.
Soil Retention and Formation	Creation of new soils and prevention of erosion, reducing need for dredging and mitigation of damage due to siltation of rivers and streams
Waste Assimilation	Filtering of pathogens and nutrients from runoff by forests and wetlands, reducing the need for water-treatment systems
Nutrient Regulation	Cycling of nutrients, such as nitrogen, through ecosystem for usage by plants, reducing need to apply fertilizers
Habitat Refugium	Benefit of contiguous patches of forest and wetland in supporting a diversity of plant and animal life
Disturbance Prevention	Mitigation of flooding and coastal damage by natural wetlands and floodplains
Pollination	Services provided by natural pollinators such as bees, moths, butterflies, and birds, avoiding need for farmers to import bees for crop pollination
Recreation and Aesthetics	Recreational benefit of natural places as well as positive impact on nearby property benefits

Source: TSS Consulting.

As explained above, this study uses the benefit transfer estimates for ecosystem goods and service by land types generated by Troy and Wilson. These benefits coefficients derived by studies employing a variety of estimation methods were inflated to 2007 US dollar values using the CPI from the Bureau of Labor Statistics. The average benefit estimates by land cover type and ecosystem service are reported in Table 5.

Table 5: Ecosystem Goods and Services Benefit Estimates $/Acre/Year by Land Cover Type and Ecosystem Service

Land Cover	Ecosystem Service	Average Benefit ($/acre/year)
Agricultural Land	Water Regulation	111.57
	Soil Formation	6.35
	Habitat Refugium	13.97
	Pollination	8.98
	Cultural and Spiritual	797.52
	Aesthetic and Recreational	28.08
	Totals	966.46
Forest Conifers	Gas and Climate Regulation (CO2)	32.86
	Habitat Refugium	127.68
	Aesthetic and Recreational	201.56
	Totals	362.10
Fresh Wetland	Water Regulation	503.73
	Waste Treatment	1,853.47
	Habitat Refugium	5.49
	Aesthetic and Recreational	2,475.51
	Totals	4,838.23
Hardwood oak woodland	Gas and Climate Regulation (CO2)	36.87
	Habitat Refugium	127.68
	Aesthetic and Recreational	29.19
	Totals	193.74
Mixed Hardwood Conifer	Gas and Climate Regulation (CO2)	34.86
	Habitat Refugium	127.68
	Aesthetic and Recreational	201.56
	Totals	364.10
Riparian Forest	Water Supply	456.63
	Water Treatment	4.79
	Habitat Refugium	970.03
	Soil Retention	134.20
	Disturbance Prevention	1,073.66
	Aesthetic and Recreational	1,237.22
	Totals	3,876.53
Urban Green	Water Regulation	6.13
	Gas and Climate Regulation	366.48
	Aesthetic and Recreational	2,098.63
	Totals	2,471.24
Open Fresh Water	Water Supply	2,708.11
	Water Regulation	30.02
	Aesthetic and Recreational	452.75
	Totals	3,190.88

The third step in the benefit estimation of Kern County agro-ecosystem goods and services is the formulation of a benefit transfer function. Equation (1) represents the agro-ecosystems goods and services benefit function used in this study, where the total ecosystem goods and services benefit of a given land cover type is calculated by adding up the individual, nonsubstitutable ecosystem goods and service benefits associated with a specific cover type and multiplied by area as follows:

$$V(ESS) = \sum_{i=1}^{13} A(LCT_i) * V(LCT_{k,i}) \qquad (1)$$

where
$V(ESS)$ represents the total benefit provided by ecosystem goods and services of the entire area;
$A(LCT_i)$ denotes the area of a specific land cover type, and $i = 1,...,13$ as there are 13 land cover types present in the study area; and
$V(LCT_{k,i})$ represents the annual benefit per unit for ecosystem service type k, associated with land cover type i, with $k = 1,...,13$ to consider the types of the ecosystem services included in the study.

Results
Results of the estimated ecosystem goods and services benefits by land type using equation (1) for Kern County are presented in Table 6.

Table 6: Total Ecosystem Non-Market Goods and Services Benefit Estimates of Ecosystem Services by Land Cover Type

Land Class	Area (Acres)	Ecosystem Benefit ($/Acre/Year)	Total ESV ($)
Agriculture	1,209,465	$966.46	$1,168,899,543.90
Forest-Conifer	176,638	$362.10	$63,960,619.80
Desert Shrub	1,338,701	Unknown	
Desert Woodland	7,141	Unknown	
Fresh Wetland	51,828	$4,838.23	$250,755,784.44
Hardwood Oak Woodland	334,265	$193.74	$64,760,501.10
Herbaceous	1,252,913	Unknown	
Mixed Hardwood Conifer	61,930	$364.10	$22,548,713.00
Riparian Forest	151,005	$3,876.52	$585,373,902.60
Shrubs	381,010	Unknown	
Urban and Barren	2,182,267	Unknown	
Urban Green	94,069	$2,471.24	$232,467,075.56
Open Fresh Water	41,689	$3,190.88	$133,024,596.32
Total Benefit of ESS			$2,521,790,736.72

Results show that ecosystems goods and services provide a relatively large stream of benefits to Kern County, with a total benefit of more than $2.5 billion per year. Agricultural land has a benefit of $966.46 per acre which provides total agro-ecosystem non-market goods and services benefit of $1.2 billion per year or approximately 50% of the estimated benefits from those land types for the ecosystem goods and services benefits that were estimated. This is primarily due to the size of the agricultural land base, relative to the other considered land types. The cultural and spiritual, and water regulation are the most valuable services provided by agricultural land. Riparian forests contribute more than $585 million, mainly through the aesthetic and recreational and disturbance prevention functions. Fresh wetlands provide by far the highest agro-ecosystem services benefit per acre. Even though they cover relatively a small area in Kern County, they do provide the third highest benefit of ecosystem goods and services with a total benefit of more than $250 million per year.

Each of the remaining land type categories contribute to the total benefit of ecosystem goods and services as follows: urban green area provides more than $232 million per year, open freshwater provides about $133 million per year, followed by hardwood and conifers which contribute respectively $64 million and $63 million per year. Desert shrub is the most predominant land cover type in Kern County. However, there are no studies available in the literature that estimate economic benefits for desert cover types and thus their ecosystem services benefit is unknown.

Conclusion

Well-managed agricultural landscapes supply important non-market goods and services to society and this ability and stream of benefits should be explicitly considered in crafting public policies and/or market-based environmental protection and enhancement incentive programs. It can be argued that in order for land-use planners and policy makers to make informed decisions that they need be made aware of the non-market ecosystem services benefits that agricultural lands provide prior to developing land use policies and programs that could have a negative impact on those benefits.

This study illustrates the use of benefit transfer methodology as a tool that can be used to provide land use planners and policy makers' information about the non-market benefits provided by agricultural lands. The benefit transfer methodology used in this study resulted in an estimate of agro-ecosystem goods and services benefit of approximately $1.2 billion or approximately 48% of the total ecosystem goods and services land type benefits in Kern County.

The benefit transfer methodology is admittedly a second-best approach to the estimation of agro-ecosystem services. A basic criticism of benefit transfer methodology is the concern over transfer error, defined as the difference between the transferred value estimate and the true (unknown) value estimate at the policy site. Ready and Navrud (2005) note that several studies find average transfer errors of 40 or 50%, but with a wide range that can span from zero percent to several hundred percent for individual transfer exercises. It can be assumed that this study has a non-zero transfer error. The magnitude of the error for this study is unknown. However, as noted in Loomis et al (2008), several aspects should be considered when determining whether to utilize the BTM or ignore the non-market benefits of a resource. First, that BTM is more accurate than using static benefits such as those that have been developed in the past by government agencies which are adjusted by inflation every year. Second, the range of errors that are associated with benefit transfer can be informative to the decision maker when there is a greater probability of making wrong decision if that decision excludes important non-market benefits. Third, if the choice occasion or policy measure is a multi-million dollar irreversible decision than the errors associated with using transfer benefit may warrant the expense of an original non-market valuation study.

A further constraint to the practical use of benefit transfer methods for assessing ecosystem benefit is the lack of GIS and/or economic expertise among public land use planners. A promising approach to the solution to this constraint is presented by Loomis, et al (2008). Loomis et al present a benefit transfer toolkit that contains that contains the need databases, average benefit tables, meta analysis-based pre-programmed spreadsheets that are necessary to estimate ecosystem goods and service benefits. They illustrate the use of the toolkit valuing non-wildlife recreation such as hiking, camping, and reservoir recreation as well as natural environments such as wilderness. It may be possible to develop a similar toolkit so that it can be used by appropriate land-use planners to evaluate the agro-ecosystem benefit of agricultural lands.

As noted earlier a valid argument for the adoption and use of transfer benefit is the needs and demands of policy makers and natural resource managers for estimates of non-market environmental benefits concomitant with time and resource scarcity. The time and money constraints faced by those policy makers and natural resource managers provides support for utilizing benefit transfer methodology when assessing the agro-ecosystem non-market goods and services that agricultural lands provide to society. It can be a useful method for explicitly considering agricultural land non-market agro-ecosystem non-market goods and services when crafting public policies and/or market-based incentive programs.

References

Bergstrom. J. C., P. De Civita. 1999 “Status of Benefits Transfer in the United States and Canada: A Review” Canadian Journal of Agricultural Economics 47, pp 79–87.

Colombo, S., J. Calatrava-Requena, and N. Hanley. 2007 “Testing Choice Experiment for Benefit Transfer with Preference Heterogeneity” American Journal of Agricultural Economics. 89(1): pp 135–151.

Costanza. R., M. Wilson., A. Troy., A. Voinov., S. Liu., J. D’Agostino. 2006 “The Value of New Jersey’s Ecosystem Services and Natural Capital”. Gund Institute for Ecological Economics, Rubenstein School of Environment and Natural Resources, University of Vermont.

Loomis, J., Timm Kroeger, Leslie Richardson and Frank Casey (2008) “Benefit Transfer Toolkit for Fish, Wildlife, Wetlands, and Open Space” Western Economics Forum VII. pp. 33-43.

McConnell, Kenneth E. (1992) “On-Site Time in Demand for Recreation” American Journal of Agricultural Economics 60 pp. 918-925.

Ready, Richard and Ståle Navrud ” Benefit Transfer: The Quick, the Dirty, and the Ugly?” Choices 3rd Quarter 2005 .

Rosenberger, R. S., J. B. Loomis. 2001 “Benefit Transfer of Outdoor Recreation Use Values - A Technical Document Supporting the Forest Service Strategic Plan (2000 revision)”. Gen. Tech. Rep. RMRS-GTR-72. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

Troy. A., M. A. Wilson. 2006 “Mapping Ecosystem Services: Practical Challenges and Opportunities in Linking GIS and Value Transfer”. Ecological Economics 60 pp: 435–449.

TSS Consultants, Spatial Informatics Group LLC. 2005 “Assessment of the Efficacy of the California Bureau of Land Management Community Assistance and Hazardous Fuels Programs”. U.S. Bureau of Land Management, pp. 1–81.

Wilson, M., J.P. Hoehn. (2006) “Valuing Environmental Goods and Services Using Benefit Transfer: The State-Of-The Art and Science” Ecological Economics 60, pp 335–342. 80(2):277-278.

Empirical Methods for Modeling Landscape Change, Ecosystem Services, and Biodiversity

David J. Lewis and Ralph J. Alig[1]

The widespread development of land has been identified as a primary driver of global ecological change (Foley et al. 2005), affecting both terrestrial (Armsworth et al. 2004) and aquatic systems (Naiman and Turner 2000). It is increasingly recognized that understanding the effects of land-use change on ecosystems requires the integration of the social and natural sciences, a primary emphasis in the scientific literature now known as *land change science* (Turner et al. 2007). The discipline of economics has much to offer to land change science. On privately-owned landscapes, decisions regarding the use of land – whether to develop houses, grow trees, or plant a particular crop – are made within the context of local land markets and global commodity markets as well as local and regional regulatory institutions. As such, quantitative econometric land-use models are useful in accounting for such markets in estimation, especially if the modeling goal is the analysis of policies aimed at altering market incentives. However, because landscape pattern is fundamentally important for understanding many ecological processes, land-use models must confront the challenges associated with modeling not just aggregate land-use shares, but the *spatial pattern* of land use. Because landscape change is fundamentally shaped by the spatial pattern of landowner decisions, modeling landscape change must begin by modeling the decisions of individual landowners.

The purpose of this paper is to synthesize recent economics research aimed at integrating discrete-choice econometric models of land-use change with spatially-explicit landscape simulations and quantitative ecology. This research explicitly models changes in the *spatial* pattern of landscapes in two steps: 1) econometric estimation of parcel-scale transition probabilities from observed data; and 2) spatially-explicit simulations of landscape change that use the estimated transition probabilities as decision rules that guide land-use change. This paper will focus on the recent literature that examines the conservation of private land – an important issue for ecological change in both the western and eastern United States. Advances occurring in the past ten years regarding spatial data availability, micro-econometric modeling, spatially-explicit landscape simulation approaches, and policy applications are highlighted. The article closes by identifying multiple research challenges in need of attention by environmental and resource economists, including: 1) an increased focus on causal identification strategies; 2) improved accounting of unobserved heterogeneity in estimation; 3) the construction of new spatial-panel datasets; and 4) the development of fully coupled econometric-ecological models of landscape change.

Distinguishing Economic Methods for Modeling Land-Use Change from Other Disciplines

Many researchers from a variety of disciplines have developed methods for modeling changes in land use. Demographers have recently teamed with landscape ecologists and geographers

[1] The authors are assistant professor, Department of Economics, University of Puget Sound, and research forester, United States Forest Service, Pacific Northwest Research Station. The authors thank two anonymous reviewers and the editor for constructive comments. Funding support is acknowledged from the USDA Forest Service Forests on the Edge Project (Cooperative Agreement 07-DG-11132544-230). Opinions expressed are those of the authors and not the funding agency.

to develop methods to project housing growth for the United States, typically using decennial Census data as a basis for estimation (e.g., Hammer et al. 2004; Gustafson et al. 2005; Theobald 2005). Similarly, the USDA Forest Service has developed watershed-scale projections of housing growth using projection-oriented methods for the forty-eight contiguous states to highlight regions of concern for deforestation or more houses in forests (Stein et al. 2005).[2] Geographers offer a substantial literature that focuses on modeling land-use and land-cover change, as opposed to just housing growth (Veldkamp and Lambin 2001; Lambin et al. 2001; Walker 2003). Further, geographers have made advances in simulation-based methods applied to landscape change (e.g., Wu 2002; Allen and Lu 2003), most recently under the framework of Agent-Based Models (e.g., see Parker et al. 2003). The simulation methods devised in the geography literature have been particularly influential in pushing the economics literature to integrate landscape simulations and econometric modeling (e.g., Lewis and Plantinga 2007).

Economic methods used to analyze land-use change employ a modeling structure derived from economic theory. It captures the motivation of the landowner to convert land from one use to another. In particular, most modern micro-econometric models emphasize the importance of land rent in specifying the individual landowner's decision, and spend considerable energy on estimating *causal* effects. In contrast, geographic and demographic methods do not impose economic structure and typically use prior estimates of rates of land-use change to project future land-use. Although both methods can be used to project large-scale changes in land-use, a primary advantage of the economic approach is the ability to examine landscape change as a function of *policy-relevant* scenarios. For example, because geographic and demographic methods do not model land-use as a function of the net returns to land, such methods cannot be used to understand the effects of changes in commodity prices or incentive-based policies (e.g., Conservation Reserve Program) on land-use change.[3] Further, the focus of many geographic and demographic methods on housing density misses other important transitions, such as the recent *increase* in forestland of three million acres in the U.S. southeast (Alig and Plantinga 2004). Given the importance of forestland for ecosystem service provision, transitions between agriculture and forestry are particularly important for policies aimed at enhancing ecosystem services.

Econometric Methods for Modeling Land-Use Change (Step One)

Beginning with Bockstael's (1996) seminal analysis, the economics literature has emphasized the estimation of discrete land-use decisions at the parcel or plot scale, e.g., develop or not. A parcel is defined by ownership boundaries, while a plot is defined as a piece of homogeneous land, typically within an individual ownership boundary. Although land-use shares models estimated at the state or county scale (e.g. Alig 1986) are useful for examining the quantity of land-use change in a region or nationwide, parcel or plot scale models are required for analyzing the spatial configuration of landscape change.

Econometric models of land-use change emphasize the discounted stream of expected land rents in their specification of a profit-maximizing landowner choosing how to allocate a

[2] In the western U.S., the USDA Forest Service projects the largest loss in forest as occurring in portions of the Sierra foothills of California and in northern Washington state.

[3] For an example of the importance of market returns on land-use, note that Lubowski et al. (2008) find that the most important factor driving the increase in U.S. forests between 1982 and 1997 was timber rents.

homogenous plot of land – see Alig (1986), Capozza and Helsley (1989), and Stavins and Jaffe (1990) for theoretical underpinnings. If rental values and conversion costs are linear in parcel size – as is typically assumed – a landowner's decision on allocating a *parcel* of heterogeneous quality can be treated as the sum of land-use choices on constituent homogeneous quality *plots* (Lubowski et al. 2006). Econometric estimation of discrete-choice decisions typically specify Probit models of the binary development decision (Bockstael 1996; Carion-Flores and Irwin 2004); Logit models of a set of multiple land-use choices involving agriculture, forest, and development (Nelson et al. 2001; Lubowski et al. 2006; Newburn and Berck 2006; Lewis and Plantinga 2007; Langpap et al. 2008); gravity models of urbanization (e.g., Kline et al. 2001); duration models of the time to conversion (Irwin and Bockstael 2002; Irwin et al. 2003; Towe et al. 2008); and jointly estimated Probit-Poisson models of the decision to develop and the decision of how many new lots to create (Lewis et al. 2009b; Lewis 2009).

Estimating the discrete-choice land-use decision requires spatial data for at least two points in time, and such data have been derived from a number of sources. Plot-level land-use data have been derived from repeated surveys by the USDA's National Resources Inventory (NRI) (Schatzki 2003; Lubowski et al. 2006; Lewis and Plantinga 2007; Langpap et al. 2008) and the USDA Forest Service Forest Inventory and Analysis (FIA) dataset (e.g., Kline et al. 2001). Parcel-scale land-use data have been primarily obtained from local tax assessor or land information offices (Irwin and Bockstael 2002, 2004; Carrion-Flores and Irwin 2004; Newburn and Berck 2006; Towe et al. 2008), and digitized paper plat maps linked with tax assessor data (Lewis et al. 2009b). Figure 1a gives an example of parcel data. To date, parcel-level datasets have primarily been used for models of urban development, while the plot-level datasets have been used in applications involving a broader land base to model conversions between agriculture, forestry, and urban development.

In selecting between the national plot-level datasets such as the NRI, or the parcel-level data obtained by local governments, the prior literature has identified several tradeoffs. First, a clear advantage of the NRI and FIA is consistent nationwide data, while digitized parcel records tend to only be available at very local scales.[4] Second, since agricultural and forestry prices typically exhibit little variation within regions such as counties, it is difficult to estimate the effects of agricultural or forestry rents on land-use change with localized data, and the NRI has been usefully deployed to expand the geographic scope for estimation in prior analyses interested in such effects (Lewis and Plantinga 2007). Third, the NRI and FIA data do not typically disclose the exact location of plots due to confidentiality concerns, thereby reducing the usefulness of these datasets for analyses interested in the effects of fine-scale factors on land-use change. Examples of fine-scale factors of interest to land-use change modelers include minimum lot zoning policies (e.g., McMillen and McDonald 1989) and spatial externalities across land-uses (e.g., Irwin and Bockstael 2002), among others. Fourth, the NRI and FIA data do not provide information on the density of urban developments, and so models derived from these data are limited in their ability to differentiate land-use change by development density. Given its basis in ownership boundaries, parcel data have been shown to be particularly suitable for modeling the determinants of low-density development (Irwin and Bockstael 2007).[5]

---

[4] Parcel-scale data has become more widely available in recent years.

[5] To further highlight the importance of data sources, it should be noted that conclusions regarding the extent of urban sprawl derived from satellite-based land cover maps (Burchfield et al. 2006) have differed substantially from results derived with parcel data – see Irwin and Bockstael (2007) for the comparison.

Numerous econometric challenges arise with discrete-choice models that the literature has attempted to address – though much effort has been focused on the treatment of unobserved heterogeneity in estimation. For example, the question of whether a parcel is more likely to develop if its neighbor is developed has been examined in urban-rural fringe settings, and is challenging due to the presence of unobserved *spatial* heterogeneity (Irwin and Bockstael 2002, 2004; Newburn and Berck 2006). In particular, difficulties in estimating the effects of spatial externalities arises from the endogeneity of measures of neighboring development,[6] and, although there is evidence that spatial externalities are important (Irwin and Bockstael 2002)[7], this issue remains an active area of research. Another challenge from unobserved heterogeneity arises when researchers are interested in quantifying the determinants of development density, e.g. average lot size. Using data on observed developments to estimate the effects of a variety of covariates on density (e.g., McConnell et al. 2006) is subject to sample selection bias if there are unobservables correlated across both the decision to develop and the density decision. Recent work has specified jointly estimated Probit-Poisson models to account for such selection bias (Lewis et al. 2009b). One common feature of some of the most recent parcel-scale models is the use of simulation in the estimation stage as a means of accounting for important unobserved heterogeneity (e.g., Newburn and Berck 2006; Lewis et al. 2009b; Lewis et al. 2009c). Recent advances in micro-econometric estimation techniques (e.g., Train 2003) and computational speed have greatly facilitated simulation-based estimators and allow for parcel-scale econometric models with a less restrictive set of assumptions regarding the statistical independence of land-use decisions across parcels.[8]

Linking Econometric Land-Use Models with GIS and Ecological Models (Step Two)

Parcel-scale econometric models of land-use change generate estimates of the transition probability of a parcel of land. Such transition probabilities are a function of parcel-scale covariates such as lot size and physical characteristics (Irwin and Bockstael 2002), aggregated measures of net returns to various land uses (Lewis and Plantinga 2007; Langpap et al. 2008), or land policy variables such as zoning (Newburn and Berck 2006; Lewis et al. 2009b). Spatial data on each covariate found in the econometric model are then used to link the estimated transition probabilities to particular points on a landscape. Digitized GIS data from tax assessor databases typically provide the foundation necessary for landscape simulations when econometric estimation is derived from local tax assessor data. However, other sources of spatial GIS data must be used for landscape simulations when the land-use model is derived from NRI data.

[6] The endogeneity of measures of neighboring development in land-use change models arises due to the presence of spatially-correlated unobservables that influence multiple development decisions. For example, suppose parcel A develops because its development rents are bid up due to its location next to a scenic bluff. If neighboring parcel B is observed to develop after A, and the presence of the scenic bluff is not accounted for, then the effects of A's development status on B's decision is confounded by the presence of the bluff (an unobservable that is spatially-correlated across both A's and B's development decisions).

[7] In a binary land development model, Irwin and Bockstael (2002) argued that including variables indicating the amount of neighboring development would produce positively biased parameter estimates of such variables. Therefore, their estimate of a negative externality effect is bound from above.

[8] For example, a traditional Logit model of the binary development decision requires an assumption that unobservable components of the net returns to land-use are independent across observations. Simulation-based estimators – such as Random-Parameters Logit – allow researchers to relax this independence assumption in a variety of ways.

Simulations of landscape change can be performed once the estimated transition probabilities are linked to points on a landscape. Early analyses treated the transition probabilities as deterministic rules by, for example, assuming that each parcel converts to the use with the highest estimated transition probability (Chomitz and Gray 1996; Irwin and Bockstael 2002). Although such an approach has the advantage of producing a single estimated landscape pattern, Train (2003) argues that interpreting choice probabilities as deterministic rules is "opposed to the meaning of probabilities and the purpose of specifying choice probabilities" (p.73). An alternative method is to simulate a large number of different landscapes that conform to the underlying probabilistic transition rules (Lewis and Plantinga 2007). Such simulations are performed by repeating the land-use decision for each parcel multiple times through the use of random number generators. For example, suppose a parcel's estimated probability of converting from agriculture to development is 0.2, while its probability of remaining in agriculture is 0.8. The land-use decision can be simulated by drawing a random number *r* from a $U \sim [0,1]$ distribution, where the parcel remains in agriculture if $r \leq 0.8$, and converts to development otherwise. Repeating this process *S* times for *each* parcel on the landscape generates *S* different spatial landscape patterns.

The repeated Monte Carlo simulation approach is theoretically consistent with the econometric specification, but produces many different landscape patterns that must be summarized with spatial indices or some other measure of landscape output. The measure of output chosen largely depends on the goals of the analysis, and past studies have calculated the following metrics for *each* simulated landscape: core forest and average forest patch size (Lewis and Plantinga 2007; Lewis et al. 2009b), environmental benefit indices (Newburn et al. 2006), watershed health indices (Langpap et al. 2008), and lakefront development density (Lewis et al. 2009a). The landscape simulations generate distributions of each output measure that can be used to estimate moments, such as the mean and variance.

In terms of explicitly integrating economic and ecological models, the two-step approach has the advantage of being able to link with any ecological model that uses landscape pattern to estimate ecological response – a common feature in the field of landscape ecology. For example, Nelson et al. (2008) and Lewis et al. (2009c) use the two-step landscape modeling approach to estimate explicit biodiversity indices, defined to represent population persistence probabilities over a set of 24 terrestrial species in the Willamette Basin of Oregon. Lohse et al. (2008) use a two-step model to forecast the spatial pattern of land development and its corresponding effects on fish populations in a California watershed conservation analysis. Lewis (2009) simulates lakeshore development patterns in northern Wisconsin and integrates an ecological population model that estimates the effect of development on the extinction probability of green frogs (figure 1b). These examples are notable for explicitly integrating behavioral land-use decision models with quantitative ecological models, and thus are a step in fulfilling the broader goals of quantitatively coupling human and natural systems.

Policy Analysis with Landscape Models

Contemporary land-use policy tools range from government or non-profit purchases of land and easements, other voluntary incentives such as found in the U.S. Farm Bill programs, and local regulatory approaches such as zoning. All these policies can be and are frequently used to alter the provision of the many environmental public goods that arise from landscapes. The two-step landscape models offer the ability to examine the landscape consequences of alternative policy scenarios. The policy link derives from the fact that the underlying econometric models are functions of either net returns to land, or functions of regulatory policies such as zoning. As such, because the transition probabilities provide the foundation for landscape simulations, the effects of policy scenarios on landscape pattern can be examined. This last section looks at two example policy analyses conducted with the two-step landscape modeling framework.

The question of where to purchase land reserves when budgets are limited has occupied the conservation biology literature for at least 20 years. However, no analyses in conservation biology account for heterogeneity in both land costs and the probability of losing different types of undeveloped land to development. Newburn et al. (2006) devise a modeling framework that combines the two-step approach discussed above with a dynamic programming algorithm to optimally target conservation funds to increase the provision of environmental public goods at least cost. The analysis is conducted using tax assessor data in Sonoma County, CA, and demonstrates how the positive correlation between land costs and the probability of land-use conversion significantly alters optimal conservation targeting strategies.

Use of voluntary payments for altering land practices is now a widely discussed policy instrument. However, using voluntary payments to achieve spatial goals is challenged by the fact that the willingness of private landowners to accept a payment is private information, and thus, agencies cannot directly control landscape pattern through voluntary payments. Lewis et al. (2009a) discuss the theoretical issues that arise when such information problems combine with the fact that the marginal benefits of forest restoration are convex due to habitat fragmentation effects. In particular, their theoretical results show that conservation targeting might optimally involve corner solutions when deciding how much of particular regions to restore as forest. A two-step empirical landscape model is developed for the coastal plain of South Carolina to demonstrate the targeting solution and compare its results to other spatial targeting strategies. Private information on the willingness of landowners to accept conservation payments is empirically accounted for in the two-step model by treating land-use decisions in a probabilistic fashion and simulating multiple realizations of landscape change.

Concluding Thoughts

This paper has synthesized the recent literature pertaining to models of landscape change using a two-step approach that combines parcel-scale econometric models with GIS-based landscape simulations. Given the widely acknowledged importance of spatial landscape pattern for understanding the links between land-use, ecosystem services, and biodiversity, the two-step approach provides an empirical framework to integrate rigorous economic models with ecology. As demonstrated in multiple papers, such a framework provides a tool for resource economists to engage ecologists directly in analyzing policies to enhance the provision of environmental public goods from landscapes.

Future research in the spatial land-use modeling area can be enhanced in multiple ways. First, on the estimation side, further attention should be paid to causal identification strategies through greater use of quasi-experimental methods (e.g., Greenstone and Gayer 2009). For example, the hedonic pricing literature has recently made great strides with identification strategies based on techniques such as regression discontinuity (e.g., Chay and Greenstone 2005) and difference-in-differences (e.g., Horsch and Lewis 2009). In addition, because data available for estimation are often limited, continued refinement of micro-econometric approaches can improve the manner in which unobserved heterogeneity is accounted for in estimation.

Second, the resource economics profession should continue to exploit new spatial data sources, and in some cases, develop new datasets. Many advances that have been made in this literature in recent years have been made possible by enhanced data, especially increased availability of GIS land-use datasets, including increasing availability of local digital parcel data. Linking together multiple sources of local digitized parcel data would allow the geographic scaling up of many localized models. At the national scale, there are new challenges because the last year of available plot-level data from the NRI is 1997, and it is uncertain when additional plot-level data will be available to researchers in the future. Therefore, more work is needed to explore how other sources of nationally-consistent spatial data, such as the National Land Cover Dataset, could be exploited.

Finally, policy relevance for conservation can be strengthened through greater integration with quantitative ecology. The most promising integrations are for those ecosystem goods and services that are impacted by land-use change, such as wildlife conservation and water quality. A particularly challenging task is the development of fully coupled economic-ecological models, whereby estimation accounts for feedbacks between economic and ecological systems. Such an estimation task requires detailed historical data on land-use change, along with indicators of ecosystem goods and services. Development of such a fully-coupled analysis would represent a significant contribution of economics for land change science.

References

Alig, R.J. 1986. "Econometric Analysis of the Factors Influencing Forest Acreage Trends in the Southeast." *Forest Science* 32(1): 119-134.

Alig, R.J., and A.J. Plantinga. 2004. "Future Forestland Area: Impacts from Population Growth and Other Factors that Affect Land Values." *Journal of Forestry*, December, 19-24.

Allen, J., and K. Lu. 2003. "Modeling and Prediction of Future Urban Growth in the Charleston Region of South Carolina: A GIS-Based Integrated Approach." *Conservation Ecology*, 8(2): 2. URL: http://www.consecol.org/vol8/iss2/art2/.

Armsworth, P.R., B.E. Kendall, and F.W. Davis. 2004. "An Introduction to Biodiversity Concepts for Environmental Economists." *Resource and Energy Economics* 26: 115-136.

Bockstael, N.E. 1996. "Modeling Economics and Ecology: The Importance of a Spatial Perspective." *American Journal of Agricultural Economics* 78:1168-1180.

Burchfield, M., Overman, H.G., Puga, D., and M.A. Turner. 2006. "Causes of Sprawl: A Portrait from Space." *Quarterly Journal of Economics*, 121: 587-633.

Capozza, D., and R. Helsley. 1989. "The Fundamentals of Land Prices and Urban Growth." *Journal of Urban Economics,* 26:295-306.

Carrion-Flores, C. and E.G. Irwin. 2004. "Determinants of Residential Land-Use Conversion and Sprawl at the Rural-Urban Fringe." *American Journal of Agricultural Economics* 86(4): 889-904.

Chay, K. and Greenstone, M. 2005. "Does Air Quality Matter? Evidence from the Housing Market." *Journal of Political Economy*, 113(2), 376-424.

Chomitz, K.M., and D.A. Gray. 1996. "Roads, Land Use, and Deforestation: A Spatial Model Applied to Belize." *The World Bank Economic Review* 10(3): 487-512.

Foley J et al. 2005. "Global Consequences of Land Use." *Science*. 309(5734): 570-574.

Greenstone, M., and T. Gayer. 2009. "Quasi-Experimental and Experimental Approaches to Environmental Economics." *Journal of Environmental Economics and Management*, 57(1): 21-44.

Gustafson, E.J., Hammer, R.B., Radeloff, V.C., and R.S. Potts. 2005. "The Relationship between Environmental Amenities and Changing Human Settlement Patterns between 1980 and 2000 in the Midwestern USA." *Landscape Ecology*, 20: 773-789.

Hammer, R.B., Stewart, S.I., Winkler, R.L., Radeloff, V.C., and P.R. Voss. 2004. "Characterizing Dynamic Spatial and Temporal Residential Density Patterns from 1940-1990 across the North Central United States." *Landscape and Urban Planning*, 69: 183-199.

Horsch, E.J., and D.J. Lewis. 2009. "The Effects of Aquatic Invasive Species on Property Values: Evidence from a Quasi Experiment." *Land Economics,* 85(3): 391-409.

Irwin, E. and N.E. Bockstael. 2002. "Interacting Agents, Spatial Externalities and the Evolution of Residential Land Use Patterns." *Journal of Economic Geography* 2: 331-54.

Irwin, E., Bell, K., J. Geoghegan. 2003. "Modeling and Managing Urban Growth at the Rural-Urban Fringe: A Parcel-Level Model of Residential Land-Use Change." *Agricultural and Resource Economics Review,* 32(1): 83-102.

Irwin, E.G., and N.E. Bockstael. 2004. "Land Use Externalities, Open Space Preservation, and Urban Sprawl." *Regional Science and Urban Economics* 34: 705-725.

Irwin, E.G., and N.E. Bockstael. 2007. "The Evolution of Urban Sprawl: Evidence of Spatial Heterogeneity and Increasing Land Fragmentation." *Proceedings of the National Academy of Sciences*, 104(52): 20672-20677.

Kline, J., A. Moses, and R. Alig. 2001. "Integrating Urbanization into Landscape-Level Ecological Assessments." *Ecosystems* 4: 3-18.

Lambin, E.F., Geist, H.J., and E. Lepers. 2001. "Dynamics of Land-Use and Land-Cover Change in Tropical Regions." *Annual Review of Environment and Resources*, 28: 205-241.

Langpap, C., Hascic, I., and J. Wu. 2008. "Protecting Watershed Ecosystems through Targeted Local Land Use Policies." *American Journal of Agricultural Economics*, 90(3): 684-700.

Lewis, D.J., and A.J. Plantinga. 2007. "Policies for Habitat Fragmentation: Combining Econometrics with GIS-Based Landscape Simulations." *Land Economics,* 83(2): 109-127.

Lewis, D.J. 2009. "An Economic Framework for Forecasting Land-Use and Ecosystem Change." *Resource and Energy Economics* (Forthcoming).

Lewis, D.J., Plantinga, A.J., and J. Wu. 2009a. "Targeting Incentives to Reduce Habitat Fragmentation." *American Journal of Agricultural Economics* (In Press), DOI: 10.1111/j.1467-8276.2009.01310.x.

Lewis, D.J., Provencher, B., and V. Butsic. 2009b. "The Dynamic Effects of Open-Space Conservation Policies on Residential Development Density." *Journal of Environmental Economics and Management*, 57: 239-252.

Lewis, D.J., Plantinga, A.J., Nelson, E., and S. Polasky. 2009c. "The Efficiency of Voluntary Incentive Policies for Preventing Biodiversity Loss." University of Wisconsin-Madison Department of Agricultural and Applied Economics Staff Paper No. 533. Available at http://www.aae.wisc.edu/pubs/sps/pdf/stpap533.pdf.

Lohse, K.A., Newburn, D.A., Opperman, J.J., and A.M. Merenlender. 2008. "Forecasting Relative Impacts of Land Use on Anadromous Fish Habitat to Guide Conservation Planning." *Ecological Applications*, 18: 467-482.

Lubowski, R.N., Plantinga, A.J., and R.N. Stavins. 2006. "Land-Use Change and Carbon Sinks: Econometric Estimation of the Carbon Sequestration Supply Function." *Journal of Environmental Economics and Management*, 51(2): 135-152.

Lubowski, R.N., Plantinga, A.J., and R.N. Stavins. 2008. "What Drives Land-Use Change in the United States? A National Analysis of Landowner Decisions." *Land Economics*, 84(4): 529-550.

McConnell, V., Walls, M., and E. Kopits. 2006. "Zoning, TDRs, and the Density of Development." *Journal of Urban Economics,* 59: 440-457.

McMillen, D.P., and J.F. McDonald. 1989. "Selectivity Bias in Urban Land Value Functions." *Land Economics*, 65(4): 341-351.

Naiman, R.J., and M.G. Turner. 2000. "A Future Perspective on North America's Freshwater Ecosystems." *Ecological Applications,* 10: 958-970.

Nelson, G.C., Harris, V., and S.W. Stone. 2001. "Deforestation, Land Use, and Property Rights: Empirical Evidence from Darien, Panama." *Land Economics* 77(2): 187-205.

Nelson, E., S. Polasky, D. Lewis, A. Plantinga, E. Lonsdorf, D. White, D. Bael and J. Lawler. 2008. "Efficiency of Incentives to Jointly Increase Carbon Sequestration and Species Conservation on a Landscape." *Proceedings of the National Academy of Sciences* 105(28): 9471-9476.

Newburn, D.A., Berck, P., and A.M. Merenlender. 2006. "Habitat and Open Space at Risk of Land-Use Conversion: Targeting Strategies for Land Conservation." *American Journal of Agricultural Economics*, 88(1): 28-42.

Newburn, D.A., and P. Berck. 2006. "Modeling Suburban and Rural-Residential Development Beyond the Urban Fringe." *Land Economics*, 82(4): 481-499.

Parker, D.C., Manson, S.M., Hoffmann, M., Deadman, P. 2003. "Multi-Agent Systems for the Simulation of Land Use and Land Cover Change: A Review." *Annals of the Association of American Geographers*, 93(2): 314-337.

Plantinga, A.J. 1996. "The Effect of Agricultural Policies on Land Use and Environmental Quality." *American Journal of Agricultural Economics* 78: 1082-1091.
Schatzki, T. 2003. "Options, Uncertainty and Sunk Costs: An Empirical Analysis of Land Use Change." *Journal of Environmental Economics and Management*, 46(1): 86-105.

Stavins, R.N., and A.B. Jaffe. 1990. "Unintended Impacts of Public Investments on Private Decisions: The Depletion of Forested Wetlands." *American Economic Review* 80(3): 337-352.

Stein S., McRoberts, R., Alig, R.J., Nelson, M.D., Theobald, D., Eley, M., Dechter, M., and M. Carr. 2005. Forests on the Edge: Housing Development on America's Private Forests. Gen. Tech. Rep. PNW-GTR-636. Portland, OR: U.S.

Theobald, D.M. 2005. "Landscape Patterns of Exurban Growth in the USA from 1980 to 2020." *Ecology and Society*, 10(1): 32. [online] URL: http://www.ecologyandsociety.org/vol10/iss1/art32/ .

Towe, C.A., Nickerson, C.J., and N. Bockstael. 2008. "An Empirical Examination of the Timing of Land Conversions in the Presence of Farmland Preservation Programs." *American Journal of Agricultural Economics,* 90(3): 613-626.

Train, K. 2003. *Discrete Choice Methods with Simulation.* Cambridge University Press.

Turner, B.L., Lambin, E.F. and A. Reenberg. 2007. "The Emergence of Land Change Science for Global Environmental Change and Sustainability." *Proceedings of the National Academy of Sciences*, 104(52): 20666-20671.

Veldkamp, A. and E.F. Lambin. 2001. "Predicting Land-Use Change." *Agriculture, Ecosystems, and Environment*, 85(1-3): 317-332.

Walker, R. 2003. "Mapping Process to Pattern in the Landscape Change of the Amazonian Frontier." *Annals of the Association of American Geographers*, 93(2): 376-398.

Wu, F. 2002. "Calibration of Stochastic Cellular Automata: the Application to Rural-Urban Land Conversions." *International Journal of Geographic Information Science*, 14(7): 625-648.

Figure 1. Example of Two-Step Modeling Framework – Shoreline Development across Northern Wisconsin Lakes (from Lewis 2009)

Figure 1.a Input to econometric model: spatial-panel data from local land information office and plat maps

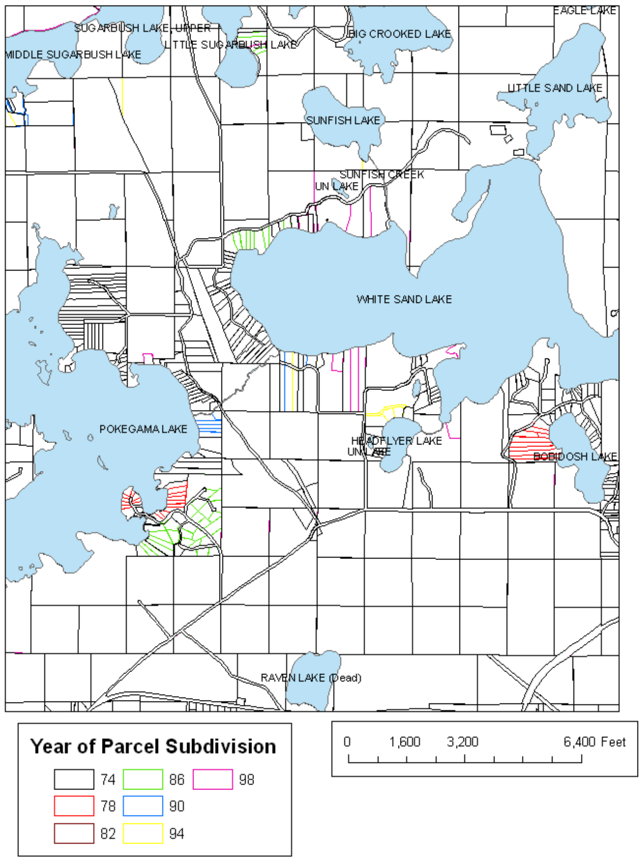
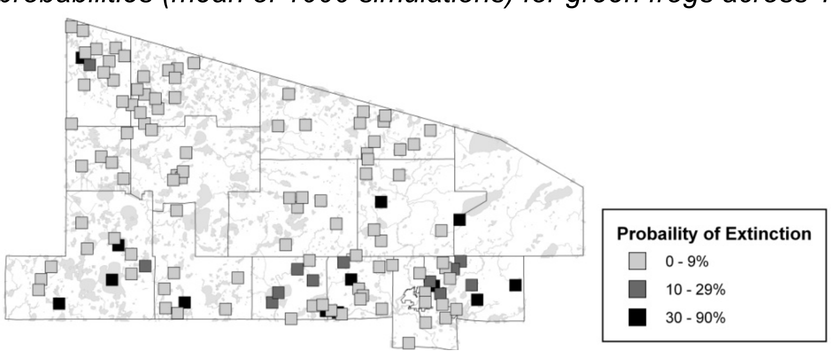


Figure 1.b Output from landscape simulations: 20-year forecast of expected extinction probabilities (mean of 1000 simulations) for green frogs across 138 lakes



Reclamation Costs and Regulation of Oil and Gas Development with Application to Wyoming

Matt Andersen, Roger Coupal, and Bridgette White[1]

Introduction

Boom and bust in Wyoming's energy sector is common and almost expected in the Rocky Mountain West's economy. However, the current energy boom in Wyoming has resulted in substantially more development than previous booms. For example, in the period 1988 to 1998 well counts grew at an annual average rate of 15 percent per year compared to 41 percent per year in the period 1998 to 2008.[2] As energy production increases there is growing concern about the pace of development and issues related to the reclamation of disturbed lands.

This study draws from a previous work by Andersen and Coupal (2009) that analyzed costs and policies that affect land reclamation decisions by oil and gas firms. We begin by providing a brief description of the current regulatory setting that governs the oil and gas industry in Wyoming and focus our attention on reclamation bonding requirements, which are intended to insure the proper reclamation of disturbed land. The most important issue affecting the decision to reclaim is the cost of reclaiming the disturbed land (although other factors such a clear reclamation guidelines and standards set by land management agencies are important as well). Therefore, we provide a detailed analysis of the cost of reclaiming orphaned wells in Wyoming using data provided by the Wyoming Oil and Gas Conservation Commission (WOGCC). The results are used to predict the current reclamation costs for Wyoming's oil and gas industry and to provide information on ways to improve the current bonding system.

As of 2009, there were more than 60,000 active oil and gas wells in the state operated by approximately 900 separate firms. This level of activity suggests that reclamation issues will become more important in the future as these wells are plugged and released or abandoned. Factors that become important in successful reclamation include the regulatory environment, industry structure, and environmental factors associated with the specific location of the field or well. Given the sheer number of wells and their distribution across varying ecological and precipitation regimes, as well as the sharp increase in development over the past decade, the structure and expectations of reclamation regulations becomes an important policy issue for State and Federal Agencies.

Regulatory Structure and Bonding Requirements

The Bureau of Land Management (BLM) is the main regulatory agency for oil and gas development on federal land. There are two aspects to the BLM's regulatory structure that are part of the reclamation decision and performance: the stated goals of reclamation and the

[1]The authors are Matt Andersen, Assistant Professor, Roger Coupal, Associate Professor and Department Head, and Bridgette White, graduate student, in the Department of Agricultural and Applied Economics, University of Wyoming, Laramie, WY 82071.

[2] Authors calculations based on WOGCC data, available on line at http://wogcc.state.wy.us

bonding parameters. The BLM's land management objective over the years has been to reclaim up to the level that minimizes spillover damages on associated tracts. Reclamation in this federal regulation [43 CFR 23.3] is defined as follows:

> "…Reclamation means measures undertaken to bring about the necessary reconditioning or restoration of land or water that has been affected by exploration or mineral development, mining or onsite processing operations, and waste disposal, in ways which will prevent or control onsite and offsite damage to the environment."

The BLM focus was on minimizing off-site damages. The language in the rule under proposal now dramatically expands the scope of what is expected of reclamation (Lahti, 2009). The proposed rule focuses on both short term and long term goals, and establishes reconstruction of the previous ecosystem as priority:

> "Short term goal: immediately stabilize disturbed areas and provide conditions necessary to achieve the long term goal. Long term goal: facilitate eventual ecosystem reconstruction to maintain a safe and stable landscape and meet the desired outcomes of the land use plan." [Lahti, 2009]

The interesting difference is the reference to ecosystem parameters that existed before the development. This suggests a higher standard than the guidelines that governed previous operating procedures.

A second aspect of the existing regulation is the reclamation bond. An environmental bond represents a guarantee against the failure to cure environmental damage from mining (Webber, 1985). A study conducted by the Political Economy Research Center (Gerard, 2000) concluded that bonding "is a market-based enforcement mechanism that relies on financial incentives and reputation effects to deliver site reclamation at the lowest possible cost." Some of the potential advantages of reclamation bonds include increasing the probability of reclamation and regulatory flexibility in monitoring and enforcement activities. Bonding mechanisms also have inherent limitations such as the opportunity costs associated with investment of firm resources in bonds, administrative costs, and legal restrictions (Shogren, 1993).

Bonding can occur through various instruments: cash outlays, capital liens, or surety bond companies who pay the bond on promise that the reclamation will be completed by the oil and gas company. The latter approach allows companies to minimize cash outlays to cover bonds, and is a common practice in the industry. However, recent reports on the surety bond market suggest that a market approach to bonding may be limited (Kirschner and Grandy, 2002). Surety bonds are increasingly difficult to secure because of general market conditions and higher risk.

The current bonding requirements for oil and gas development depends on the type of land under development, with slightly different regulation covering federal land as opposed to state and private land. The Bureau of Land Management (BLM) has authority to require a bond under the Mineral Leasing Act (MLA), and the current fees range from $10,000 for a single lease that may cover multiple wells to $150,000 for a national blanket bond that covers all production activities (across state-lines) and often cover hundreds of wells under a single blanket bond. In addition, producers can apply for a blanket bond of only $25,000 to cover all the wells drilled within one state. In Wyoming, the WOGCC sets the bonding requirements for private lands and they are similar to the federal requirements although the WOGCC has recently made some changes to the rules including adding a fee for idle wells.[3]

The biggest weakness of the current bonding requirements is that they are not linked to production, but are instead a fixed cost that is essentially a sunk cost from the perspective of the operator. The bonding requirements are poorly designed, and the bond amounts posted are low relative to the cost of actually performing the reclamation, which is the subject of the remainder of this study. Given accurate reclamation cost estimates, appropriate bonding requirements can be established that fully account for the cost of reclamation.

Reclamation Costs for Orphaned Wells

The following analysis of the cost of reclaiming land disturbed by oil and gas development in Wyoming was conducted using data from the WOGCC.[4] The cost figures represent the actual costs incurred by WOGCC in the process of fully reclaiming a total of 48 separate locations on fee lands that included a total of 255 orphaned wells in Wyoming from 1997-2007.[5] As a starting point, Table 1 shows the actual cost, bond amount, and variance (difference between cost and bond) for the full set of 255 wells: 1) per foot of drilling depth; and 2) per well.

Table 1: Orphaned Oil & Gas Wells in Wyoming (1997-2007)

	Actual Cost	Bond	Variance
Per foot	$10.01	$1.59	$8.42
Per well	$27,555	$5,302	$22,253

Notes:
a. Averages from full database (48 locations and 255 wells).
b. Includes orphaned wells with no bond posted.

The actual cost of the full reclamation of the 255 wells was $10.01 per foot of well depth, and approximately $27,555 per well. The bond per foot of well depth was $1.59, and per well was $5,302. Part of the reason why the bond amount per foot of well depth and per well seems low is because the full sample includes some wells that had no bond posted, as their development likely pre-dated the bonding regulations. However, this gives a good indication of the variance that currently exists in Wyoming because there is a mix of older wells with no bond posted, and newer wells that are fully bonded. The existence of the older un-reclaimed wells with no bond posted places an added financial burden on the state, above and beyond insuring that funds are available in the future to reclaim current development.

[3] The WOGCC has the authority to set additional bonding requirements for State and fee lands, among which includes the option of imposing an additional fee of $10 per foot of drilling depth for idle wells. See WOGCC Rules and Statutes, revised Chapter 3, Section 4(c). Available on line http://wogcc.state.wy.us/rules-statutes.cfm?Skip='Y'.

[4] The data in this analysis were provided by Don Likwartz, *State Oil and Gas Supervisor*, WOGCC (Fall 2008).

[5] It is important to note that the funds for reclaiming orphaned wells in Wyoming come from a mill-levy paid by the oil and gas industry, and do not come from the general tax fund.

Table 2 shows descriptive statistics clustered by single and multiple well locations. The first thing to note is that on a depth-per-well basis, single-well locations are substantially deeper than multiple-well locations Single-well locations averaged 4,602 feet / well, and multiple-well locations averaged 2,038 feet / well. The average cost per foot of drilling depth is similar between single and multiple well locations; however, the cost per well is very different. The cost per well at multiple well locations was much less than single well locations ($13,681 and $35,880 respectively). The large difference in the cost per well is mostly a result of the fact that single well locations are on average deeper than the multiple well locations. Also, reclamation is a capital intensive process that requires moving heavy machinery to remote locations, and therefore it is likely cost effective to reclaim multiple wells at a given location, and this would imply a lower cost per well relative to single well locations. Finally, the variance between the bond and the reclamation cost was also much larger for single well locations. This is probably because single well locations tend to have lower bonding requirements and higher per well reclamation costs relative to multiple well locations.

Table 2: Orphaned Oil & Gas Wells in Wyoming 1997-2007 (Clustered by Single Well and Multiple Well Reclamation Sites)

	Single Well	Multiple Well	Difference
Number of wells	1	12.5	
Depth (feet)	4,602	35,751	
Depth per well (feet)	4,602	2,038	2,564
Total cost ($)	$35,880	$202,028	
Cost per foot ($)	$9.77	$10.41	-$0.64
Cost per well ($)	$35,880	$13,681	$22,199
Bond ($)	$5,733	$29,556	
Bond per foot ($)	$0.89	$2.77	-$1.88
Bond per well ($)	$5,733	$4,584	$1,150
Variance ($)	$31,695	$194,609	
Variance per well ($)	-$30,146	-$172,472	$142,326

Notes:

a. All figures are simple averages and include locations with no bond posted.
b. Single well averages include 30 observations (30 wells).
c. Multiple well averages include 18 observations with a total of 225 wells.

Our cost analysis also revealed a very strong relationship between the total drilling depth at any location and the total cost of reclamation. The simple correlation between these variables is 0.985. The strength of this correlation suggests one simple method for estimating the total outstanding reclamation bill for Wyoming's oil and gas industry. To do this we used additional data from WOGCC that includes most of the active wells in Wyoming, and wells that are inactive but un-reclaimed (or under-reclaimed). The data includes 60,403 active wells under various classifications.[6] The total drilling depth for all 60,403 wells is 260,819,811 feet. Recall that reclamation costs were $10.01 / foot in our orphaned well database. Using this estimate, we calculated the current potential total outstanding reclamation costs for Wyoming as: (260,819,811 cumulative feet of well depth)×($10.01 / foot) = $2.61 billion. It is important to note that we are not implying that the public will pay for this reclamation cost as most of these costs will be paid by legitimate oil and gas producers. However, the number is a good indication of the size of the reclamation task ahead.

Parametric Estimates of Reclamation Costs

In this section we specify a model of reclamation costs and obtain parametric estimates of costs using the WOGCC orphaned well data, as well as some additional data from the Bureau of Land Management (BLM).[7] The combination of the BLM and WOGCC data resulted in 67 orphaned well locations that were reclaimed in the period 1997 to 2007. We pooled all of the observations into a single database to obtain parametric estimates of reclamation costs.[8] Table 3 shows descriptive statistics for the variables in the regression analysis.

Table 3: Descriptive Statistics by Location of Orphaned Wells

Variable	*Mean*	*S.D. Mean*	*Min*	*Max*
Cost ($)	82,082	33,392	658	2,135,217
Depth (feet)	14,134	6,525	295	430,867
Cost per well ($/well)	30,340	7,134	569	428,656
Depth per well (feet/well)	4,220	419	148	14,824
Number of wells	4.18	1.37	1	57
Precipitation index	2.22	0.08	1	3

Source: WOGCC and BLM orphaned well database compiled by authors.
Notes:
a. Orphaned well locations include single and multiple well sites.
b. The total number of observations (locations) is N = 67.
c. The total number of wells in all locations is 280.
d. The precipitation index (P) is a 30-year average from 1971-2002, and is equal to 1 if $0 < P \leq 10$ inches, is equal to 2 if $10 < P \leq 25$ inches, and is equal to 3 if $P > 25$ inches of average annual precipitation.

[6] Most of the WOGCC data used in this study are available on line: http://wogcc.state.wy.us/. Note that the WOGCC database is constantly updated and our data represent most but not all of the current active wells.

[7] The BLM data include 19 orphaned well locations provided by the Cheyenne office.

The sample includes a total of 280 orphaned wells at 67 separate locations, for an average of 4.18 wells per location. The average cost of the locations is $80,082, and the average cost per well (among the locations) is $30,340. The average drilling depth per location is 14,134 feet, and the average depth per well is 4,220. The total drilling depth among all 67 locations is 946,978 feet.

In the following regression analysis we specify a 'Hedonic' cost function for reclamation, where the total cost of reclamation in each location is assumed to be a function of three primary attributes, the number of wells per location, the total drilling depth per location, and the 30-year average of annual precipitation at the location. The number of wells and the drilling depth are obvious factors affecting the total cost of reclamation at each location. The precipitation index was also included as an environmental control variable. The logic of including the precipitation index is that areas with higher average precipitation are likely to experience relatively more natural re-vegetation while a well is under production compared to arid areas, and this is hypothesized to reduce final reclamation costs. The estimating equation is specified as:

$$C_i = n_0 + n_1 W_i + n_2 D_i + n_3 P_i + n_i . \qquad (1)$$

Where for each location i = 1,2,…,67, C_i is the total cost of reclamation, W_i is the number of wells, D_i is the total drilling depth, P_i is the 30-year average of precipitation, and ε_i is an i.i.d. error term with zero mean and constant variance. Equation (1) was estimated using an Ordinary Least Squares (OLS) estimation procedure and the results are presented in Table 4.

Table 4: OLS Regression Results

Dependent variable = Total Cost	
Variable	*Coefficient (t-stat)*
Wells	1,560* (1.79)
Depth	4.80*** (26.23)
Precipitation	-22,059** (-2.24)
Intercept	56,761** (2.48)
Goodness-of-fit	
Adjusted *R*-squared	0.9593

Notes:

a. Number of observations = 67.
b. Calculated *t*-statistics in parentheses.
c. *** denotes statistically significant at the 1% level, ** denotes statistically significant at the 5% level, and * denotes statistically significant at the 10% level.

The adjusted *R*-squared indicates that the independent variables jointly describe approximately 95 percent of total reclamation costs. The depth variable is highly significant and the wells variable is statistically significantly different from zero at the 10 percent level of significance. The precipitation variable and the intercept are also statistically significant at the 5 percent level.[9] Using the econometric results we obtained predicted costs for the current active wells in Wyoming based on the three key variables – number of wells, depth, and precipitation. The formula for the predicted cost, $\hat{C}_i$, of any location *i* is defined by Equation (2).

$$\hat{C}_i = 56761 + 1560 \times W_i + 4.80 \times D_i - 22059 \times P_i \qquad (2)$$

The results show that there is a substantial fixed cost equal to $56,761 for each reclamation location. However, because the data are organized by location (the cost estimates are by location not per well), some additional modifications are necessary to obtain a prediction of cost per well. From Table 3 we can see the average number of wells per location in this database is 4.18, implying a fixed cost of $13,584 per well.[10] The fixed costs are independent of the number of wells and drilling depth, and probably the largest fixed cost is related to road reclamation.

The variable costs of reclamation are related to the number of wells and total drilling depth per location. For each additional well drilled at a given location total costs increase by $1,560, and for each additional foot of drilling depth total costs increase by $4.80. Furthermore, reclamation costs are reduced in areas with higher precipitation. However, the interpretation of the estimated coefficient on precipitation is not as straightforward because the precipitation variable is not continuous (it is an indicator variable). The negative $22,059 estimate can be interpreted as a $22,059 reduction in the cost per location as we move from one precipitation classification to next. On a per well basis this is equal to $5,277.[11] The predicted cost, $\hat{C}_j$, for any well *j* is then given by Equation (3):

$$\hat{C}_j = \left(\frac{\hat{\beta}_0}{\bar{W}} + \hat{\beta}_1 \right) + \hat{\beta}_2 D_j + \frac{\hat{\beta}_3 P_j}{\bar{W}} \qquad (3)$$

Where $\bar{W}$ is the average number of wells per location. Note that in equation (3) we assume that the variable cost of an additional foot of drilling depth is the same as for Equation (1), but in Equation (3) the data are now on a per well basis as denoted by the subscript *j*. Predicted costs can then be calculated for any individual well using Equation (3) and the regression results

[9] We also conducted two diagnostic tests, including a Breusch-Pagan Test for heteroscedasticity, and a Ramsey RESET Test for omitted variables. The Breusch-Pagan Test indicated that we fail to reject the null hypothesis of constant variance and the Ramsey RESET Test indicated that we fail to reject the null hypothesis of no omitted variables.

[10] This estimate is $56,761 divided by the average number of wells per location = 4.18.

[11] This estimate is $22,059 divided by the average number of wells per location = 4.18.

$$\hat{C}_j = 15144 + 4.80 \times D_j - 5277 \times P_j \tag{4}$$

And the total predicted costs for any group of wells $j = 1,2,\ldots,J$ is:

$$\sum_{j=1}^{J} \hat{C}_j = J \times \left(\frac{\hat{\beta}_0}{\bar{W}} + \hat{\beta}_1 \right) + \hat{\beta}_2 \sum_{j=1}^{J} D_j + \hat{\beta}_3 \sum_{j=1}^{J} P_j \tag{5}$$

Plugging in our estimated coefficients we can calculate the total reclamation bill for Wyoming:

$$\sum_{j=1}^{J} \hat{C}_j = J \times 15144 + 4.80 \times \sum_{j=1}^{J} D_j - 5277 \times \sum_{j=1}^{J} P_j \tag{6}$$

Using Equations (4) and/or (6) we can obtain predicted cost estimates for reclaiming an individual well, an average well, and/or all active oil and gas wells in Wyoming. Evaluating Equation (6) at the means of the variables results in an estimated cost per well equal to $23,662. The 95 percent confidence interval for this estimate is $20,427 to $26,897, implying we can be 95 percent confident that this interval contains the true average cost of reclaiming a well in Wyoming. What is the total reclamation bill for the entire state? We can answer this two ways: 1) multiply the estimated average cost per well by the number of active wells; and 2) plug J, $\sum D_j$, and $\sum P_j$ directly into Equation (6) and evaluate. The number of active wells in our WOGCC database is 60,403. Using the first method we get ($23,662 per well) × (60,403 wells) = $1.43 billion. Method two results in a total reclamation cost of $1.46 billion.

Finally, within the WOGCC orphaned well database there is a subset of 25 fully bonded locations with data on the bond amount that was posted and ultimately forfeited to the WOGCC. The sample of 25 locations includes a total of 220 wells, and the average bond per well was equal to $10,180 Given this is a relatively small sample of wells, and the fact that the data only include State and fee lands (no federal lands), the statewide average of bond per well may be substantially different from this figure. However, if we extrapolate the $10,180 average bond per well to the entire state, this suggests an average bond variance equal to $13,482 per well, which is the difference between the predicted cost per well of $23,662 and the average bond per well of $10,180. Multiplied by 60,403 active wells this suggests a current shortfall of $814 million in the bond pool.

Conclusions

The full reclamation of land disturbed by oil and gas development is critical to the protection of Wyoming's natural heritage as well as to the long run viability of the oil and gas industry. If an environmental bonding requirement continues to be a part of the regulation that insures proper reclamation then a serious overhaul of the current system is warranted. We estimate the total cost of reclaiming all of the active wells in Wyoming is approximately 1.5 billion dollars.

The biggest weakness of the current bonding requirements is that they are not tied to production. This study has shown the strong link that exists between certain key production variables (such as drilling depth) and the cost of reclamation. Given accurate estimates of the cost of reclamation, an appropriate system of bonding requirements can be established that is linked to production and fully covers these costs. The most effective system would require a fixed bond amount per well plus an additional fee per foot of drilling depth, and this study provides estimates of these parameters.

In Section 2 we discussed the BLM's recent policy shift toward performance-based standards, and this is a move in the right direction. The final economic incentive that is required is to make defaulting on reclamation as costly as doing the actual reclamation.

References

Andersen, M.A. and R. Coupal. "Economic Issues and Policies Affecting Reclamation in Wyoming's Oil and Gas Industry," Paper presented at the 2009 National Meeting of the American Society of Mining and Reclamation, Billings, MT. *Revitalizing the Environment: Proven Solutions and Innovative Approaches* (June 2009).

Gerard, David. "The Law and Economics of Reclamation Bonds," *Resources Policy* 26 (2000).

Kirscher, S., and E.B. Grandy. "Mining and the Vanishing Surety Bond Market," *Natural Resources and Environment* 17(3) (2003).

Lahti, Thomas. "Wyoming Reclamation Policy," *Instruction Memorandum wy*-2009-022. Bureau of Land Management, Wyoming State Office (March 2009).

Shogren et al. "Limits to Environmental Bonds," *Ecological Economics* 8 (1993).

Sult, D. "The Effect of Coal Mining Bonding Systems on the Probability of Reclamation," *Unpublished PhD Dissertation*, Colorado School of Mines (2004).

United States Code of Federal Regulations. Title 43 SURFACE EXPLORATION, MINING AND RECLAMATION OF LANDS, Definitions Section 23.3.

Webber, B.S. "Promoting Economic Incentives for Environmental Protection in the Surface Mining Control and Reclamation Act of 1977: An Analysis of the Design and Implementation of Reclamation Performance Bonds," *Natural Resources Journal* 25 (1985)