SOCIO-ECONOMIC CAUSES AND CONSEQUENCES OF FUTURE ENVIRONMENTAL CHANGES WORKSHOP

A WORKSHOP SPONSORED BY THE U.S. ENVIRONMENTAL PROTECTION AGENCY'S NATIONAL CENTER FOR ENVIRONMENTAL ECONOMICS (NCEE), NATIONAL CENTER FOR ENVIRONMENTAL RESEARCH (NCER)

November 16, 2005

EPA Region 9 Building

75 Hawthorne Street 1st Floor Conference Room San Francisco, CA

Prepared by Alpha-Gamma Technologies, Inc. 4700 Falls of Neuse Road, Suite 350, Raleigh, NC 27609

ACKNOWLEDGEMENTS

This report has been prepared by Alpha-Gamma Technologies, Inc. with funding from the National Center for Environmental Economics (NCEE). Alpha-Gamma wishes to thank NCEE's Cynthia Morgan and Jennifer Bowen and the Project Officer, Cheryl R. Brown, for their guidance and assistance throughout this project.

DISCLAIMER

U.S. Environmental Protection Agency
Socio-Economic Causes and Consequences of Future Environmental Changes Workshop

November 16, 2005
EPA Region 9
75 Hawthorne Street
1st Floor Conference Room
San Francisco, CA

8:45-9:15	**Registration**	
9:15 -9:30	**Introductory Remarks – Tom Huetteman, Deputy Assistant Regional Administrator, USEPA Pacific Southwest Region 9**	
9:30-11:30	**Session I:**	**Trends in Housing, Land Use, and Land Cover Change** Session Moderator: Jan Baxter, US EPA, Region 9, Senior Science Policy Advisor
	9:30 – 10:00	Determinants of Land Use Conversion on the Southern Cumberland Plateau **Robert Gottfried (presenter)**, Jonathan Evans, David Haskell, and Douglass Williams, University of the South
	10:00– 10:30	Integrating Economic and Physical Data to Forecast Land Use Change and Environmental Consequences for California's Coastal Watersheds Kathleen Lohse, David Newburn, and **Adina Merenlender (presenter)**, University of California at Berkeley
	10:30 – 10:45	**Break**
	10:45 – 11:00	Discussant: Steve Newbold, US EPA, National Center for Environmental Economics
	11:00 – 11:15	Discussant: Heidi Albers, Oregon State University
	11:15 – 11:30	Questions and Discussions
11:30 – 12:30	**Lunch**	
12:30 –2:30	**Session II:**	**The Economic and Demographic Drivers of Aquaculture and Greenhouse Gas Emissions Growth** Session Moderator: Bobbye Smith, U.S. EPA Region 9
	12:30 – 1:00	Future Growth of the U.S. Aquaculture Industry and Associated Environmental Quality Issues **Di Jin (presenter)**, Porter Hoagland, and Hauke Kite Powell, Woods Hole Oceanographic Institution

	1:00 – 1:30	Households, Consumption, and Energy Use: The Role of Demographic Change in Future U.S. Greenhouse Gas Emissions Brian O'Neill, Brown University, **Michael Dalton (presenter)**, California State University – Monterey Bay, John Pitkin, Alexia Prskawetz, Max Planck Institute for Demographic Research
	1:30 – 1:45	Discussant: Tim Eichenberg, The Ocean Conservancy
	1:45 – 2:00	Discussant: Charles Kolstad, University of California at Santa Barbara
	2:00 – 2:30	Questions and Discussion
2:30 – 2:45	**Break**	
2:45 - 4:55	**Session III:**	**New Research: Land Use, Transportation, and Air Quality** Session Moderator: Kathleen Dadey, US EPA, Region 9, Co-chair of the Regional Science Council
	2:45 - 3:10	Transforming Office Parks Into Transit Villages: Pleasanton's Hacienda Business Park **Steve Raney (presenter)**, Cities21
	3:10 – 3:35	Methodology for Assessing the Effects of Technological and Economic Changes on the Location, Timing and Ambient Air Quality Impacts of Power Sector Emissions Joseph Ellis and **Benjamin Hobbs (presenter)**, Johns Hopkins University, Dallas Burtaw and Karen Palmer, Resources for the Future
	3:35 - 4:00	Integrating Land Use, Transportation and Air Quality Modeling **Paul Waddell (presenter)**, University of Washington
	4:00- 4:25	Regional Development, Population Trend, and Technology Change Impacts on Future Air Pollution Emissions in the San Joaquin Valley Michael Kleeman, Deb Niemeier, **Susan Handy (presenter)**, Jay Lund, Song Bai, Sangho Choo, Julie Ogilvie, Shengyi Gao, University of California at Davis
	4:25 – 4:55	Questions and Discussion
4:55 – 5:00	**Wrap-Up and Closing Comments**	

U.S. EPA Socio-Economic Causes and Consequences of Future Environmental Changes Workshop

San Francisco, CA
November 16, 2005

Introductory Remarks
Tom Huetteman, Deputy Director, Policy & Management Division, Region 9

I'd like to welcome everyone to today's workshop. My name is Tom Huetteman, and I'm *not* the regional administrator, although earlier agendas indicated that that's who would be delivering our opening address. I am the Deputy Director of the Policy and Management Division here at Region 9.

[aside regarding his headset and the fact that the workshop is being webcast]

My division has a lot of different responsibilities—we do the financial management, information management, internal facilities operation for the region, and regional planning, and then we also have science support, which involves our regional laboratory and other science support functions. One of my roles is the Science Lead on our Senior Management Team, so I'm often asked to help out and speak at events like this.

[aside providing the facility logistical information]

We're very happy to have this event here in Region 9 and would like to thank the Office of Research and Development STAR (Science to Achieve Results) Program and the National Center for Environmental Economics for having this conference here in Region 9. A number of people here in the Region 9 office have helped to put this together, and I'd especially like to thank our regional science council and a number of Region 9 staff who will be helping throughout today's workshop. The results of the workshop will be provided as proceedings, and all the workshop participants will be notified when those proceedings are available and accessible on the web.

Let me say a little bit about the format of today's workshop. As you can see from the agenda, we'll have three sessions. The first two sessions, which involve research that is pretty much at its conclusion with final reports being prepared, will follow a more formal format that you may not be familiar with. At the conclusion of the presentations, formal discussants will engage in a dialogue with the presenters. Then there will be an opportunity to open the discussion to general questions and answers. The third session this afternoon will present a series of newly funded research projects. These are projects that received funding from 2005 ORD sustainability grants. Those presentations do not have discussants, so there will be more of an opportunity for back-and-forth dialogue with the researchers, who are just beginning their research projects.

We had 85 registrants to the workshop, so this should be a wonderful opportunity for idea exchange and networking to occur, not only among the researchers here, but with all of you who represent a diverse group of state, local, federal EPA, private sector, and non-profit entities. This is something that ORD is emphasizing a lot more—bringing out to regional offices the research that the office is supporting. One of the things we're really trying to achieve through this type of gathering and networking is to try to better link the environmental results of our research with the actual work that's being done at the regional and local level. One reason we believe this linkage is so critical is, in part, because of some of the scrutiny our funding programs receive from the Office of Management and Budget (OMB). We're being pressured by OMB to demonstrate some tangible results for the dollars that we invest, and when we are not able to do that successfully, we run the risk of cuts to our funding programs.

Since I see a lot of unfamiliar faces out there, I want to kick things off with a few comments about Region 9. Since one of our themes today is "forecasting," I want to do a little forecasting for you about EPA and share with you some of the environmental issues that are presenting increasing challenges for us as we work to sustain environmental protection. I'll touch on some of the changing ways that we're responding to those challenges and then how that changing response is really affecting the way that EPA is organized as an agency.

If you're not familiar with the 10 EPA regions, Region 9 consists of California, Arizona, and Nevada in the Southwest and then also Hawaii and the Pacific Trust Territories. This reach encompasses the largest number of Indian tribes of any EPA region. This area gives us a really unique and diverse perspective—the trust territories stretch all the way across the Pacific, and Arizona and Nevada are two of the fastest-growing states in the nation. We also have some of the most undeveloped areas of the nation, with the Pacific islands and some of our tribes still lacking basic infrastructure, such as wastewater and drinking water. Then we also have our unique challenge of the Mexican border area.

So, as we look at the environmental issues that we face here and across the country, the common theme is that they're increasingly more complex and challenging to address, and it requires a different set of tools to solve those problems. So, I want to touch on a few of the challenges that we are facing here in Region 9 by focusing on some of the priorities we've identified, particularly those that will challenge us in the upcoming years.

Air quality has always been our highest priority in Region 9 with the issues in Southern California, so that's nothing new. However, as we look at other aspects of air pollution, such as finer particulates, we're seeing other areas of significant concern and new levels of complexity to those issues. For instance, this afternoon we'll hear about the issue in the central valley of the coming together of agriculture and development and the associated changes this brings. In particular, there are the air quality and water quality challenges presented by the rapidly growing dairy industry and the side-by-side co-existence of consolidated dairy farms and new development.

In the area of water quality, the #1 cause of water quality degradation in our region is storm water runoff. In both storm water runoff and air quality, I think the primary factor that is the most challenging to address is the collective impact of too many people. We can regulate industries and what comes out of the ends of pipes, but to change behavior is a particularly difficult challenge we face in our efforts to achieve continued environmental protection and improvement.

Also on the water front, of course we're going to see shrinking water supplies and that will also affect our water quality program. Already we're seeing increased demand for water reuse in Southern California and now elsewhere, and we're seeing more linkage as water quality standards drive improvements in wastewater, thereby creating opportunities for additional reuse.

At Region 9 and across the country we also are challenged with keeping an eye out for emerging pollutants of concern. We've had some particular experience in this regard over the last few years with MTBE and more recently with perchloride from explosives manufacturing. In the Las Vegas area this pollutant is impacting the Colorado River, which is part of the drinking water supply for 15 million people.

As we look at other areas of potential concern, one that comes up is potential endocrine-disrupting chemicals—things such as pharmaceuticals and personal care products going down the drain. Again, this gets back to individual behaviors and choices that people make and how those affect the environment. This is another increasingly challenging area.

Another issue is that our work is becoming more international in scope. A very high priority for us here in Region 9 is, of course, the Mexican border, but we're also concerned about issues of atmospheric transport of pollutants from Asia and around the globe. Then, of course, there is the question of global warming and what strategies the country will pursue in that regard. In our region, the Pacific island nations realize a very real threat of rising sea levels wiping out portions of their lands. That's a unique perspective that we can bring to that discussion.

We've recognized a common theme as part of the growing pattern of how we respond to this wide array of environmental issues. The top priority for our region at the moment is an initiative called the West Coast Diesel Emission Reduction Collaborative. I underscore the word "collaborative" because that is a theme for a lot of the work we're doing in the region. In this case, it's a public/private partnership not so much about regulatory efforts as about creating incentives and providing funding and supporting voluntary programs. Then if you look throughout watershed partnerships, pollution prevention, and collaboration, you see these kinds of themes in the way we're working, not just in the traditional regulatory mode that we've been used to for the last 35 years.

Looking forward, that's the kind of agency that we're more likely to be. We're not getting new legislative mandates. We still generate rule-making on a periodic basis, but that's likely to diminish. The titles that we're hearing for our role in the future are convener, collaborator, facilitator, and innovator. There will be an emphasis on partnerships across many levels and an effort to bring together diminishing resources from different places to be more effective, using tools such as market incentives and relying more on voluntary actions. Again, there is the challenge of trying to influence the choices that people make individually in their lives as opposed to focusing just on what we can control through our efforts with industries and municipalities.

As I've already indicated, the future indicates an increase in international focus. We here in Region 9 are already doing work in China, Vietnam, the Philippines, and Thailand. Those types of activities are often more headquarters-focused.

In this environment of more-complex, challenging issues, I believe the research we fund is increasingly more critical to us. We need to strive to find those effective tools to better understand the problems and the complexities of the issues that we face so we can be more effective in sustaining environmental protection.

Again, I thank you for being here, and I encourage everyone to take the opportunity to meet folks during the breaks and to ask questions and to engage in the discussion. I hope we have a great workshop. Thank you very much.

SOCIO-ECONOMIC CAUSES AND CONSEQUENCES OF FUTURE ENVIRONMENTAL CHANGES WORKSHOP

A WORKSHOP SPONSORED BY THE U.S. ENVIRONMENTAL PROTECTION AGENCY'S NATIONAL CENTER FOR ENVIRONMENTAL ECONOMICS (NCEE), NATIONAL CENTER FOR ENVIRONMENTAL RESEARCH (NCER)

November 16, 2005

EPA Region 9 Building

75 Hawthorne Street 1st Floor Conference Room San Francisco, CA

Prepared by Alpha-Gamma Technologies, Inc. 4700 Falls of Neuse Road, Suite 350, Raleigh, NC 27609

ACKNOWLEDGEMENTS

This report has been prepared by Alpha-Gamma Technologies, Inc. with funding from the National Center for Environmental Economics (NCEE). Alpha-Gamma wishes to thank NCEE's Cynthia Morgan and Jennifer Bowen and the Project Officer, Cheryl R. Brown, for their guidance and assistance throughout this project.

DISCLAIMER

U.S. Environmental Protection Agency
Socio-Economic Causes and Consequences of Future Environmental Changes Workshop

November 16, 2005
EPA Region 9
75 Hawthorne Street
1St Floor Conference Room
San Francisco, CA

8:45-9:15	**Registration**	
9:15 -9:30	**Introductory Remarks – Tom Huetteman, Deputy Assistant Regional Administrator, USEPA Pacific Southwest Region 9**	
9:30-11:30	**Session I:**	**Trends in Housing, Land Use, and Land Cover Change** Session Moderator: Jan Baxter, US EPA, Region 9, Senior Science Policy Advisor
	9:30 – 10:00	Determinants of Land Use Conversion on the Southern Cumberland Plateau **Robert Gottfried (presenter)**, Jonathan Evans, David Haskell, and Douglass Williams, University of the South
	10:00– 10:30	Integrating Economic and Physical Data to Forecast Land Use Change and Environmental Consequences for California's Coastal Watersheds Kathleen Lohse, David Newburn, and **Adina Merenlender (presenter)**, University of California at Berkeley
	10:30 – 10:45	**Break**
	10:45 – 11:00	Discussant: Steve Newbold, US EPA, National Center for Environmental Economics
	11:00 – 11:15	Discussant: Heidi Albers, Oregon State University
	11:15 – 11:30	Questions and Discussions
11:30 – 12:30	**Lunch**	
12:30 –2:30	**Session II:**	**The Economic and Demographic Drivers of Aquaculture and Greenhouse Gas Emissions Growth** Session Moderator: Bobbye Smith, U.S. EPA Region 9
	12:30 – 1:00	Future Growth of the U.S. Aquaculture Industry and Associated Environmental Quality Issues **Di Jin (presenter)**, Porter Hoagland, and Hauke Kite Powell, Woods Hole Oceanographic Institution

	1:00 – 1:30	Households, Consumption, and Energy Use: The Role of Demographic Change in Future U.S. Greenhouse Gas Emissions Brian O'Neill, Brown University, **Michael Dalton (presenter)**, California State University – Monterey Bay, John Pitkin, Alexia Prskawetz, Max Planck Institute for Demographic Research
	1:30 – 1:45	Discussant: Tim Eichenberg, The Ocean Conservancy
	1:45 – 2:00	Discussant: Charles Kolstad, University of California at Santa Barbara
	2:00 – 2:30	Questions and Discussion
2:30 – 2:45	**Break**	
2:45 - 4:55	**Session III:**	**New Research: Land Use, Transportation, and Air Quality** Session Moderator: Kathleen Dadey, US EPA, Region 9, Co-chair of the Regional Science Council
	2:45 - 3:10	Transforming Office Parks Into Transit Villages: Pleasanton's Hacienda Business Park **Steve Raney (presenter)**, Cities21
	3:10 – 3:35	Methodology for Assessing the Effects of Technological and Economic Changes on the Location, Timing and Ambient Air Quality Impacts of Power Sector Emissions Joseph Ellis and **Benjamin Hobbs (presenter)**, Johns Hopkins University, Dallas Burtaw and Karen Palmer, Resources for the Future
	3:35 - 4:00	Integrating Land Use, Transportation and Air Quality Modeling **Paul Waddell (presenter)**, University of Washington
	4:00- 4:25	Regional Development, Population Trend, and Technology Change Impacts on Future Air Pollution Emissions in the San Joaquin Valley Michael Kleeman, Deb Niemeier, **Susan Handy (presenter)**, Jay Lund, Song Bai, Sangho Choo, Julie Ogilvie, Shengyi Gao, University of California at Davis
	4:25 – 4:55	Questions and Discussion
4:55 – 5:00	**Wrap-Up and Closing Comments**	

Determinants of Land Conversion On The Southern Cumberland Plateau

Robert R. Gottfried, Professor
Department of Economics &
Sewanee Landscape Laboratory
The University of the South

E. Douglass Williams, Associate Professor
Department of Economics &
Sewanee Landscape Laboratory
The University of the South

Matthew Lane, GIS Analyst
Tennessee Department of Transportation

Kevin Willis, Fellow
Sewanee Landscape Laboratory
The University of the South

December 8, 2005

Although the research described in this article has been funded wholly or in part by the United States Environmental Protection Agency through grant/cooperative agreement R- 83980201 to Robert R. Gottfried, it has not been subjected to the Agency's required peer and policy review and therefore does not necessarily reflect the views of the Agency and no official endorsement should be inferred.

Introduction

Within the Southeast, where forest issues are politically volatile, the Cumberland Plateau of southeastern Tennessee has attracted regional and national attention as a major hotspot for forestry-related, landscape-level change. The Plateau, the western portion of the Appalachian mountains, extends from northeastern Alabama to southwest Virginia, ranging in altitude from 2,000 to 4,145 feet. Part of the Allegheny Plateau, it continues north to the Mohawk Valley of New York.

As discussed below, the seven counties of the southern Tennessee Cumberland Plateau, our study area, have experienced a loss of about 20% of its native forest canopy from 1981 to 2003, with the rate of loss accelerating over time. This period also experienced a severe outbreak of the southern pine beetle and divestiture of substantial timberland holdings.

The removal of the native forest to permit other uses may have significant ecological implications. The Cumberland Plateau in Tennessee contains some of the largest remaining tracts of privately owned, contiguous temperate deciduous forest in North America. From a conservation biology standpoint this area has received special attention because of the extremely rich animal and plant diversity associated with these remaining tracts of native hardwood forest habitat (Clements and Wofford, 1991; Martin *et al*., 1993; Evans, 1996). Native forests on the Cumberland Plateau consist predominately of a mixture of oak (Quercus spp.) and hickory (Carya spp.) species, along with other hardwood species. These forest tracts represent migratory songbird habitat and serve as the headwaters to some of the most biologically diverse, freshwater stream systems found in the world (Ricketts *et al*. 1999).

The Cumberland Plateau also has some of the highest predicted herpifaunal diversity of anywhere in the state and one of the most diverse communities of woody plants in the eastern United States (Durham 1995; Ricketts *et al*. 1999). The hard mast (acorns) associated with the mature oak canopy of the plateau forest serves as a keystone resource within the food web of this ecosystem. The availability of this oak mast resource

Although the research described in this article has been funded wholly or in part by the United States Environmental Protection Agency through grant/cooperative agreement R- 83980201 to Robert R. Gottfried, it has not been subjected to the Agency's required peer and policy review and therefore does not necessarily reflect the views of the Agency and no official endorsement should be inferred.

directly or indirectly affects the survivorship of hundreds of animal species inhabiting the forest (McShea and Healy 2002).[1] Because of the rapid forest change and the ecological importance of the native hardwood forests, the Tennessee Nature Conservancy has launched a major effort to maintain forest cover in the northern and southern portions of Tennessee's Cumberland Plateau. The National Resources Defense Council also has focused recently on the Plateau and pine conversion there, declaring it a "biogem," along with the Everglades, the Tongass National Forest, and the Yellowstone/Greater Rockies.

This paper constitutes part of a U.S.E.P.A.-funded project under the STAR program to develop a GIS simulation model of land use change and associated water quality and avifaunal diversity changes on a seven-county portion of the surface (i.e., excluding the slopes) of the southern Tennessee Plateau. We present here initial results of the building and location of homes on parcels of ten acres or more for the period 1981-2003, as well as a discussion of preliminary insights into the drivers of land cover change over this time period. As such our study represents one of only a few that use parcel level data to examine land conversion in a rural context, as opposed to the urban fringe. However, the nature of the available data and of the study area make this study even more interesting. The bluffs that characterize the edges of the Plateau comprise unique amenities that command a high premium. Our GIS data allow us to examine their impact on land use conversion. Using land cover data we also can examine the impact that a parcel's land cover, and land cover in the surrounding area, has on the probability a home will be built. Accordingly, we can examine the extent to which pine conversion and conversion to grassy cover affect landowners who use their land primarily for recreation and residence, homeowners who may value environmental amenities greatly. We also can explore changes in land cover due to homebuilding and timber company divestitures. This paper focuses on homebuilding and changes in land use/land cover (LULC) for the period 1981 to 2003.

The paper proceeds as follows. After a brief review of the literature, the paper develops a theoretical framework for land use change. It then describes the case study area and the data available. The subsequent sections discuss the results of 1) the logit

---

[1] This preceding sentences are largely taken from Evans, Pelkey and Haskell (2002).

analysis of homebuilding, and 2) a preliminary examination of the causes of land cover change. The last section provides some concluding thoughts.

Review of the literature

The growth of landscape ecology and conservation biology has highlighted the importance that the pattern of land cover (determined by humans' use of the land), has on ecological processes. Therefore, ecological models rely on land use/land cover (LULC) patterns. This dependence has spawned the development of models of LULC change at the regional, or landscape, level (for a good discussion see Bockstael and Irwin, 2000).

Noneconomists have developed spatially explicit models of landscape change, sometimes incorporating economic variables such as distance to roads, population, and distance to towns into the analysis. However, these models fail to make explicit the underlying socioeconomic processes causing the landscape to change (Bockstael and Irwin, 2000).

On the other hand, economists have worked on spatial issues a great deal, examining the underlying processes of change in LULC.[2] Although economists make explicit their behavioral assumptions and analysis underlying LULC change, the lack of data (or the expense of collecting it) at the appropriate spatial scale for supporting ecological models has, in part, forced them to operate at larger scales (Baker, 1989; Bockstael and Irwin, 2000; Miller and Platinga, 1999). Most spatial models of land use change track changes in the distribution of land area among one or more variables. Typically they specify changes in the share of land uses at some aggregate level, such as the county (see Alig, 1986; Alig and Healy, 1987; Hardie and Parks, 1997; Hardie, *et al*., 2000; Miller and Platinga, 1999; Parks, 1987; Platinga,1996; Stavins and Jaffe, 1990; White and Fleming, 1980; Wu and Segerson, 1995). While more spatially explicit, these models do not provide information on actual locations or configurations of land use. Baker concludes,

[2] For good discussions of the theory of land use, see Alonso (1964) and Randall and Castle (1985**.** See Baker (1989) Parks and Alig (1988), and Bockstael and Irwin (2000) for discussions and typologies subsequent models of land use.

> The most important present limit to the development of better models of landscape change may be a lack of knowledge of how and why the landscape changes, and how to incorporate such knowledge in useful models, rather than a lack of technology to develop and operate models of landscape change (p. 127).

Among the four approaches he suggests to address this lack of knowledge he includes multivariate analyses of possible exogenous and endogenous contributions to empirically-derived rates of landscape change. Acknowledging that multivariate analyses have their own limits, he suggests that modeling itself may offer an alternative route to the identification of key variables.

There exists a small literature of economic models and their applications at a finer scale of resolution. Cropper, Puri and Griffiths (2001) analyze parcel level data using bivariate logit to determine the location of deforestation and its rate, utilizing soil quality, impedance-weighted distance to the nearest market, distance to a road, population density, and locational dummy variables. Turner, Wear and Flamm (1996) examine land cover transitions of cells of a grid superimposed upon the landscape in two watersheds using multinomial logit. Transition probabilities vary according to slope, elevation, distance to roads and markets, and population density. They find differences in transition probabilities over time, perhaps caused by omitted variables such as timber or agricultural prices. Nelson and Hellerstein (1997) use cross-section data from satellite imagery to examine land use as a function of slope, soil quality, aspect, and access to roads and to villages. Landis (1995) and Landis and Zhang (1998) utilize a multinomial logit model to estimate the probability of land use change for the San Francisco Bay and Sacramento areas based upon site and community characteristics. They use these results, in turn, to calculate land use transition probabilities. As Bockstael and Irwin (2000) point out, this model does not directly explain land prices and uses cells rather than land parcels, the actual decision making unit, as the scale of analysis.

For purposes of our research Bockstael (1996) and Costanza *et al.* (1996) provide, perhaps, the most useful attempt at disaggregated modeling of land conversion. They examine residential conversion in the Patuxent watershed, near Washington, D.C. by first estimating the value of land in alternative uses by using the hedonic approach. They then estimate the probability of a parcel's being converted as a function of its value in alternative uses and its costs of conversion. As Bockstael points out, one drawback of this model is that it does not provide an economic explanation for the level of land use change, only its location. Geogehegan, Wainger and Bockstael (1997) develop a model in which the coefficients of some explanatory variables vary over space. They find, for instance, that the value of an additional unit of access to roads and lot size varies according to the distance from the central business district. Bockstael and Irwin (2000) rightly point out that the above spatially disaggregated models require huge datasets that typically are unavailable.

Subsequent work by their research team utilizes a hazard model to examine land use change. Irwin and Bockstael (2001, 2002) model land use change in both time and space by examining optimal timing decisions. The former paper incorporates actor interaction effects whereby residential land parcels exert a negative effect on one another, leading to fragmented land development patterns. The latter paper examines the relative magnitude and directions of these effects, and the effect of policies intended to cluster development and promote open space. Whereas these models permit an analysis of land use change over time in terms of optimal timing, they do not address the external driving forces behind land use changes over time – changes in interest rates, population, income, etc. – that are of prime interest for the research described below.

Based upon our analysis of Tennessee's Forest Greenbelt Program, experience, and theoretical intuition, landowner and buyer characteristics should play important roles in determining land use patterns over time (see Gottfried, 1998, 1999; Brockett and Gebhard, 1999; Brockett, Gottfried and Evans, 2001; Williams, *et al*., 2001). Bockstael and Irwin (2000) point out that agent-interaction models of urban land use patterns are driven by interactions between spatially distributed agents. These interactions may occur through market forces, nonpecuniary externalities from land uses or economic activities (such as social interactions) that affect the agents' utility or profits. The spatial distribution of current agents over the landscape, and their interactions, affect future location decisions, making their spatial distribution endogenous. This leads to a complex urban spatial structure that "is characterized by multiple equilibria, path dependence, and what Arthur (1989) terms 'historical chance'" (p. 29).

Our research will add to the sparse economics literature of land use change at the parcel level. It will build on the work of Bockstael *et al*. by utilizing a model that explicitly incorporates the impact of exogenous economic variables on land use change over time, while including owner characteristics and interactions between parcels. In this way we not only contribute to the small number of models at this scale, but also contribute to the few studies examining land use change over time and the driving forces behind it. Most parcel level studies of land use change focus on areas experiencing urban pressures. This study examines a very rural area where pressures stem largely from changes in resource use and relatively light residential development. As such, it may shed light on change in other rural areas throughout the South.

Theoretical Framework

The probability that a given parcel will convert to some other use, j, depends upon five factors: 1) The relative value of land in use j compared to those of other uses (assumed to be given – the region is a price-taker in the land market). These are the bid prices prospective buyers for different uses on average would be offering. 2) The probability that the land owner will encounter a prospective buyer for use j. 3) The probability that that buyer, if not representing the highest-valued land use, will not face competition from another buyer desiring the land for a higher-valued use. 4) The probability that the value for use j will exceed the owner's reservation price (comprised of the use value of the land plus the owner's present value of intangible benefits, the reservation premium). 5) The cost of conversion to use j.

The relative values of the parcel in different uses will depend, in part, upon the suitability of that parcel for these uses as determined by the parcel characteristics as well as exogenous economic variables such as population growth and interest rates. The probability of conversion depends positively on the difference between the value of the land in the alternative use j and the current use i. The values in different uses capture the expected net benefits that prospective buyers anticipate from use j. Note that the value of the land may differ from price. The former represents the value land would have if it were in a particular use, the market for which may not as yet be present in an area.

1) $V_{tj} - V_{ti} = f(e_{jt}, c, N_{jt}) – g(e_{it}, c, N_{it})$

where V_{tj} = value of parcel in alternative use j at time t

V_{ij} = value of parcel in current use i at time t

e_t = exogenous economic variables at time t

c = parcel characteristics

N_t = land use in time t of nearby parcels

Landowners may change land use themselves without first selling to someone who then changes its use. To simplify modeling, when landowners themselves consider changing land use, the model treats this as an encounter with a buyer for that prospective land use. The probability of an encounter of a landowner with a prospective buyer who would convert to another land use j depends upon relative land values, parcel characteristics (including land use/land cover), area land use, and owner characteristics. The higher the value of land in a given use, the more incentive buyers have to seek parcels they can use for that purpose. They, of course, will seek parcels having characteristics most suitable for that use. Finally, particularly when the prospective land use is relatively new to the area, information on that use and/or the suitability of the parcels in the region for that use, may be scarce. Therefore, landowners close to an industrial pine plantation, for instance, may be more likely to consider converting their land to pine, or buyers may be more inclined to think that neighboring parcels might prove suitable for pine given the presence of a nearby plantation. Similarly, for residential development the initial residential development in an area may provide the idea to other developers that this area is suitable for development – it may signal the presence of a market that before they were unaware of. Agglomeration effects may also work so that real estate agents more likely will come to an area where other agents are at work – prospective clients may find it easier to deal in an area where there are many agents than a few. Accordingly, prospective buyers for these uses may be more present where there already has been such activity in the area. Positive and negative externalities associated with the uses of nearby parcels will affect the attractiveness of the parcel a given use. Finally, owner characteristics will affect the probability of their being aware of other land use options.

2) $E_{tj} = h(V_{tj}, V_{ij}, c, N_t, O_t)$,

where E_{tj} = probability that a landowner encounters a prospective buyer for land use j at time t

O_t = owner characteristics at time t

The probability that a particular buyer representing a given land use will offer the highest of competing prices will depend, of course, on the value of the land for different uses and the probabilities of encounters between the owner and prospective buyers for other land uses E_k through E_m..

3) $S_{tj} = p(V_{tk}, \ldots, V_{tm}, E_{tk}, \ldots, E_{tm})$,

where S_{tj} = probability that the bid price, or value, offered by a buyer for use j will be the highest price offered the landowner at time t.

The probability that the bid price for use j will exceed the owner's reservation price depends upon value of a parcel for use j, the value of the land in its current use, and the owner's reservation premium, which varies according to owner characteristics.

4) $G_{tj} = r(V_j, V_i, RP_t(O_t))$,

where G_{tj} = probability that bid price for use j is greater than the owner's reservation price t at time t

RP_t = reservation premium, a function of owner characteristics

O_t = owner characteristics

Finally, the cost of converting the land to use j will depend upon the cost of inputs to the conversion process, the characteristics of the parcel itself, and the opportunity cost of changing from the current land use.

5) $T_{tij} = s(I_{tj}, c, V_{ti})$,

where T_{ij} = cost of converting land to use j from use i

I_t = cost of inputs to conversion process t time t

Given the above, the following function, therefore, determines the probability, Ctij, that a given parcel will change to some alternate use j from use i at time t.

6a) $C_{tij} = m(V_{ti}, V_{tj}, E_{tj}, S_{tj}, G_{tj}, T_{tj})$

or

6b) $C_{tij} = m\ (e_t, c, N, O_t, I_t)$.

The Case Study Area

The study area comprises 616,000 acres of the top of the Cumberland Plateau in southeastern Tennessee (see Figure 1). As such it includes part or all of seven counties: Franklin, Marion, Grundy, Sequatchie, Warren, Van Buren, and Bledsoe.

Data developed by the Sewanee Landscape Laboratory for the Small Area Assessment Forestry Demonstration Project of the Southern Forest Resource Assessment (Evans *et al*. 2002) and for the current project found that from 1981 to 2003 intact native forest canopy declined in the southern Cumberland Plateau by about 19% (approximately 90,000 acres). This conversion tended to be concentrated in certain areas. During the same time pine plantations increased by 100% (35,000 to 70,000 acres) and agriculture/residential (grass/shrub land cover) by 50% (77,000 to 115,000). Figure 2 shows that the acres of native forest lost per year has increased steadily over the period, while the increase in acres of pine has increased at a decreasing rate from 1990 to 2003. Most significant, perhaps, is the marked increase in the rate of increase of agriculture/residential from 2000 to 20003.

Figure 3 shows that up to the 1997-2000 period native forest tended to convert to pine rather than agriculture/residential (ag/res). However, in that period the situation changed dramatically as conversion to ag/res far outstripped pine conversion. The decline in the annual rate of pine conversion, as well as rising rates of conversion of pine to ag/res, may result from the disastrous southern pine beetle epidemic that started around 2000.

Over the period 1981-2001 the rate of land sales increased dramatically starting in 1986 (Figure 4). The rate of home also construction increased steadily through 1999, with several counties experiencing downturns in the last four years. It is interesting to note that Van Buren County, which experienced a large divestiture of Huber land starting in 1998, experienced a large increase in the annual rate of home construction recently compared to other counties. The real price per acre of tracts from 10 to 200 acres has increased since 1984, whereas larger parcels have increased in price since about 1986 (Figure 5).

These changes have occurred in an area characterized by a skewed land distribution. Considering only parcels over ten acres, in the year 2000 the largest 1% of landowners owned 49% of the Plateau surface. Similarly, fifty-six percent of the Plateau surface was owned by owners holding 1000 acres or more. Timber companies held twenty percent of the Plateau surface while other businesses held an additional eighteen percent. Owners with mailing addresses outside of the county where the parcel was located or of a neighboring county (absentees) owned 51% of the land. However, the business-oriented owners tended to hold larger parcels. Business-oriented owners held only 13% of land in parcels from 10 to 500 acres compared to 63% of land in parcels 500 acres or more. Individuals, however, owned 83% of land in small parcels compared to 22% of the land in large parcels. Similarly, owners from outside of the area held 70% of the land in parcels over 500 acres compared to only 30% of the land in parcels under 500 acres.

Within the study area this landownership pattern has changed dramatically since 2000. Of the ten largest landowners in the study area, all but four (a timber company, a developer, the State of Tennessee and The University of the South) have sold their lands. Van Buren County represents the most extreme case of skewed land distribution and divestiture. Prior to 1997 two timber companies owned about 90% of the County, which lies almost totally on the top of the Plateau. Since 2000 one of these firms divested itself of all of its Plateau land, generally selling to developers or individuals.[3] There are relatively few public lands in the study area.

The study area resembles much of Appalachia, with its relatively high levels of unemployment and poverty, and low levels of education. Towns tend to be small and small in number, and with a few exceptions, relatively stable in population. County populations, however, generally have grown, with inmigration exceeding outmigration since 1983-84. Migrants tend to come from other counties in Tennessee, with large numbers also coming from the South and Midwest. Exactly how many migrants settle on the Plateau is more difficult to determine. Van Buren and Grundy counties, which are almost totally on the Plateau, may provide some more insight. Grundy County only regained the population it had had in 1980 by 1995. Inmigration to Grundy has trended upward since 1991-92, the majority of migrants coming from neighboring counties and Hamilton County (Chattanooga). Van Buren's population has remained a relatively constant 5,000 (Moore, Pickron and Tucker 2000). Yet, anecdotal evidence continues to point to an influx of people, often second home owners and retirees, coming to these areas for its natural amenities. Realtors relate that many lot sizes for retiree/second homes tend to be large, often 20 to 100 acres. Of course, once land has been divided into lots and held by people desiring green space for their home, this change may prove largely irreversible, making it difficult for others to buy the land for pine plantations, for instance.

[3] Bowater, the other timber company and the largest landowner on the Plateau, has announced it will sell much or all of its Tennessee landholdings. This may mean that shortly almost all of the land in Van Buren will have changed hands since 1997, and that only three of the original ten largest landowners in 2000 will remain as of 2005.

Description of Data

Developing a micro-level land use transition model for this region requires spatially explicit parcel level characteristics data, parcel level data on LULC over time, information on landowners and potential buyers, and regional economic data. We possess all this information to varying degrees. Tennessee has a centralized county revenue system whereby almost all property tax records are standardized and coordinated by the State, thereby providing a standardized, intercounty compatible tax database. We have obtained from the State the December 1999, 2000, 2001, and 2002 and early 2004 tax assessor data for all our counties. We have digitized all parcels of ten acres or more in the study area to create tax map GIS coverages for 2000 or 2001, depending upon the county. Because these tax maps were drawn by hand at each court house, they introduce some spatial error. We have linked the 2000 assessor data to the 4,792 parcels of ten acres or more as of 2000/2001, creating a GIS coverage that permits spatial analysis of any data contained in the property tax database, such as parcels owned by out-of-state individuals or businesses or parcels with structures worth more than a given dollar amount. Consequently, towards the end of our study period we have detailed parcel level spatial and economic information. Unfortunately, the state maintains no historical data so that we lack comparable data for earlier years. Consequently, as the year of home construction and land cover changes diverges from 2000/2001 both the parcel boundaries and associated tax data become less accurate.

Finally, we have GIS coverages for 1981, 1990, 1997, 2000 and 2003 of land cover in pine plantations, native hardwood, and “other” (grassy/shrub cover, such as lawns or pasture). These relatively spatially accurate coverages do not always align perfectly with the hand-drawn parcel boundaries, thereby introducing error in the land cover of each parcel. The tax data indicate the number and type of residential structures on a parcel and their year of construction. However, they do not give the location of the structure. Therefore, when a house is built we only know the area within which it was built, but not its precise location on the ground.

Of the 851 houses built during 1980-2003, 794 represent the first houses built on a parcel. Of these, 609 represent the case where only one house was built on the parcel when the first house was built and 174 represent cases where two homes were built on previously undeveloped land. This paper will focus on the building of one or more houses on previously undeveloped land.

This raises the question of what "residential land use" means in a rural context. Much land development in the case study area consists of selling tracts of 10 to 100 acres for recreation land or hobby farms/forests. Many of these parcels ultimately may have a home built upon them. Because the towns on the Plateau tend to be relatively low density and relatively stable, most of the active development tends to occur on these medium size parcels. As seen below, the land market for parcels from ten up to ninety acres appears to differ from that for parcels ninety acres and greater. Building a home may or may not change the land cover to a significant degree. The following section discusses a logit analysis of homebuilding. It then explores possible determinants of changes in land cover.

Analysis of Changes in Land Use/Land Cover

Residential Development of Undeveloped Land

Table 1 summarizes the variables used in the logit analysis along with their expected signs. Our dependent variable for the logit analysis is a dummy variable (hbuilt) taking the value of 1 if one or more homes are built on previously undeveloped land during the year. We follow previous research and include both site characteristics, neighborhood characteristics, and amenity variables. Site characteristics variables include bluff frontage, access to public water, sewer, natural gas, and electricity, location on a paved road, distance to a city and to a major road, and size of parcel. The effect of these location variables is unclear because of the tradeoff between convenience and privacy. One would expect smaller parcels to have a greater probability of home construction.

Land cover of a parcel should affect its attractiveness for housing vis-à-vis other uses. Thus, land cover may be viewed from the perspective either of aesthetic amenities or productivity. For example, native forest may have more aesthetic value to landowners than a pine forest, while grassy land used for grazing cattle may have more productive value than a hardwood forest. The relative effects of these land cover variables are ambiguous as they depend upon the preferences of landowners. We would expect native forest and grass/shrub to have more aesthetic value than pine, and therefore to have a positive sign, whereas grass may have more productive value relative to the other land covers and therefore have a negative sign. However, in the latter case greater cleared area also lowers the cost of home construction, causing the percentage of a parcel in grass/shrub to have an ambiguous expected sign.

The neighborhood, of course, should affect the likelihood of building a house on a parcel. The more attractive it is the greater the probability of a home being built on a parcel. This may be captured, in part, by the average value of homes on nearby parcels. Because of the rapid changes in land cover occurring on the Plateau, we are particularly interested in understanding how changes in land cover affect residents and landowners. Land cover in the area surrounding a parcel should affect its attractiveness for home construction. Two sets of buffer variables capture the effect of neighboring land cover. The first measures the percentage of a 0.1 km buffer around a parcel in native forest, pine, and grass/shrub (two other land covers that have been combined, reservoirs and "mixed pine", serve as the default). The second variable consists of a 1 km buffer. Thus, the former captures land use immediately surrounding the parcel whereas the latter captures land use in a larger area. One might expect that having forest nearby makes a parcel more attractive for homes whereas having a pine plantation makes it less attractive. Grass/shrub nearby provides scenic, rural vistas, and therefore has a positive expected sign. Protected areas similarly may provide positive amenities to homebuilders. Consequently, parcels adjacent to a protected area should experience a greater probability of building. Finally, a larger number of homes in the vicinity and a close proximity of a neighboring home provide the information that residential land use is a possibility for a parcel as well as provide amenities in terms of having neighbors.

Ownership also should affect homebuilding. Timber companies should be less likely to build on their land. Business owners include firms who either develop land or may be prone to selling to developers. For years prior to 1999-2001 parcels owned by business in 1999-2001 less likely will experience homebuilding inasmuch these owners no longer would hold the land if it had been built on previously. However, post 1999-2001 such parcels more likely will be developed than others.

Finally, external economic drivers should affect the probability of building of a home. Declines in mortgage rates, population growth in the southeastern US, lower home construction costs, lower unemployment rates (as an income proxy) and rises in the stock market (wealth) all should affect homebuilding positively.

Results

Table 2 shows the results of the logit analysis utilizing the 0.1km buffers for land use around a parcel. Analysis using the 1km buffer yields very similar results. Preliminary work showed that parcels greater than ninety acres tended to behave differently from those less than ninety. Consequently, all dependent variables were interacted with a dummy for parcels greater than or equal to ninety acres. Similarly, the period from 1997 onward appeared to show different characteristics than the earlier period, so all independent variables were interacted with a dummy for the period for 1997 to 2003. Interaction terms that did not add significantly to the model were removed.[4]

The model performed largely as expected. Consider parcel characteristics. Homes appeared more often on parcels of less than ninety acres than on larger parcels. Parcels with bluff frontage, water, gas, and electricity all had a greater probability of construction. Parcels with sewer had an even greater probability after 1996 whereas larger parcels with electricity were more likely to experience construction than smaller. The reason for the latter is unclear. Distance from a city and a major road, as well as location on an unpaved road increased probability, probably reflecting a desire for privacy. For large parcels distance from a major road decreased the probability of home construction. Bluff frontage increased the likelihood of construction for small parcels but decreased it for large. The latter may be due some interaction between large parcels on

[4] Some care needs to be exercised in interpreting the coefficients. These present the marginal effect of a one unit increase in the variable on the probability of a house being built. In the case of an interaction term its coefficient must be added with that of the regular variable in order to obtain its effect on probability; i.e., its coefficient shows the marginal contribution to probability relative to the regular variable. So, for SEWER1997, for instance, its impact on probability is given by summing its coefficient with that for SEWER.

bluffs and the types of owners who hold them. For instance, during this period CSX Corporation owned a large tract with miles of bluff but did not use it to build homes. Note the negative sign for BUSOWNER, even after 1996 (though the businesses were more likely to build in the second period than in the first). Large parcels with larger percentages of native forest had lower probabilities, especially in the second period. In the earlier period small parcels with pine had larger probabilities whereas in the later period they had smaller probabilities. Larger parcels experienced declines in probability as pine increased, particularly in the second period. Larger percentages of grass/shrub cover increased home construction for small parcels in the period before 1997 but decreased it after that. For larger parcels more grass/shrub decreased probability, especially so in the second period. Pine decreased probability more than native forest or grass.

With respect to neighborhood characteristics only the buffer for grass/shrub resulted significant. The more grass/shrub (relative to mixed pine/hardwood) adjoining the parcel the less likely a home will be built. Evidently grass/shrub presents a disamenity. The average value of homes in the area, number of nearby houses, and distance to the nearest parcel with a house all had significant coefficients with the expected sign. However, the latter variable had less of an impact on large parcels. This may result from the development of large tracts, which tend to be further from developed areas than small tracts. Location next to a protected area seems to have no impact on homebuilding.

As expected, parcels owned by timber companies as of 2000/2001 showed lower probabilities, as did parcels owned by businesses. However, the latter effect declined for the second period. The latter may result from the purchase of former timber lands by development businesses starting in 1997. Because some “business” lands as of 2000 actually were timber company lands prior to 1997, such parcels would be more likely to be developed in the second period.

The county dummy variable coefficients show the likelihood of development compared to Bledsoe County.

Finally, the time series variables were insignificant with the exception of the Wilshire index. The latter probably reflects the impact on wealth of the large run-up in the stock market during the 1990's and its subsequent decline. Though the other variables resulted insignificant they all have their expected signs.

Table 3 summarizes the above results.

Changes in Land Use/Land Cover

The question remains as to the impact that homebuilding has on land cover. Changes in land use may or may not be reflected in changes of land cover. When owners convert part or all of their parcel to a grassy/shrub cover, that cover may be used for pasture, a golf course, or a lawn. As of the current state of our data, we cannot distinguish between these uses. Similarly, when a landowner builds a house, they may nestle the house in the forest, or may clear some or all of their land for lawn. An owner changing the use of his native forest holding from hardwood production to recreation or low density housing may change land cover very little.

One might expect that the influx of new permanent and second homeowners would constitute a prime cause of change of native forest to grass. However, this may not be the case. Analysis of all new homes on parcels under 100 acres (for 1980 to 2000) reveals that all these parcels contained native forest, the average being 20 acres. The majority also had some grass, with the average grass per parcel being about 10 acres. Therefore, these wooded parcels often presented already cleared areas where, conceivably, home construction could proceed without clearing. When home construction caused a change in LULC for at least some of the parcel, in the great majority of cases native forest changed to only one other LULC. These "pure" conversions (about 20% of the home construction from 1980-90 and 1990-2000) usually entailed clearing native forest for grass/shrub. The remainder went to "logged," which ultimately would result either in pine or grass. The average clearing size for grass was 9 and 13 acres respectively for each of the two periods. Only four pure conversions of native forest as the result of homebuilding occurred during 1997-2000 and these resulted in no conversion to grass/shrub. The relatively small numbers of conversions from native forest to grass/shrub, and the small sizes of these conversions, suggests that in all likelihood homebuilding did not represent the prime driver of the large changes of native forest to grasss/shrub that the Plateau has experienced. Of course, the yet-to-be-performed analysis for the period 2000-2003 may reveal otherwise.

Surprisingly, most of the increase in grassy/shrub cover may result from growth of agriculture, in particular for pasture or hay production. A large proportion of the growth in grass/shrub in the most recent period has occurred on former timber lands in Van Buren County that were sold to one land developer that, in turn, has sold to individuals and other developers. Informal interviews with county officials, buyers of the developers' land, and the developer itself indicate that many local landowners had been waiting for years to expand their pastures or their hay operations. When the timber company divested, they bought substantial acreage, often in tracts of one thousand or more acres. Approximately 2,000 head of cattle have been added to the county herd since about 2000 (Swoape, 2005). In Grundy County, the county experiencing the next largest amount of conversion to grass/shrub anecdotal evidence suggests that perhaps three to four hundred acres have been cleared in the last two to three years for cattle production due to the high cattle prices (Kimbro, 2005).

A similar process has occurred on a large tract at the opposite end of the study area. The same company as in Van Buren County sold its timber rights to this tract to another timber company and then sold the land to an individual from Florida who, in turn, sold the now harvested land to a local developer. That developer, in turn, is selling the land off in tracts from ten to hundreds of acres, largely to Floridians. However, some nearby landowners also have bought hundreds of acres of this large tract for horse pasture. The Floridians evidently seek solitude. Accordingly to the developer they are unlikely to clear much of their land. Other individuals indicate that many immigrants to this part of the study area clear at least some of their land when they build. The question remains, however, whether this acreage represents a significant portion of the conversion the data reveal.

Part of the conversion to grass/shrub also may result from changed corporate strategy as the result of the pine beetle epidemic. The developer that bought the Huber lands in Van Buren County claims to have cleared no land itself. As much of the divestiture in Van Buren County occurred around the time of the pine beetle, it is possible that clearing occurred originally with the intention to establish a pine plantation(s) but that the owners decided against that after the hardwood harvest. This cleared land then became available for pasture. It has proven difficult to establish who actually cleared that land. It appears that divestiture created the opportunity for agricultural expansion as well as homebuilding. Thus, divestiture, particularly in concert with the pine beetle, may have promoted conversion of native forest to grass at least indirectly.

We intend to apply the theoretical framework developed above to a multinomial probit analysis of changes in LULC. Most studies of change in LULC have divided the landscape into cells and analyzed the conversion of cells. We had intended to study LULC conversion at the scale of the parcel as a more logical unit of decisionmaking than a cell. However, because many parcels contain various management units with different LULC's, we have decided to analyze the conversion of these subparcel units over time, allowing for a finer degree of resolution than a parcel level analysis and for a more behaviorally appropriate analysis than a cell level approach.

Given the fact that the tax parcel boundaries and the LULC do not line up precisely we have encountered many subparcel polygons that result from the process of intersecting of these two datasets. They represent spurious management units and, as such, need to be eliminated from the analysis. We currently are engaged in that task. This also may necessitate recalculation of various spatial variables for these polygons. After that has been completed we then will engage in the probit analysis.

Conclusions

The region's changes in land use trends since 1996 towards clearing native forest for grass/shrub cover as opposed to pine, and the massive divestitures that have started in 1997, appear to be reflected, at least indirectly, in the logit analysis of homebuilding. Certainly the model shows that variables often behave differently after 1996 in ways that appear to reflect the above. For instance, parcels surrounded by larger amounts of grass/shrub appear to have experienced more homebuilding in the first period than those with smaller amounts of grass, but experienced the opposite in the second period when increased conversion to grass was occurring. The behavior of the landowner variables suggest that divestiture may have affected the likelihood of homebuilding, as would be expected.[5] The model generally behaved as expected.

While data problems have precluded a probit analysis of changes in land use/land cover, analysis of the data along with anecdotal evidence suggest that much of the change of native forest cover to grass/shrub may result more from agricultural conversion than from homebuilding. Subsequent probit analysis should enable us to test this hypothesis.

REFERENCES CITED

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 R. G. Healy. 1987. Urban and Built-Up Land Area Changes in the United States: An Empirical Investigation of Determinants. *Land Economics* 63(3): 215-226.

Arthur, W. G. 1989. Competing Technologies, Increasing Returns, and Lock-In by Historical Events. *Economic Journal* 99: 116-31.

Baker, W. L.1989. A Review of Models of Landscape Change. *Landscape Ecology* 2(2): 111-133.

Bockstael, N. E. 1996. Modeling Economics and Ecology: the Importance of a Spatial Perspective. *American Journal of Agricultural Economics* 78(5): 1168-80.

Bockstael, N. E. and E. G. Irwin. 2000. "Economics and the Land Use-Environment Link." In T. Tietenberg and H. Folmer, eds. *The International Yearbook of Environmental and Resource Economics 2000/2001*. Northampton, MA: Edward Elgar.

Clements, R. and E. Wofford. 1991. The Vascular Flora of Wolf Cove, Franklin County, TN. *Castanea* 56:268-286.

Costanza R, Wainger L, Bockstael N. 1996. Integrating spatially explicit ecological and economic models: theory and applications in the Patuxent River watershed, Maryland. In: Costanza R, Segura O, Martinez-Alier J, eds. *Getting Down to Earth: Practical Applications of Ecological Economics*. Washington, DC: IslandPress, pp. 249-84.

Cropper, M., J. Puri, and C. Griffiths. 2001. Predicting the Location of Deforestation. *Land Economics* 77(2): 172-86.

Evans, J.P. 1996. Forward. In: *Managing Natural Resources: A Planning Guide for Franklin County*. Edited by D. Durham. Tennessee Conservation League.

Evans, J. P., N. Pelkey and D. Haskell. 2002. *An Assessment of Forest Change on the Cumberland Plateau in Southern Tennessee*. Small Area Assessment Forestry Demonstration Project for the Southern Forest Resource Assessment. Final Report

[5] Attempts to include variables to capture divestiture failed. STATA would eliminate any such variable from the analysis inasmuch as it completely determined failure.

submitted to the U. S. Environmental Protection Agency and The U.S. Fish and Wildlife Service. Sewanee Landscape Analysis Laboratory, The University of the South, Sewanee, TN. March.

Durham, D., ed. 1996. Managing Natural Resources: A Planning Guide for Franklin County. Tennessee Conservation League Publication.

Geoghegan, J., Wainger, L., Bockstael, N. 1997. Spatial Landscape Indices in a Hedonic Framework: an Ecological Economics Analysis Using GIS. *Ecological Economics* 23: 251-264.

Gottfried, R.1988. The Effect of Recreation Communities on Local Land Prices: The Case of Beech Mountain. *American Economist* 22(1).

Hardie, I. and P. Parks. 1997. Land Use with Heterogeneous Quality: An Application of an Area Base Model. *American Journal of Agricultural Economics* 77: 299-310.

Hardie, I., P. Parks, P. Gottlieb, and D. Wear. 2000. Responsiveness of Rural and Urban Land Uses to Land Rent Determinants in the U.S. South. *Land Economics* 76(4): 659-73.

Irwin, E. G. and N. E. Bockstael. 2001. Interacting Agents, Spatial Externalities, and the Endogenous Evolution of Residential Land Use Pattern. *Journal of Economic Geography*. Forthcoming.

_____. 2002. Managing Urban Sprawl: The Effects of Land Use Externalities. Paper presented at the Lincoln Institute for Land Policy workshop on "Analysis of Urban Land Markets and the Impact of Market Regulation," Cambridge, MA, July 10-12.

Irwin, E. G. and N. E. Bockstael. 2001.The Problem of Identifying Land Use Spillovers: Measuring the Effects of Open Space on Residential Property Vales. *American Journal of Agricultural Economics* 83(3): 698ff.

Kimbro, C. 2005. Personal communication. University of Tennessee Agricultural Extension Agent, Grundy County.

Landis, J. 1995. Imagining Land Use Futures: Applying the California Urban Futures Model. *Journal of the American Planning Association* 61(4): 438-57.

Landis, J. and M. Zhang. 1998. The Second Generation of the California Urban Futures Model. Part 2: Specification and Calibration Results of the Land-Use Change Submodel. *Environment and Planning B: Planning and Design* 25: 795-824.

Martin, W., S. Boyce, and A. Echternacht. 1993. *Biodiversity of the Southeastern United States: Upland Terrestrial Communities*. NY: Wiley and Sons.

McShea, W. J. and W. M. Healy.2002. *Oak Forest Ecosystems*. Baltimore, MD: Johns Hopkins University Press.

Miller, D. J. and A. J. Platinga. 1999. Modeling Land Use Decisions with Aggregate Data. *American Journal of Agricultural Economics* (81): 180-94.

Moore, L., N. Pickron, and M. Tucker. 2000. *Demographic Analysis of Bledsoe, Franklin, Grundy, Marion, Sequatchie, Van Buren and Warren Counties: 1980 to 1997*.Unpublished report. Sewanee Landscape Laboratory.

Nelson, G. A. and Daniel Hellerstein. 1997. Do Roads Cause Deforesation? Using Satellite Images in Econometric Analysis of Land Use. *American Journal of Agricultural Economics* 79: 80-88.

Parks, P. J. 1987. *The Influence of Economic and Demographic Factors on Forest Land Use Decisions in North Carolina.* Report of the Southeastern Center for Forest Economics Research.

Parks, P. J. and R. J. Alig.1988. Land Base Models for Forest Resource Supply Analysis: A Critical Review. *Canadian Journal of Forest Research* 18: 965-973.

Ricketts, T. H., E. Dinerstein, D. Olson, C. J. Loucks, W. Eichbaum, D. Della Sala, K. Kavanagh, P. Hedao, P. Hurley, K. Carney, R. Abell, and S. Walters. 1999. *Terrestrial Ecoregions of North America*. Washington, DC: Island Press, Washington.

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): 337-52.

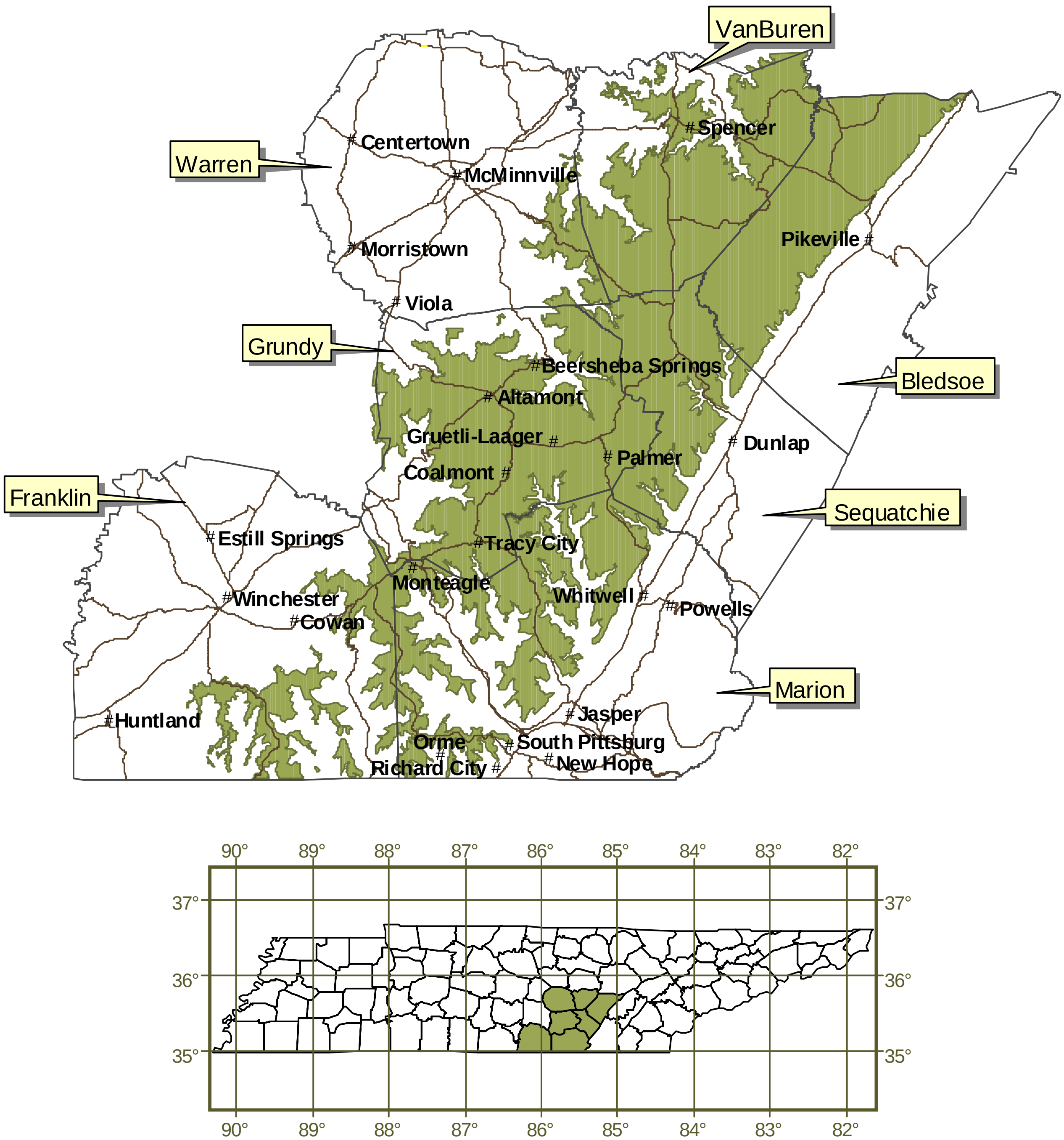
Swoape, S. 2005. Personal communication. University of Tennessee Agricultural Extension Agent, Van Buren County.

Turner, M., D. Wear, and R. Flamm. 1996. Land Ownership and Land-Cover Change in the Southern Appalachian Highlands and the Olympic Peninsula. *Ecological Applications* 6(4): 1150-72.

White, F. and F. Fleming. 1980. An Analysis of Competing Land Uses. *Southern Journal of Agricultural Economics* 12: 99-103.

Wu, J. and K. Segerson. 1995. The Impact of Policies and Land Characteristics on Potential Groundwater Pollution in Wisconsin. *American Journal of Agricultural Economics* 77: 1033-47.

Figure 1


VanBuren
Warren
Grundy
Franklin
Bledsoe
Sequatchie
Marion
Centertown
McMinnville
Morristown
Viola
Spencer
Pikeville
Beersheba Springs
Altamont
Gruetli-Laager
Palmer
Dunlap
Coalmont
Estill Springs
Tracy City
Monteagle
Winchester
Cowan
Whitwell
Powells
Huntland
Jasper
Orme
South Pittsburg
Richard City
New Hope
90° 89° 88° 87° 86° 85° 84° 83° 82°
37° 36° 35°

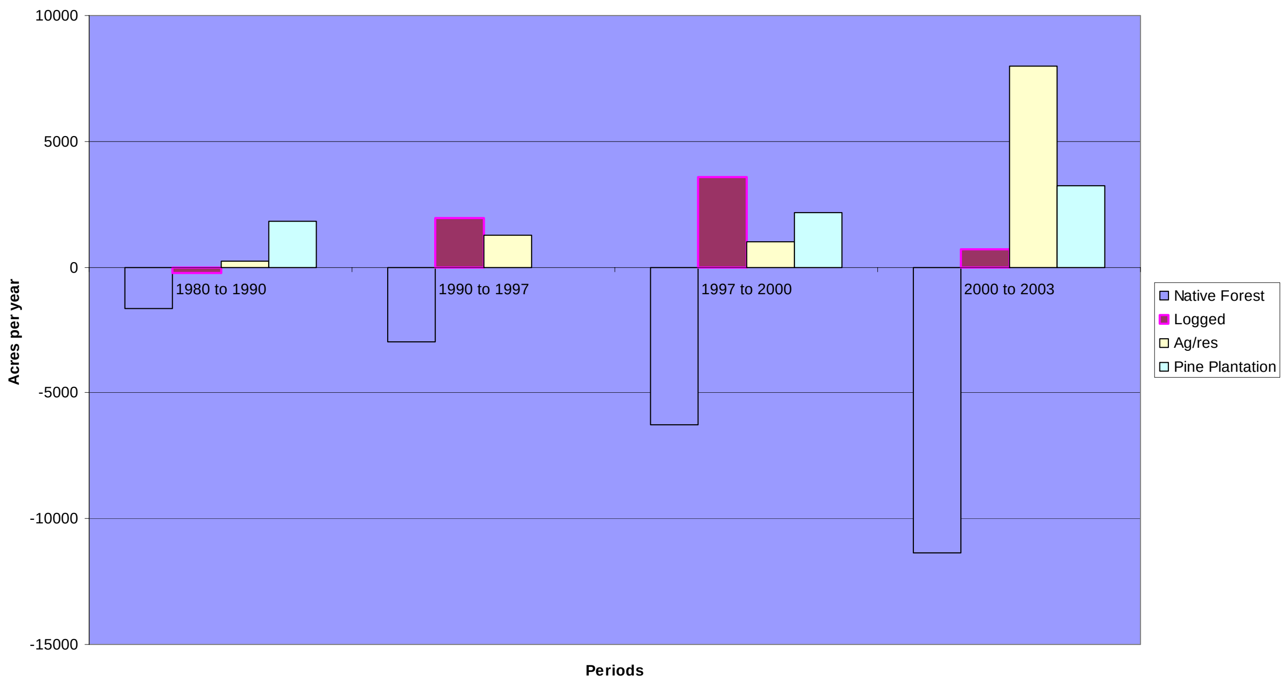


Figure 2. Annual Rate of Land Cover Change by Period

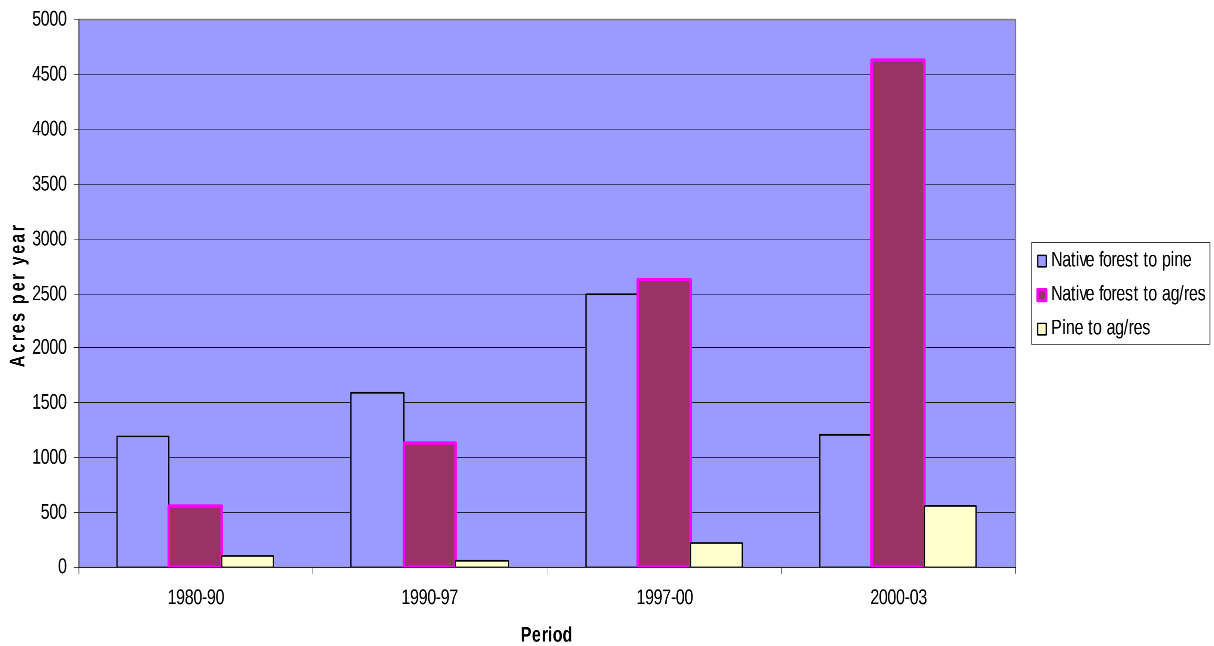


Figure 3. Annual Rates of Land Cover Conversion

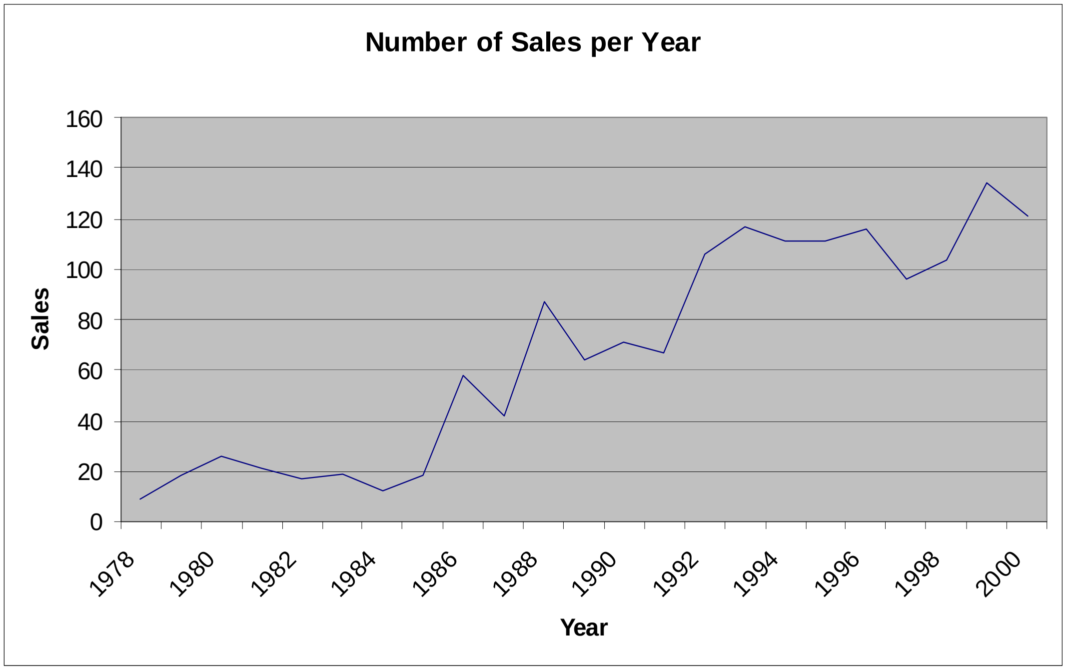


Figure 4. Land Sales per Year

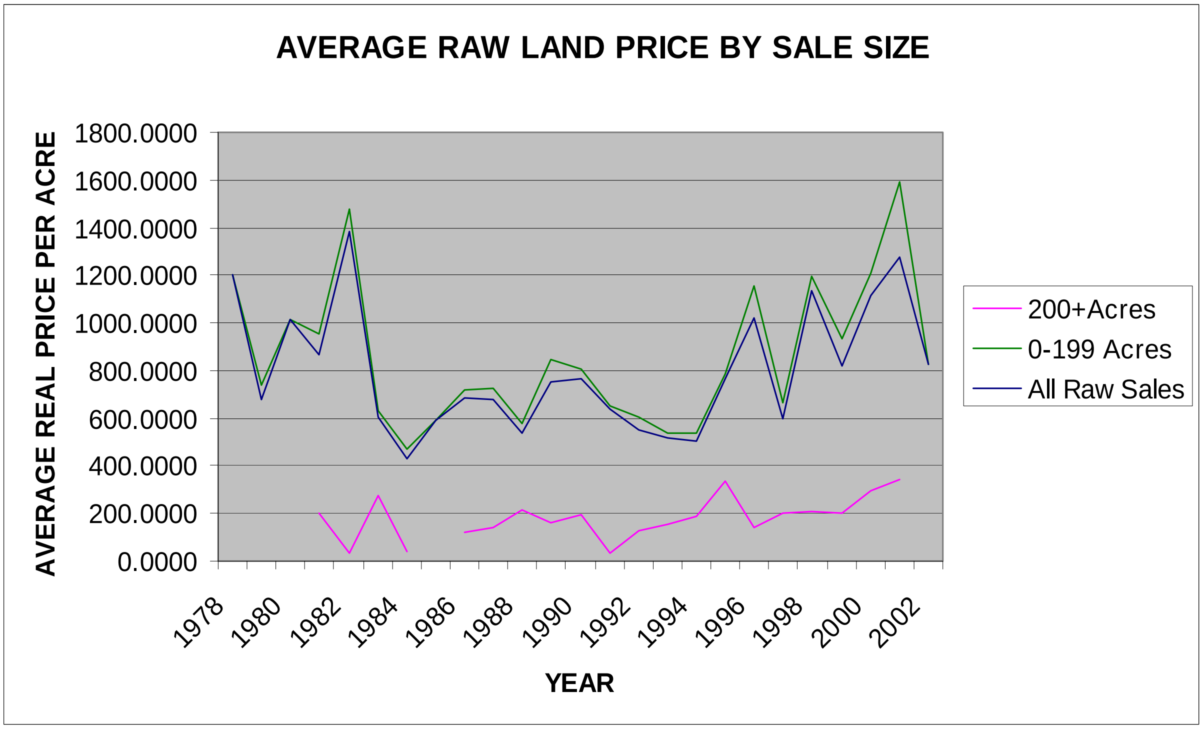


Figure 5. Trends in Price Per Acre of Raw Land

Table 1. Variables for the Logit Model

Variable	Description	Expected Sign
HBUILT	House built on parcel during the year	Na
"COUNTY"	Dummy for counties	?
BUFFER%MR	Percent of land within a radius of 0.1 or 1km in mixed pine or reservoir	?
BUFFER%PINE	Percent of land within a radius of 0.1 or 1km in pine plantation	-
BUFFER%AR	Percent of land within a radius of 0.1 or 1km in agriculture or residential (grassy/shrub)	+
BLUFF_FRONTAGE	Parcel located on bluff (0,1)	+
SIZELT90	Size of parcel less than 90 acres (0,1)	+
PERC_NF	% of parcel in native forest	?
PERC_PP	Percentage of parcel in pine plantation	-
PERC_OT	Percentage of parcel in grass/shrub	?
PAVED	Parcel on a paved road	?
NEIGHB_AVG	Average value of houses on parcels within 1km of a parcel	+
WATER	Parcel has public water (0,1)	+
SEWER	Parcel has public sewer (0,1)	+
GAS	Parcel has natural gas (0,1)	+
ELEC	Parcel has electricity (0,1)	+
NEARBY_HOUSES	Number of houses on parcels within 1km	+
DISTWHOLES	Distance to nearest parcel with a house, counting areas with parcels <10 acres as having houses	-
LNDISTCITY	Log of distance to nearest city (meters)	?
ADJ_PROT_AREA	Parcel adjacent to a protect area (0,1)	+
DIST_ROAD	Straight line distance to nearest major road (meters)	?
BUSOWNER	Parcel owner is a business (0,1)	+
TIMBEROWNER	Parcel owner is a timber company (0,1)	-
MORTGAGE_RATE	Mortgage rate on a home	-
POP_SE_CHANGE	Change in population in SE United States	+
MS_CONST_COST	Marshall Swift Construction Cost Index (deflated by CPI)	-
WILSHIRE	Wilshire stock index	+
UNEMPLOYRATE_TN	Unemployment rate in Tennessee	-
Interaction terms	*GE90: parcels 90 acres or more *1997: for period 1997 or later	

Table 2. Logit Results for Homebuilding Model

Marginal effects from logit Number of obs = 83603
chi2(47) = 677.17
Prob > chi2 = 0.0000
Log Likelihood = -3715.3375 Pseudo R2 = 0.0804

Dependent Variable: HBUILT

Independent Variables	Coef.	Std. Err.	P>z
Franklin County	-0.00022	0.000876	0.80
Grundy County	-0.00058	0.000639	0.36
Marion County	-0.00104	0.000758	0.17
Sequatchie County	0.001231	0.000715	0.09
Van Buren	-0.00111	0.000663	0.09
Warren County	-0.00074	0.0013	0.57
Marion1997	-0.00496	0.001225	0.00
Warren1997	-0.00503	0.002882	0.08
BUFFER%FOR, 0.1km	-0.00237	0.002749	0.39
BUFFER%PINE, 0.1km	-0.00465	0.00425	0.27
BUFFER%GRASS, 0.1km	-0.00662	0.003002	0.03
BLUFF_FRONTAGE	0.001431	0.000604	0.02
BLUFF_FRONTAGEGE90	-0.00345	0.001332	0.01
SIZELT90	-1.8E-05	9.81E-06	0.07
PERC_NF	0.002506	0.0018	0.16
PERC_NF1997	-0.00534	0.001705	0.00
PERC_NFGE90	-0.0046	0.001185	0.00
PERC_PP	0.006388	0.004348	0.14
PERC_PP1997	-0.02865	0.011432	0.01
PERC_PPGE90	-0.03883	0.015888	0.02
PERC_OT	0.007696	0.002035	0.00
PERC_OT1997	-0.00871	0.001871	0.00
PERC_OTGE90	-0.00854	0.008816	0.33
PAVED	-0.00087	0.000399	0.03
NEIGHB_AVG	1.33E-08	6.90E-09	0.05
WATER	0.000974	0.000421	0.02
SEWER	0.00085	0.000933	0.36
SEWER1997	0.006597	0.001352	0.00
GAS	0.002662	0.001148	0.02
ELEC	0.00327	0.00048	0.00
ELECGE90	0.001785	0.000834	0.03
NEARBY_HOUSES	0.000159	3.01E-05	0.00
DISTWHOLES	-4.18E-06	1.01E-06	0.00
DISTWHOLESGE90	3.97E-06	1.07E-06	0.00
LNDISTCITY	8.41E-05	5.21E-05	0.11
ADJ_PROT_AREA	-0.00139	0.001061	0.19
DIST_ROAD	1.54E-06	4.93E-07	0.00
DIST_ROADGE90	-5.64E-06	1.93E-06	0.00
TIMBEROWNER	-0.00858	0.004016	0.03
BUSOWNER	-0.00502	0.001635	0.00
BUSOWNER1997	0.004498	0.002103	0.03
MORTGAGE_RATE	-5.2E-05	0.000125	0.68
POP_SE_	2.82E-09	4.30E-09	0.51
MS_CONST_COST	-0.0019	0.007755	0.81
WILSHIRE	3.82E-07	1.31E-07	0.00
WILSHIRE1997	3.47E-07	1.72E-07	0.04
UNEMPLOYRATE_TN	-0.00014	0.000179	0.44
CONSTANT	-0.02558	0.005769	0.00

Table 3. Factors Affecting Probability of Home Construction

Significant variables with positive effect

BUFFER%MR, 0.1km (relative to native forest)
BLUFF_FRONTAGE, SMALL PARCELS
SIZELT90
PERC_AR>PERC_AR1997 (relative to native forest)
NEIGHB_AVG
WATER
SEWER, after 1997
GAS
ELEC, particularly after 1997
NEARBY_HOUSES
LNDISTCITY
DIST_ROAD, small parcels
WILSHIRE

Significant variables with negative effect

BUFFER%AR, 0.1km >BUFFER%PP, 0.1KM (relative to native forest)
BLUFF_FRONTAGE, LARGE PARCELS
PERC_PP1997
PERC_PP, LARGE PARCELS
PAVED
DISTWHOLES for small parcels
DIST_ROAD, large parcels
TIMBEROWNER (less likely than business owner)
BUSOWNER, particularly before 1997

Forecasting Land Use Change and Environmental Consequences for California's Coastal Watersheds

Kathleen Lohse, David Newburn, and **Adina Merenlender (presenter)**, University of California at Berkeley

Abstract

Land-use change has received less attention than other threats to natural systems and in particular, exurban development is poorly understood despite the fact that it is the fastest growing type of land use in the United States. In this study, land use and cover information was integrated with watershed variables at two different scales resulting in new insights regarding the importance of addressing the environmental impacts of exurban development. The results from a coarse scale examination of the relationship between land cover and in stream habitat demonstrate that the proportion of agriculture and urban development at a watershed scale can be useful for predicting downstream embeddedness (amount of fine sediment in fish spawning gravels). Findings from our study indicate, for the first time, that urban and exurban development patterns have differential impacts on streams, suggesting that it is no longer appropriate to aggregate these land use types in risk assessment and forecast models. Improved parcel-level land use change models were used to estimate the expected changes to land cover due to land use change and how these changes may impact future stream conditions. This approach provides thresholds of different types of land use change beyond which stream habitat is likely to be impacted from increased sediment, which in turn can influence anadromous fish population recovery.

Introduction

Land-use change has received less attention than other threats to natural systems such as global climate change and air and water pollution. This is true despite the fact that land-use change is the primary driver of habitat loss and ecosystem degradation and greatly exacerbates most of the other threats to the environment (Harte 2001). Land-use change has multiple socio-economic drivers and complex biophysical outcomes that generally elude our ability to provide a technical fix for the problems generated. In general our approach has been to address the process and pattern of past land-use change, forecast future land-use change, and determine the risk of these changes to the environment to help plan for a more sustainable future.

In particular, the characteristics associated with and processes that lead to exurban development are poorly understood despite the fact that this is now the fastest growing type of land use in the United States (Theobald 2001). This lower density development is different than the dense suburban development that commonly occurred from 1960 to 1990. Exurban development results in an unorganized scattering of homes on large parcels of land (1 unit/4-16 ha or 10-40 acres) along rural roads that do not have street lights, which rely on private water wells and individual sewage systems (Theobald 2001).

The increased rate of exurban development, along with the larger land area required to support it, means that ten times the amount of land in the United States was converted to low-density development as compared to urban densities (at least 1+ unit/4 ha or 10 acres) in 2000 (Theobald 2001). Estimates based on night-time satellite imagery suggest that 37 percent of the U.S. population now lives in exurban areas that account for 14 percent of the land area. Purely urban areas including traditional dense suburban development account for only 1.7 percent of the land area and house 55 percent of the population. In contrast, rural areas (84 percent of the land area) contain only 8 percent of the population (Sutton et al. 2005). Here we demonstrate the importance of addressing this type of develop when exploring land use change and its impacts to the environment in coastal California watershed.

Land-use is thought to be a primary cause of sediment production and delivery to streams but predicting in-stream sediment levels based on patterns of land use within a watershed have not been well-developed (Nilsson et al. 2003). It has been suggested that building empirical relationships between land use and observed sediment fluxes or concentrations may be a useful approach (Nilsson et al. 2003). In particular, sedimentation has been identified as a primary agent degrading freshwater ecosystems and limiting the persistence and recovery of salmonid populations along the Pacific coast of the United States because high levels of fine sediment (< 2 mm diameter) in spawning gravels are correlated with low survival of salmonid eggs and alevins (Kondolf 2000).

Exploring the relationship between land use, excluding and including exurban development, and environmental impacts is an important first step. For this study, we did this by examining the relationship between land cover and the condition of down stream habitat using land use/cover data at two different resolutions – TM Satellite data and parcel level county data. Satellite imagery is commonly used to determine land use, yet can not resolve low density residential development. Once relationships between land use and impacts to stream habitat are established we then used parcel-level land use change models to forecast the consequences of likely future change on down stream habitat.

Methods

Study Region

The Russian River basin is located in Sonoma and Mendocino Counties in northern California (Figure 1). The 3,850 km^2 basin is underlain primarily by the Jurassic-Cretaceous-age Franciscan Formation and experiences a Mediterranean climate with cool, wet winters and hot, dry summers, with mean annual rainfall ranging from 69 to 216 cm. Natural vegetation consists mostly of mixed-hardwood forests, oak savannas, and grassland with conifer-dominated forests occurring near the coast and intermittently on north-facing slopes throughout the basin. Primary land uses include vineyards, timber harvest, urban, and residential development. Currently, there are high rates of land-use change on the hillslopes with conversions from natural vegetation to vineyard (Merenlender 2000) and suburban and exurban development (Merenlender et al. 2005).

Analysis

We developed statistical models to explore the relationship between upland land use and stream habitat at two different resolutions. The first was done using satellite data for land cover classes and the second used land cover types designated by Sonoma County at the parcel level. In both cases, we draw on existing habitat data at the reach scale from field surveys by the California Department of Fish and Game. Specifically, we used embeddedness scores as the dependent variable. Between 1997 and 2000 field crews recorded the concentration or level of fine sediment within gravel and cobble substrate, termed "embeddedness," at each potential spawning site on a four-level, ordinal scale, from one (very low levels of fine sediment) to four (very high levels of fine sediment). Through dynamic segmentation and calibration, we spatially linked reach-scale data to a drainage network within the GIS.

We delineated approximately 150 watersheds in the Russian River basin and extracted watershed and land use change metrics that were potentially important in determining in-stream and watershed scale responses. For the coarse scale analysis we used land classifications based on LANDSAT TM imagery to determine the proportion of watersheds covered in different land uses (e.g. urban, agriculture, forest). We then examined the statistical relationships between land use /land cover and embeddedness. Furthermore, we examined the scale of influence of land use cover within watersheds as well as across watersheds.

To examine the impacts of rural residential development and couple empirical regression stream habitat models with the land use change models, we developed new statistical models based on the land cover as designated by parcel level data and tax assessor data rather than LANDSAT imagery data. Developing parcel-level land use maps also allowed us to capture individual decision-making processes and to measure the effects of different residential densities (low, medium, and high). For this scale of analysis, we selected watersheds with stream gradients less than 0.03, to evaluate depositional stream reaches most likely impacted by sediment. Based on these criteria, we selected 64 watersheds (surveyed from 1994-1997) for model development and 41 watersheds (surveyed from 1998-2002) as a validation set. Watersheds ranged in size from from 500 to 18,165 ha,

We developed multiple ordinal logistic regression models to examine the relative contribution of land use at the parcel level on embeddedness. Multiple ordinal logistic regression applies maximum likelihood estimates (MLE) after transforming the dependent variable into a logit value, the natural logarithm of odds of the dependent occurring or not occurring;

$\log (P_i/1\text{-}P_i) = B_i + B_1X_1 + B_2X_2 + B_3X_3$ where i = 1, 2, and 3 rank response (response-1). Much like ordinary least squares regression models, multiple ordinal logistic models can be used to determine the percent of the variance in the dependent variable explained by the independent and rank the relative importance. Unlike OLS, logistic regression models do not assume linearity of relationships and do not require normally distributed data. Rather, logistic functions model a threshold response, in this case, the probability of reduction in substrate quality associated with increases in different land use, periods of land use or cumulative land use.

Model performance was evaluated based on usefulness (strength of the relationship, pseudo-R^2), accuracy (percent of correctly predicted maximum likelihood estimators), and significance (model chi-square or deviance). Restricted chi-square tests were employed to test the importance of the explanatory variables and their additivity.

The spatially explicit land-use change model used for the final application of this research was constructed using parcel-level data (Bell and Irwin 2002). The model is conditioned on the initial land-use state, taken as "developable" parcels in 1990. This excludes those lands protected in parks and reserves and parcels already converted to residential, vineyard or other high-intensity land uses prior to 1990 based on existing land-use maps. Land-use conversion is defined as transitions from developable parcels in 1990 to either a residential type or vineyard use during the period 1990-2000. The conversion decision is considered irreversible due to the substantial up-front fixed costs. The classes of residential densities used are in Table 1. Because Suburban and Exurban were highly correlated ($r^2 = 0.68$), we aggregated these two classes. The land use change models were calibrated separately for each of the major land uses since the likelihood of development for each land use type depended on different factors.

Table 1: Housing density land use classification (adapted from Theobald 2003).

Housing density class	Acres/structure	Housing density (structures/acre)	Residential land use
Very High	0.25	≥ 4	Urban
High	0.25-1	≥1	Urban
Medium	>1-5	<1 and ≥ 0.2	Suburban
Low	>5-40	<0.2 and ≥ 0.025	Exurban
Very Low	>40	<0.025	Rural

Given the three possible land-use outcomes over the period 1990-2000, a multinomial logit model was employed to explain land-use transitions as a function of parcel site and neighborhood characteristics. The Sonoma County Tax Assessor's Office database provides the land-use data source, which was linked to the digital parcel map within a GIS. Parcel boundaries permitted the overlay and extraction with GIS layers to obtain many site and neighborhood characteristics on land quality, accessibility to urban centers, public water and sewer services, zoning and neighboring land use. For example, average percent slope and elevation in meters was calculated for each parcel. Growing-degree days, summed over the April to October vineyard growing season, serves as a proxy for microclimate. A dummy variable was used to represent whether a given parcel is situated within the 100-year floodplain. An optimal routing algorithm within the GIS was used to calculate the minimum travel time in minutes between each parcel and San Francisco along the road network, utilizing weighted travel speeds of 55 mph on major highways and 25 mph on county roads.

Logit parameters are potentially biased in the presence of spatially autocorrelated errors. We estimated logit on random stratified bootstrapped samples taken from the full data set. These samples did not have sample-selection bias and had less spatial autocorrelation than the full sample, because the parcels were farther apart. This bootstrapped subsampling technique did not have noticeably different parameter estimates or prediction errors as compared to standard logit estimation.

Finally, we forecasted substrate quality and its uncertainty based on the average land use change for 2010. Estimated coefficients from the multinomial logistic regression are employed to predict the relative probability of land-use change, since the site characteristics for all parcels are known within the GIS. For this prediction phase, explanatory variables for percentages of neighboring land uses are updated from 1990 to 2000. The model output is the relative probability of future residential and vineyard development for each of the 16,773 developable parcels.

These models were used to convert the current land cover types for each parcel to their estimated future type of land cover. Land cover conversions for 2002-2010 were estimated using a Markov decision process, where transitions were considered stochastic with decisions partly informed by site specific characteristics. Monte carlo simulation methods were repeated 1000 times to obtain the average area converted to exurban, urban, and vineyard development. Then we were able to calculate the percent of the different land uses in each watershed (% of total watershed area) for the past (1990), recent (1997), current (2002) and future (2010) time periods.

Results

Results from our first set of analyses, using land cover designations from satellite imagery, showed a strong relationship between embeddedness and proportion of watersheds in urban and agricultural land use. The power of the empirical regression model depended on the size of the watershed. Generally, the watershed scale was the best predictor of embeddedness compared to other local or drainage network scales of influence (Opperman et al. 2005).

The parcel level models again demonstrated that agricultural land in the watershed is a significant predictor of embeddedness, but they also reveal the importance of even low density housing on stream condition. Preliminary results show that low-medium residential housing and agriculture have a strong impact on the concentration of fine sediment in streams. During the land use transition period from 1990 to 1997, 92% of parcels developed for housing were converted to the urban housing class. In contrast, 77% of the acreage developed for housing was converted to exurban housing (60% as exurban and 17% as suburban). These results demonstrate the importance of addressing exurban development in examining land use across these watersheds. Simple logistic regression models of recent development (1997) revealed significant and negative nonlinear effects of different land uses on substrate quality (Figure 2). While urban has the most adverse impact on embeddedness, this is followed by exurban development and then vineyards.

The strongest multiple ordinal logistic regression model to explain embeddedness combines past development of exurban housing with expansion of urban and vineyard during the recent growth period from 1990-1997. The combined land use model predicted the maximum likelihood estimator for embeddedness with 80% accuracy and fell within 95% confidence intervals for watersheds surveyed from 1998- 2002 (when one outlier stream with channelized banks was removed).

Estimation results for this land-use change model indicate that conversion to vineyard use is more likely on areas with lower slope and higher growing-degree days (warmer microclimate). Steeper slopes raise expected vineyard establishment costs and lower grape yields, while cooler coastal microclimates are less likely to allow grapes to reach maturity. Vineyards are also more likely in areas designated for "land intensive agriculture" or "diverse agriculture" under the 1989 General Plan. These zoning designations correspond to the prime agricultural areas within the County, and future residential development is highly restricted.

Residential conversion is more likely in areas zoned for rural or urban residential, the baseline zoning category in table 1, and more likely on parcels zoned for smaller minimum lot sizes. The importance of zoning for residential conversion is clear since higher density zoning increases rents per acre associated with residential uses. Areas with access to urban services are estimated to be more likely to be developed for residential use, whereas residential conversion is less likely on steeper slopes and within the 100-year floodplain. Residential use was expected to have higher likelihood in the southern region of Sonoma County; however, the estimate coefficient for travel time to San Francisco is positive. The percentage of neighboring 1990 urban development increases the likelihood of residential conversion, whereas the percentage of protected open space did not appear to significantly affect residential conversion.

Forecasts for 2010 stream conditions resulted in different estimated embeddedness levels for each watershed and with the level and type of development (Figure 3). Various development scenarios can be run to evaluate high and low growth options.

Discussion

This research shows that increased sediment from urban, exurban, and agricultural areas and associated roads may be one cause of stream habitat degradation that could potentially influence salmonid abundance and recovery. This landscape-scale analysis emphasizes the overarching importance of large-scale land-use patterns on environmental condition. In areas where rural residential development is pervasive it is critical to be able to measure the extent of this type of development – a land use type that is not detectable using many of the readily available methods of assessing land cover/use based on remote sensing.

Understanding the influence of upland land use on stream habitat that influences salmonid survivorship is important to consider for restoration strategies. Much attention and resources have been spent on piece-meal stream restoration and sediment control efforts at the local scale (e.g., bank stabilization). This research indicates that the benefits of localized restoration efforts may be overwhelmed by ongoing land use at larger scales. To improve salmon habitat conditions, restoration efforts should emphasize protecting riparian corridors throughout entire watersheds and promoting programs or policies that ameliorate the influence of urban development, roads and agricultural land use.

One of the major advancements of this work is the calibration of LUC models to distinguish among different levels of residential density. Findings from our study indicate that urban and exurban development patterns have differential impacts on streams. Zoning that allows for low density residential development may have adverse impacts at the larger watershed scale possibly due to heavily used unpaved road networks and development of steep hillsides.

In our study area it would not be appropriate to aggregate all types of residential development into a single land use type in risk assessment and forecast models. Rather we need to move towards considering human development along a continuum (Theobald 2004). We further suggest that parcel level data may be the fundamental unit of land use change analysis because it represents the economic decision unit for land owners and resolves issues of geographical scale and boundary issues that have long hampered the progress in ecological forecasting scale (Nilsson 2003). Such data will help to overcome the challenges of coupling ecological and economic forecast models that operate at different spatial and temporal scales, and help us move towards a more sustainable future.

The models developed during this research project were also used to improve targeting for land conservation (Newburn et al. 2006). This approach incorporates threat and cost into the selection criteria for prioritizing land conservation and also has application to evaluating outcomes of private land conservation tools such as conservation easements (Merenlender 2004). To implement the ideas developed from this research we work closely with the Sonoma County Agricultural Preservation and Open Space District and the Sonoma County Water Agency.

Literature Cited

Bell, K., and E. Irwin. 2002 Spatially Explicit Micro-Level Modeling of Land-use Change at the Rural-Urban Interface. Agricultural Economics 27:217-232.

Harte, J. 2001. Land use, biodiversity, and ecosystem integrity: the challenge of preserving earths' life support system. Ecology Law Quarterly 27: 929-965.

Kondolf, G.M. 2000. Assessing salmonid spawning gravel quality. Trans. Am. Fish. Soc., 129: 262-281.

Merenlender, A. M., Brooks, C., Shabazian, D., gao, S., and R. Johnston. 2005. Forecasting exurban development to evaluate the influence of land-use policies on

wildland and farmland conservation. Journal of Conservation Planning 1(1):64-88.
Merenlender, A. M., Huntsinger, L., Guthey, G., and S. K. Fairfax. 2004. Land trusts and conservation easements: Who is conserving what for whom? Conservation Biology 18(1):65-75.
Merenlender, A. M. 2000. Mapping vineyard expansion provides information on agriculture and the environment. California Agriculture 54(3):7-12.
Newburn, D., 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
Nilsson, C., J. , Pizzuto, E., Moglen, G. E., Palmer, M. A., Stanley, E. H., Bockstael, N. E. & Thompson, L. C. (2003) Ecosystems **6,** 659-674.
Opperman, J. J, Lohse, K., Brooks, C., Kelly, N. M., and Merenlender, A. M. 2005. Influence of land use on fine sediment in salmonid spawning gravels within the Russian River basin, California. Canadian Journal of Fisheries and Aquatic Science 62:2740-2751
Sutton, P., T. J. Cova, and C. D. Elvidge. 2005. Mapping "exurbia" in the conterminous United States using nighttime satellite imagery. Geocarto. In press.
Theobald, D. M. 2001. Land-use dynamics beyond the American urban fringes. Geographical Review 91: 544-564.
Theobald, D. M. 2003. Targeting conservation action through assessment of protection and exurban threats. Conservation Biology **17,** 1624-1637.
Theobald, D. M. 2004 Placing exurban land-use change in a human modification framework. Frontiers in Ecology and the Environment **2,** 139-144.
.

Figure 1. Location of the Russian River basin in California.

Figure 2.
Along the x axis is the percent of exurban, urban, and vineyard land use types and the y axis represents the probability of the ranked embeddedness score. These odinal logistic regression models results show nonlinear effects of increasing land use on embeddedness. Increases in land use in the watershed reduced the odds of low embeddedness occurring.

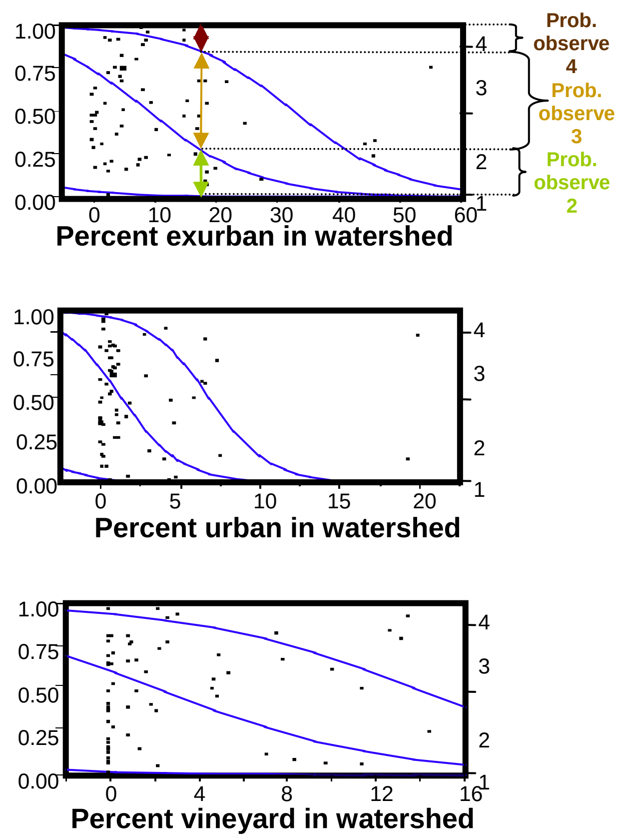
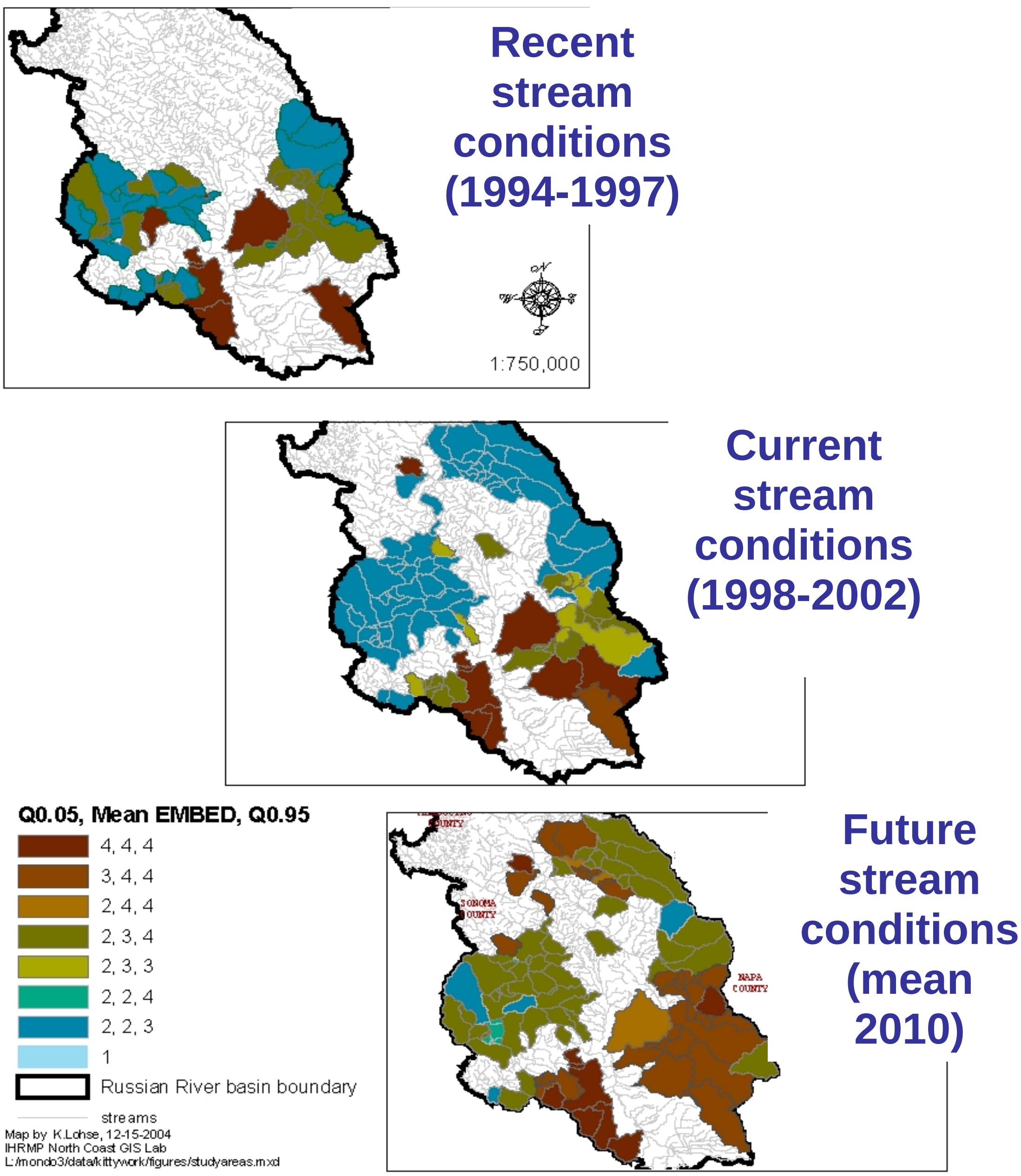


Figure 3. : Predicted patterns of embeddedness based on minimum, average, and maximum levels of land use in the build and test watersheds. Maximum levels of development were based on the mean and 2 standard errors predicted from Monte Carlo Simulations. Minimum levels of development were based on 25% of the average development scenario.



Modeling land use change:
discussion of Gottfried et al. and Merenlender et al.

Stephen C. Newbold
U.S. EPA – National Center for Environmental Economics
1200 Pennsylvania Ave NW – MC1809T
Washington, DC
newbold.steve@epa.gov
(202) 566-2293

Based on a discussion presented at the EPA workshop, "Socio-Economic Causes and Consequences of Future Environmental Changes"

U.S. EPA Region 9
San Francisco, CA

17 November 2005

Introduction

This note discusses two reports presented at the EPA workshop, “Socio-Economic Causes and Consequences of Future Environmental Changes,” held 17 November 2005 in San Francisco, CA: “Determinants of land conversion on the southern Cumberland Plateau,” presented by Gottfried, and “Forecasting land use change and environmental consequences for California’s coastal watersheds,” presented by Merenlender and Newburn.

Models for forecasting land use changes can be useful for environmental policy evaluation in at least two ways. First, they can be used to characterize the changing baseline (no-policy) conditions against which proposed policies should be compared. Second, they can aid in the geographical targeting of habitat protection efforts. Although the research projects discussed in this note are not yet completed (which perhaps can account for some of the questions I raise below), it is clear that these projects are tackling a range of interesting and important questions about the drivers of land use change and that they have the potential to make contributions along both dimensions indicated above.

I will address several issues specific to each paper in turn, and then raise a few policy (and other) questions and offer some recommendations that may be relevant for both sets of authors.

Gottfried et al.

The overall goals of the larger research program lead by Gottfried are to develop a spatial socioeconomic model of land use/land cover (LULC) change for the Southern Cumberland Plateau, integrate the LULC change model with bird, amphibian, and water quality landscape models, and to use the integrated models to evaluate potential environmental impacts of, and policy responses to, likely socioeconomic events or trends.[1] The report presented at the workshop focused on one component of this larger research agenda, the determinants of homebuilding in the Cumberland Plateau.

The report begins with a review of the economic literature on land use change that neatly sets the stage for a presentation of the current work. Next the authors develop a “theoretical model of land use change,” which comes in the form of a series of stylized equations and accompanying prose descriptions of the process of land use change through the emergence of markets for new land uses and the search by individuals for the purchase of parcels and their conversion. However, it is not clear that the stylized equations add much of substance to the narrative description of the theorized process of land use change. The authors could consider either (1) tightening up this section by removing the stylized equations (distinctions could still be made in narrative form between the different components of the land use change process that currently are highlighted by the equations), or (2) expanding this section to make better use of the equations by way of a more explicit linkage to work done by previous researchers and the authors’ own intentions for operationalizing the framework. Have

[1] http://cfpub.epa.gov/ncer_abstracts/index.cfm/fuseaction/display.abstractDetail/abstract/5436

previous researchers focused on just one or a few of the separate processes identified by each stylized equation? Have previous researchers combined certain processes where they might be better treated separately? Will the authors attempt to model each of these processes independently? If so, how will they be combined in the end? And so forth.

While it is difficult to place some of the preliminary results into the context of the larger research project, at least one result is particularly suggestive. In the logit model of homebuilding a dummy variable for years after 1996 is found to be statistically significant. If I understand the authors' interpretation correctly, this is taken as evidence of a large scale structural change in the market owing to massive divestitures of pine plantations by the few large landowners in the area, which in turn may have been partly influenced by the southern pine beetle outbreak around this time. Earlier in the report the authors discussed the importance of changes in large scale economic (or in this case ecological) conditions as drivers of land use change, and their interpretation of the logit modeling results seems consistent with that idea. In this case an essentially unpredictable ecological change at a scale much larger than the study area, the pine beetle outbreak, led to decisions by a small handful of individuals in (or out of?) the study area, owners of pine plantations, which finally led to the changes in land use the authors are interested in forecasting.

This raises questions about the kinds of explanatory variables that should be included in the model, the appropriate scale at which to measure them, and the potential accuracy of long run forecasts of land use change. If much land use change is due to largely unpredictable shifts in macro-economic or ecological conditions, then how much confidence can we have in the quantitative predictions of models that exclude such factors? Can we rely on the idea that such unpredictable structural changes will likely affect both the baseline and policy cases in a similar manner so our policy evaluations, which rely on differences between baseline and policy conditions, should still be reliable? These questions are not taken up by the authors in this report, but their results begin to suggest future research along these lines.

The report concludes with a brief description of plans to "apply the theoretical framework developed above to a multinomial probit analysis of changes in LULC." The authors can be forgiven for restricting the present report to the preliminary results currently available and plans for future work. However, a more detailed description of how the theoretical model, which isolated a series of causal processes that combine to determine the rate of land use change, will be operationalized with a single statistical model would be useful.

Merenlender et al.

The overall objective of the larger research program led by Merenlender is to "examine the environmental consequences of land use change for California coastal watersheds that impact anadromous fish," and the specific goals are to develop land use change models, forecast land cover changes, and predict the effects of those changes on stream conditions and salmon populations.[2] The report presented at the workshop contains preliminary results from one

[2] http://cfpub.epa.gov/ncer_abstracts/index.cfm/fuseaction/display.abstractDetail/abstract/5627/report/0

component of this larger research program: an empirical model of the effects of watershed land use conditions on the quality of stream habitat. (Two other models also were mentioned in the report: a model of land use change, and a simulation exercise that used the land use change model and the watershed embeddedness model together to forecast future stream conditions. However, the main focus of the report was on estimating the relationship between land use conditions and stream habitat quality.)

The report used a regression model to characterize the effects of various land use types – specifically agriculture, urban, and exurban lands – on embeddedness in downstream river reaches at various spatial scales. The fit of the regression model was highest when the explanatory variables were measured at the watershed scale, and the effects of each land use type were found to be substantially different. It appears that the amount of urban and vineyard acres in a watershed increases embeddedness at a higher rate than exurban acres, but this ordering was not completely clear from the graphs presented in the report. A table of regression results and an expanded prose interpretation of the results would be helpful here.

It also was not immediately clear what the per household effect on embeddedness was for urban and exurban land uses. Strong claims were made about the importance of distinguishing between urban and exurban land uses, so an expanded discussion of their differential effects on embeddedness would strengthen the report. In particular, even though urban areas appear to have a larger impact per acre, they could have a smaller impact per household if the difference in the average housing density between the two land use types is large enough. This could have a bearing on recommendations one would draw from these results for zoning restrictions or other similar land use policies.

Some general policy questions and recommendations

Several policy questions and recommendations apply more or less equally to both reports. First, a general issue that both research teams should be able to address is how land use protection efforts should be targeted geographically. An agency interested in spending funds on land protection generally will confront a continuum of expensive land in immediate danger of conversion to inexpensive land that may not be converted for a long time to come, if ever. The nature of the tradeoff here is obvious – with a limited budget one could purchase a small amount of land that very likely would be converted otherwise, or one could buy more land that may not be in need of protection.

Recently, the Merenlender research team has published an essay on this topic in *Conservation Biology* (Newburn et al. 2005). It should be possible to say something concrete in specific cases if the empirical relationship between the probability of conversion and land values is known. Just such a modeling exercise is one of the goals of both of these research projects.

As a simplified first cut at addressing this question, consider using either probit or logit regression to estimate a model of land conversion probabilities as a function of land values (plus whatever other explanatory variables are thought to be important). For example, a logit model with just two land use states, undeveloped or developed, would be:

$$P_i = \frac{e^{a+bV_i}}{1+e^{a+bV_i}}$$

where P_i is the probability that parcel *i* will be converted from an undeveloped state to a developed state (over some time period of interest), V_i is the assessed value of parcel *i* (i.e., the price it should fetch if sold on the land market), and *a* and *b* are parameters to be estimated.

Now consider a land protection agency who wants to maximize the amount of land left in an undeveloped state. This gives the following optimization problem:

$$\underset{x_i}{Max} \quad I - \sum_{i=1}^{I} P_i \left(1 - x_i\right)$$

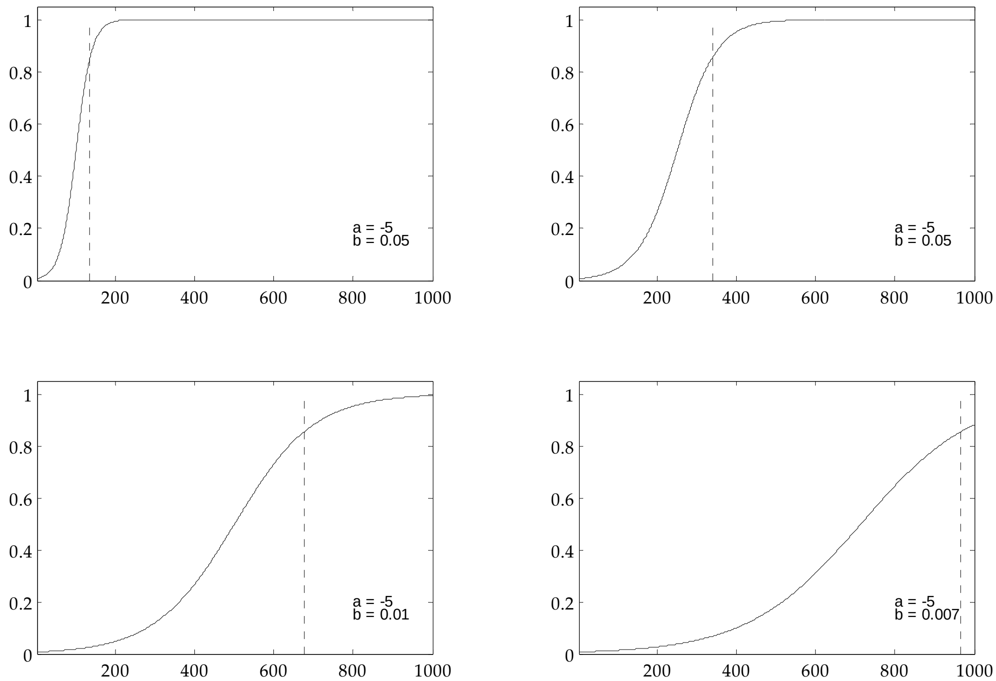
subject to:

$$B \geq \sum_{i=1}^{I} x_i V_i$$

where x_i is 1 if parcel *i* is purchased and 0 otherwise, *I* is the total number of parcels (all land parcels are the same size in this example), and *B* is the amount of funds available for purchasing land. The expression to be maximized is the expected area of land left in an undeveloped state, and the land protection agency is constrained by a limited budget. Posed this way this is a classic knapsack problem, the solution of which is to choose parcels in decreasing order of their benefit-to-cost ratios (Dantzig 1957). Since the objective is to maximize the total expected area of undeveloped land, the benefits are P_i and the costs are V_i.

With the *P(V)* function estimated using the logit model, it is straightforward to find the value of *V* that maximizes the expression for the benefit cost ratio, $R(\equiv P/V)$. A few examples are shown in the graphs on the following page.

The solutions (found numerically by identifying where $\partial R/\partial V$ switches from positive to negative as *V* increases) are at the shoulder of the S-curve that describes the probability of conversion as a function of land values (identified by the vertical dashed lines in the graphs). This suggests that more land will be left undeveloped if the land protection agency targets parcels for purchase that are somewhat less than 100% certain to be developed otherwise, but not too much less. The optimal probabilities for targeting in the four examples below are between 80-85%. Also note that a corner solution is possible (not shown in the graphs). If the probability of conversion even for the most valuable parcels is low enough, the agency should target the highest valued parcels for purchase.



This model is overly simplified in several ways (I have been particularly vague about the dynamic aspects of the problem and the time horizon), but I believe it points to the potential practical utility of the research being conducted by both Gottfried and Merenlender. It would be instructive to work out this problem in particular case studies using empirical results that should emerge from both of these research projects.[3]

Another suggestion for both authors is to review the behavioral rationale given for the standard multinomial logit model of site choice in the recreation demand literature (e.g., Haab and McConnel 2002, especially Ch 8 and App B). The behavioral and informational assumptions there are clearly spelled out: there is maximizing behavior assumed on the part of the recreators, some variables are assumed unknown to the researcher but known to the recreators, and so forth. There may be a close analogy to be made with the land use change case: a parcel is either left in its current use or converted to another use in any given time period depending on which has the highest expected NPV, similar to a recreator choosing to stay at home or to visit a particular recreation site on any give choice occasion depending on which will deliver the greatest utility. This might help to forge a tighter link between the behavioral economic model and the statistical model used to analyze the land use change data.

Other considerations also may be important when choosing between a reduced form and a structural modeling approach to land use change. For example, a naive application of a

[3] In a forthcoming article, Newburn et al. (2006) use a dynamic programming approach to address this issue in a much more rigorous way than the simple model sketched here.

hedonic property value model for forecasting land use changes typically would assume that the cross sectional data used to estimate the model represented a market equilibrium. What are the implications if the data were collected when the market was going through a major adjustment? What if the market is always adjusting? With time series data on land use conditions and macro-economic conditions, research in this area has the potential to estimate dynamic models of property values and land use changes. This would allow researchers to address such questions as: How long does a differential between expected PV and conversion costs persist; in other words, how long does it take for land markets to achieve equilibrium? Do observed conditions approximate an equilibrium conditional on, say, last year's macro economic conditions? Or do these larger scale drivers change so rapidly and unpredictably relative to the speed of adjustments in the land market that observed prices are always adjusting? What implications would this have for policy evaluation? Under what conditions will using a static hedonic property model that assumes the market is in equilibrium when it actually is in the process of adjustment lead to biased forecasts of land use changes?

Finally, it would helpful to know what types of policies the authors imagine their research informing, both in general and specific terms. Does the analyst just get qualitative lessons in the form of rules of thumb, or does the analyst get generally applicable numerical models that can be applied in many other settings if the appropriate data are collected? Can the models be used to evaluate zoning changes, water withdrawal restrictions, within-watershed land use changes including riparian buffers or set-backs, on farm best management practices, etc? What "instructions for use" would the authors give to policy makers or analysts for applying their models and results? Answers to these questions are rarely spelled out in scholarly articles, which means that professional policy analysts that want to use the results of research such as this often must fill in some large gaps as best they can. In my experience, this seems to be a major source of much uncertainty in the final policy analysis.

References

Dantzig, G.B. 1957. Discrete-variable extremum problems. *Operations Research* 5(2):266-277.

Haab, T.C., and K.E. McConnell. 2002. Valuing Environmental and Natural Resources: The Econometrics of Non-market Valuation. Northampton, MA: Edward Elgar.

Newburn, D., 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., Reed, S., Berck, P, and A. Merenlender. 2005. Economics and land-use change in prioritizing private land conservation. *Conservation Biology* 19(5):1411-1420.

Heidi J. Albers (Department of Forest Resources, Oregon State University)
Session I Discussant

Comments on:
Gottfried's "Determinants of Land Use Conversion on the Southern Cumberland Plateau" and Merenlender's "Integrating Economic and Physical Data to Forecast Land Use Change and Environmental Consequences for California's Coastal Watersheds"

Thank you for giving me the opportunity to be here and to read these papers. I work on similar issues but using different techniques and reading these papers was a good chance for me to think about things differently, which is always a useful exercise. I will make a few general comments, then some specific comments on each paper, and then return to a few more general comments for this literature.

General Comments:

Both papers do two things that are important and helpful.

First, both papers use parcels as the unit of analysis. They have both argued that using parcels is a good thing and I am confirming that point. Often these data do not exist and we are forced to use other units of analysis and then do some hand-waving to interpret results. But, with the parcel as the unit of analysis we have a direct correspondence between the unit over which people make decisions and the unit of analysis, and that improves the discussion of policy and causality.

Second, most of the literature that uses this kind of analysis and these types of data sets focus on either urban or tropical settings, and today's papers focus instead on non-urban areas of the US. I am convinced, for the following reasons, that land use patterns away from cities but still in the US are important and understudied:

- Land in those areas provides ecosystem services (even though outside of protected areas) that are potentially quite important. In fact, I would hazard a guess that a large fraction of the ecosystem services of importance to the US are generated outside of urban areas, such as biodiversity protection, watershed protection, and recreation opportunities. In urban areas, some land certainly provides ecosystem services and benefits but those benefits may accrue largely to the local people, such as through view and dog parks. So, much of the land that generates ecosystem services is out of urban areas.
- In biodiversity protection, for example, both policy and ecological literatures emphasize the importance of biodiversity outside of protected areas and often on private land. The question of how to create incentives and policies to promote ecosystem service provision on private land has become large, and some programs such as CREP try to do that. But, without studies like the ones presented this morning, we have little information about land use and land cover change decisions on private land away from urban areas and so have little information about the potential response to policies aimed there.

- Should we expect land use patterns in these areas to be influenced by the same things as in urban areas and/or to respond to policy in the same way? If not, policy that is developed based on analysis of urban areas will not improve land use patterns in rural areas. These studies provide useful information about how land decisions in non-urban settings differ from those in urban settings.

Some Specific Comments on Adina Merenlender's paper:

In addition to the emphasis on non-urban location, I really like the development of a framework that seeks to link land use patterns to a conservation outcome/ecosystem service (here sediment that decreases spawning sites for salmonid populations). To further that sort of interdisciplinary connection, I suggest that the authors look at the watershed models that examine salmon populations as a function of water temperature and of riparian land use (such as those by Junjie Wu and others).

The paper focuses on the watershed as a whole rather than looking only at the riparian portions of the watershed, and I agree that that focus is important. Still, the riparian land use is particularly important in protecting rivers from sediment and from temperature and I imagine that it wouldn't be difficult, with such a great data set, to develop some riparian measures in addition to the watershed measures to examine their relative importance. Also, although many policies do aim at local scale improvements such as bank stabilization, as stated in the paper, millions of dollars are spent annually on implementing policies at the watershed level to protect salmonid species in Oregon alone.

The analysis here does not simply put forward averages but instead uses the probabilities of land use transitions to form the basis for generating 1000 possible future land use patterns (incorporating stochasticity based on those transition probabilities) and then analyzes the characteristics of that range or distribution of possible outcomes. I like that approach very much because it allows for more of a landscape style analysis rather than a per-parcel analysis. (It reminds me of work by Dave Lewis and Andrew Plantinga.) Ecosystem services are generated at a landscape scale and so moving from parcels – where the decisions are made – to the landscape generated by those individual decisions can be a particularly useful way of linking disaggregated decisions to the provision of ecosystem services. This mode of analysis also provides an opportunity to look at the spatial configuration of land use and the role of particular patterns on ecosystem outcomes and that opportunity has not yet been fully realized in the work presented thus far. I encourage the authors to think more in that direction.

Today's presentation discussed the role of zoning more than the paper did. I did have a concern in the paper that zoning decisions are made as a function of things like productivity and desirability of land uses and so there is some endogeneity there. But, in the presentation, the authors seem to be thinking about those aspects of zoning in an appropriate way.

Specific Comments on Gottfried's paper

The paper develops a model of the land market that I assume is meant to address characteristics of the land market in rural areas that are different from those in an urban area. I would like to see more discussion of those differences, perhaps linking to models of incomplete and thin markets as discussed in the development economics literature.

I would also like to know more about both the owner characteristics and about neighborhood characteristics. For example, why don't current owners convert to more highly valued uses? Why have they waited to expand pasture land? And does the amount of a particular land use, say horse stables, in the area alter the value of that land use (localized supply effects)?

As a new Oregonian, I would be remiss to not inquire about the issues of timber land in this region. First, are there links to the national phenomenon of diverse forest products companies selling off forest land to focus only on producing paper/wood goods as opposed to also producing timber? This research may be able to contribute to the discussion of that national trend. Second, the paper refers to a company with a mill located not too far away and that company's need to "feed" that mill. The mill's presence is potentially very important in driving the market – and the land use of pine versus hardwood. The mill needs raw wood every year – does that fact inform land management in the area and can that type of issue be teased out of these data? In Oregon, mills have closed down all across the state (due in part to restrictions on harvesting on federal land) and dramatically altered the location of timber production. That fact leads me to believe that some analysis about feeding that mill could prove important.

I would also like to see more detail or more use of the data in determining the divisions made here: lots under 90 acres versus larger; and pre/post 1999-2001. How can you use the data to test for differences across sizes and times rather than subdividing prior to analysis?

General Comments

Both papers find that open space is not significant in residential conversion. As someone who studies open space, who makes my own location decisions as a function of open space, and who sees developers incorporating open space into their decisions, this lack of significance bothers me. Is my research of no value? But maybe this result is exactly why we need analyses of non-urban settings: perhaps open space works very differently in less densely populated areas where people get many of those benefits from their own multi-acre sized lots. This lack of significance on open space, then, underscores the importance of doing research that distinguishes between land use decisions made in urban settings (where open space is typically quite important) and those made in non-urban settings, both through models and through empirical testing of those models.

The one thing that is missing from these papers and from most of this literature is a spatially-explicit behavioral model. I remember discussing "economies of configuration" with Professor Gottfried about ten years ago. Ecologists have been describing the importance of configuration for ecosystem services for at least that long. But economists have not yet done a good job of examining how disaggregated decisions by landowners add up to different configurations of land cover. This literature relies on proximity measures to a large degree and has not developed behavioral models of spatial configuration. Because many ecosystem services are a function of configuration of land uses, we need to understand how behavior leads to configuration.

Overall, both papers represent the tip of the iceberg in terms of what these projects will generate and contribute. Both research projects, in their use of parcels and in their focus on non-urban areas, take important steps toward understanding land use patterns in those settings and provide a foundation for exploring the links between policy, decisions, and ecosystem services or outcomes. And I applaud them for this work.

Summary of the Q&A Discussion Following Session I

Mark Johnson, (EPA Region 10)
Directing his question to Dr. Gottfried, Mr. Johnson noted that in his introductory remarks Dr. Gottfried had referred to "water quality proxies" but then hadn't specified what those dependent variables were.

Dr. Robert Gottfried, (University of the South)
Dr. Gottfried responded, "Initially we were going to work with macro-invertebrates in the streams," but he acknowledged that the data was difficult to collect and they didn't have enough samples to connect land-use changes with that variable. Although he still feels "that would be a good way to go," he stated that for now they are left with the "crude" proxy of "data about landowner types and what sorts of buffers have been maintained along riparian zones." He said that he would "love to have a real sediment model operating, but that's going to have to be down the road somewhere."

Joseph Mihelarakis, (California Department of Transportation)
Mr. Mihelarakis wondered what was the motivating factor for Bowater's divestiture of all their acreage, which comprised a significant portion of the area covered by Dr. Gottfried's study. He added that he "didn't get the connection between the demand for paper, which seems to be rising, and the lowering demand for pine in the region."

Dr. Robert Gottfried
In response, Dr. Gottfried explained, "If I understand it correctly, newsprint demand is going down because of the internet and so forth, so there is that element." He added that Bowater's initial establishment of pine plantations was due, in part, to the insurance companies' requirement that a paper mill have a secure supply of inputs. In other words, they needed a captive source of timber. He went on to explain that "these days with the amazing amount of pine that's grown in the Southeast, they no longer have to have their own captive source" to demonstrate that they have a secure source of inputs. Consequently, Bowater and other paper companies are choosing "rather than have a long-term return off of land that's rather low" to sell the land and put the money in other investments that offer a quick return—and to go ahead and buy pine on the market.

Dr. Gottfried wondered whether in the long run these paper companies are "in a sense shooting themselves in the foot" by selling off their internal production control capacities and totally relying on the market for their supply.

Pierre duVair, (California Energy Commission)
Mr. duVair addressed Drs. Merenlender and Newburn on "the causal relationships between land use change and degree of embeddedness or sedimentation," saying he was "curious about the potential ability to distinguish between natural versus anthropogenic sources of sedimentation." For instance, he wondered about the ability to "understand the relationship of construction and stormwater runoff versus climate change and variability and how that might influence natural erosion."

Dr. Adina Merenlender, (University of California at Berkeley)
Dr. Merenlender began by re-emphasizing “how much variation there is in the embeddedness” and she related how they tried to at least tackle some of the data outliers and understand what was going on there. She said the research team, which was charged with studying land-use and forecasting land-use changes and hopefully making some predictions based on those forecasts, was strengthened by the addition of a geologist who was able to help present and analyze other possibilities. She added that, “Unfortunately, the historic timber harvest plan databases are rather limited, but we *were* able to get some idea of where the California Department of Forestry and Fire Protection had mapped timber harvest plans and we also looked at different geologies and found that it did not enhance the model in any way.” She quickly added that the models used “are not 100% predictive”—they are generally happy to get 70-80% explanatory power out of them—“so, there is a lot about the system that we cannot explain by the simple variables that we try to plug in.” She agreed that there is a lot going on regarding the general morphology and geology and other aspects that are studied on a more site-specific scale.

Addressing targeting, Dr. Merenlender emphasized the importance of looking at priorities for acquisition over time. She noted that “as you allocate your budget for conservation, when one thinks about threat and acquiring sites that *are* threatened, it’s important to think about acquiring those sooner, as threat progresses and changes the patterns on the landscape, than to acquire the next set of threatened resources.” She cited the current situation along the Pacific coast where coastal forests with their redwoods and other flora receive a lot of exposure and advocacy despite the fact that the hardwood rangelands are actually more threatened to development, near term. She closed by reiterating that it’s important to allocate local budgets more in tune with addressing identified near-term resource threats as opposed to long-term threats. She also proposed more focus on wildland configurations and explorations of the types of relationships that clearly show the impacts of protective changes that are made so there can be an effective measurement and assessment of progress.

END OF SESSION I Q&A

SOCIO-ECONOMIC CAUSES AND CONSEQUENCES OF FUTURE ENVIRONMENTAL CHANGES WORKSHOP

A WORKSHOP SPONSORED BY THE U.S. ENVIRONMENTAL PROTECTION AGENCY'S NATIONAL CENTER FOR ENVIRONMENTAL ECONOMICS (NCEE), NATIONAL CENTER FOR ENVIRONMENTAL RESEARCH (NCER)

November 16, 2005

EPA Region 9 Building

75 Hawthorne Street 1st Floor Conference Room San Francisco, CA

Prepared by Alpha-Gamma Technologies, Inc. 4700 Falls of Neuse Road, Suite 350, Raleigh, NC 27609

ACKNOWLEDGEMENTS

This report has been prepared by Alpha-Gamma Technologies, Inc. with funding from the National Center for Environmental Economics (NCEE). Alpha-Gamma wishes to thank NCEE's Cynthia Morgan and Jennifer Bowen and the Project Officer, Cheryl R. Brown, for their guidance and assistance throughout this project.

DISCLAIMER

U.S. Environmental Protection Agency
Socio-Economic Causes and Consequences of Future Environmental Changes Workshop

November 16, 2005
EPA Region 9
75 Hawthorne Street
1St Floor Conference Room
San Francisco, CA

8:45-9:15	**Registration**	
9:15 -9:30	**Introductory Remarks – Tom Huetteman, Deputy Assistant Regional Administrator, USEPA Pacific Southwest Region 9**	
9:30-11:30	**Session I:**	**Trends in Housing, Land Use, and Land Cover Change** Session Moderator: Jan Baxter, US EPA, Region 9, Senior Science Policy Advisor
	9:30 – 10:00	Determinants of Land Use Conversion on the Southern Cumberland Plateau **Robert Gottfried (presenter)**, Jonathan Evans, David Haskell, and Douglass Williams, University of the South
	10:00– 10:30	Integrating Economic and Physical Data to Forecast Land Use Change and Environmental Consequences for California's Coastal Watersheds Kathleen Lohse, David Newburn, and **Adina Merenlender (presenter)**, University of California at Berkeley
	10:30 – 10:45	**Break**
	10:45 – 11:00	Discussant: Steve Newbold, US EPA, National Center for Environmental Economics
	11:00 – 11:15	Discussant: Heidi Albers, Oregon State University
	11:15 – 11:30	Questions and Discussions
11:30 – 12:30	**Lunch**	
12:30 –2:30	**Session II:**	**The Economic and Demographic Drivers of Aquaculture and Greenhouse Gas Emissions Growth** Session Moderator: Bobbye Smith, U.S. EPA Region 9
	12:30 – 1:00	Future Growth of the U.S. Aquaculture Industry and Associated Environmental Quality Issues **Di Jin (presenter)**, Porter Hoagland, and Hauke Kite Powell, Woods Hole Oceanographic Institution

	1:00 – 1:30	Households, Consumption, and Energy Use: The Role of Demographic Change in Future U.S. Greenhouse Gas Emissions Brian O'Neill, Brown University, **Michael Dalton (presenter)**, California State University – Monterey Bay, John Pitkin, Alexia Prskawetz, Max Planck Institute for Demographic Research
	1:30 – 1:45	Discussant: Tim Eichenberg, The Ocean Conservancy
	1:45 – 2:00	Discussant: Charles Kolstad, University of California at Santa Barbara
	2:00 – 2:30	Questions and Discussion
2:30 – 2:45	**Break**	
2:45 - 4:55	**Session III:**	**New Research: Land Use, Transportation, and Air Quality** Session Moderator: Kathleen Dadey, US EPA, Region 9, Co-chair of the Regional Science Council
	2:45 - 3:10	Transforming Office Parks Into Transit Villages: Pleasanton's Hacienda Business Park **Steve Raney (presenter)**, Cities21
	3:10 – 3:35	Methodology for Assessing the Effects of Technological and Economic Changes on the Location, Timing and Ambient Air Quality Impacts of Power Sector Emissions Joseph Ellis and **Benjamin Hobbs (presenter)**, Johns Hopkins University, Dallas Burtaw and Karen Palmer, Resources for the Future
	3:35 - 4:00	Integrating Land Use, Transportation and Air Quality Modeling **Paul Waddell (presenter)**, University of Washington
	4:00- 4:25	Regional Development, Population Trend, and Technology Change Impacts on Future Air Pollution Emissions in the San Joaquin Valley Michael Kleeman, Deb Niemeier, **Susan Handy (presenter)**, Jay Lund, Song Bai, Sangho Choo, Julie Ogilvie, Shengyi Gao, University of California at Davis
	4:25 – 4:55	Questions and Discussion
4:55 – 5:00	**Wrap-Up and Closing Comments**	

[DRAFT]

Future Growth of the U.S. Aquaculture Industry and Associated Environmental Quality Issues*

Di Jin**, Hauke L. Kite-Powell and Porter Hoagland

Marine Policy Center
Woods Hole Oceanographic Institution
Woods Hole, MA 02543

October 26 2005

* Prepared for the US Environmental Protection Agency Workshop on Socio-Economic Causes and Consequences of Future Environmental Changes, San Francisco, CA, November 16, 2005.

** Corresponding author. phone: 508-289-2874; fax: 508-457-2184; djin@whoi.edu.

Acknowledgements: We would like to thank Eric Thunberg for providing helpful insights and suggestions and for supplying projections of groundfish landings in New England. This study has been supported by the US Environmental Protection Agency STAR Grant Program (Agreement Number: R82980401) and the Marine Policy Center of the Woods Hole Oceanographic Institution. The results and conclusions of this paper do not necessarily represent the views of the funding agencies. The usual disclaimers apply.

Abstract

Aquaculture is an important and growing source of the supply of protein from seafood. The potential expansion of the aquaculture industry into marine environments has become a subject of concern to other ocean users, conservationists, and pollution regulators. In forecasting the future expansion of aquaculture in coastal-ocean environments, most studies focus only on the constraint posed by the local environmental assimilative capacity. We develop an alternative market-oriented approach for projecting the growth of the industry. We evaluate equilibria in the market for seafood, where the product may be supplied either by a wild-harvest fishery or open-ocean aquaculture or both. In our framework, the net demand for farmed fish determines the size of the aquaculture industry and, in turn, the levels of pollution discharges. Analogous to studies of assimilative capacity, the socially optimal industry size may be constrained by environmental damages resulting from pollution. In open-ocean environments where the assimilative capacity is unlikely to be a serious constraint, however, the market-oriented approach is a much better method for projecting industry growth. We illustrate our approach with a case study of a groundfish fishery and the proposed open-ocean aquaculture of Atlantic cod in New England. We find that, for a range of competitive production costs for aquaculture, the optimal industry structure would comprise both a wild-harvest fishery and aquaculture. For example, with a rebuilt groundfish stock yielding 156 thousand mt annually, the optimal marine aquaculture industry would comprise 11 farms producing 23 thousand mt of cod each year. The aquaculture industry would be smaller if the industry is held to account for any damages to the environment through a pollution tax. Alternatively, the industry would be larger if effective pollution control measures can be implemented or if there is a significant expansion in the demand for seafood.

1. Introduction

The production of seafood by aquaculture is growing rapidly in many parts of the world. According to the United Nations Food and Agriculture Organization, one-quarter of the world's total seafood production of 130 million mt per year is now produced by aquaculture. Of world total aquaculture production, the marine aquaculture industry produces 15 million mt. Although the lion's share of this production occurs in other countries, especially in China and southeast Asia, many observers suggest that aquaculture has the potential to grow significantly in US marine waters. Here, we analyze the potential for the future expansion of open-ocean aquaculture in the United States, and we consider how this potential might be constrained by pollution.

A marine aquaculture industry is unlikely to realize its full potential in the United States if operators ignore several types of external effects. First, aquaculture facilities, such as netpens for growing finfish, are sources of macronutrients (nitrogen [N] and phosphorus [P]) and sediment loads. Feces and unused food diminish water quality, increasing biochemical oxygen demand and enhancing the potential for eutrophication (Folke, Kautsky, and Troell; Smearman, D'Souza, and Norton). Second, the application of therapeutants and pesticides can lead to chemical pollution. Third, in some circumstances, fish diseases can be introduced or spread more readily by aquaculture into healthy environments (Folke and Kautsky; Brennan). Finally, the farming of carnivorous species requires large inputs of forage fish for feed, potentially stressing ecosystems with which the forage fish are associated (Naylor *et al*.).[1] The destruction of mangrove forests and coastal wetlands for pond farming is another problem associated with the expansion

[1] This type of impact is a consequence of the over-exploitation of the fisheries for forage fish.

of aquaculture in coastal areas (Barbier and Cox). Table 1 summarizes key economic and ecological effects associated with marine aquaculture development. A preliminary qualitative assessment of environmental effects is presented in Figure 1.

Whether the culturing of fish causes marine pollution depends to a large extent on the assimilative capacity of the receiving environment. A water body's assimilative capacity is a function of its physical, chemical, and biological characteristics (Silvert; Brennan). Estimates of assimilative capacity using specialized water quality assessment models are the most common way to project limits to the future expansion of marine aquaculture (Gillibrand and Turrell). Typically, a water quality assessment model simulates both water flows and waste transport. Waste transport is influenced by water depth, current velocity, and the settling velocity of waste particles. For a specific pollutant, such as nitrogen (N), the model starts with the total quantity of N in feed and calculates the shares of N consumed by fish, dissolved in water, settled in the sediments, and flushed out of the system. The difference in water quality with aquaculture and without it can then be used to estimate the maximum acceptable N loading from aquaculture expansion. Finally, the maximum loading then is used to calculate the maximum "allowable" aquaculture production level (Midlen and Redding).

As an example of the water quality assessment approach, Norway has implemented a nationwide assessment of the suitability of its coastal zones and rivers for aquaculture (Ibrekk, Kryvi, and Elvestad). This assessment involves a determination of the maximum acceptable organic loading for each water body.[2] In this way, the residual capacity of a water body to handle aquaculture development can be evaluated. Under the

[2] Maximum organic loading is estimated by subtracting the existing organic loads and nutrients from an estimate of the natural capacity of the area to tolerate these inputs.

Norwegian assessment, nine percent of Norway's coastal areas have been found suitable for aquaculture. The full utilization of these areas for aquaculture would result in an annual production of 600,000 mt of salmon and trout.

In the case of open-ocean aquaculture, however, the water quality assessment approach is inappropriate for anticipating aquaculture development, because effluents disperse quickly. Further, changes in nutrient levels are difficult to gauge in an open-ocean environment. In this article, we develop a market-oriented approach for projecting the growth of an aquaculture industry in the open ocean. We evaluate equilibria in the market for seafood, where the product may be supplied either by a wild-harvest fishery or open-ocean aquaculture or both. In our framework, the net demand for farmed fish determines the size of the aquaculture industry and, in turn, the level of pollution discharges. Analogous to studies of environmental assimilative capacity, the socially optimal industry size may be constrained by environmental damages resulting from pollution. In open-ocean environments, where the assimilative capacity is unlikely to be a serious constraint, however, the market-oriented approach is a superior method for projecting industry growth. We illustrate our approach with a case study of a groundfish fishery and the proposed open-ocean aquaculture of Atlantic cod in New England.

The remainder of this article is organized as follows. Section 2 presents a review of the literature concerning pollution control and the measurement of environmental costs in marine aquaculture. Section 3 describes our analytical framework and the data used for simulations. Section 4 summarizes the results of a set of simulations. Section 5 presents some conclusions.

2. Literature Review

2.1. Marine Aquaculture and Pollution Control

Nutrient pollution (*e.g.*, excessive levels of N and P) in aquatic and marine ecosystems has been the focus of many recent studies (Beveridge; Smearman, D'Souza, and Norton; Midlen and Redding). Folke, Kautsky, and Troell conclude that salmon farming, as undertaken in Swedish coastal waters in the early 1990s, is not only ecologically but also economically unsustainable. Although there are a number of environmental impacts contributing to external costs, nutrient releases and their causal relationships to eutrophication and toxic algal blooms lead to the most significant impacts. The authors calculate that nutrient releases from a fish farm producing 100 mt of salmon each year correspond to those of a human settlement of 850-3,200 persons.

Normally, in the absence of regulation, we expect firms to disregard environmental costs. In some cases, such as netpen operations for salmon, discharges from aquaculture production facilities can be monitored and measured. Effluents from these facilities could then be regulated as point sources. One approach is to charge fish farmers a tax equal to the marginal external costs imposed by their farms on the environment at the socially optimal externality level (Smearman, D'Souza, and Norton). For example, Sylvia, Anderson, and Cai develop a procedure for calculating the optimal tax on effluent discharges from salmon netpen operations.

Waste discharges from other types of aquaculture operations, such as large-scale coastal shrimp ponds, cannot be measured so easily. Consequently, the regulation of these operations as point sources generally is not feasible. Mathis and Baker argue that in the face of uncertainty about effluent releases, the power of traditional economic instruments such as taxes and tradable permit systems to internalize environmental costs is greatly reduced. Broadly speaking, because of the complexity of production processes and pollutant releases, combinations of market-based and command-and-control instruments may be required (Stanley). Studies by GESAMP and by Brennan describe the key factors affecting environmental management in aquaculture, highlighting a range of potentially useful policy instruments, such as pollution standards, taxes, legal liability measures, and best management practices (BMPs).

Stanley suggests that wastewater discharges from coastal shrimp farms are non-point source pollution, because the wastewater may be released at irregular times and levels from large numbers of farms covering large geographic areas. The nature of non-point pollution implies that the direct regulation of aquaculture operations is not feasible. The shrimp farming industry apparently favors the implementation of BMPs, which would involve the adoption of voluntary pollution controls that are not easily observed or enforced.

Brennan provides an overview of pollution control options currently practiced in the marine aquaculture industry. First, pollution may be managed through siting decisions that involve a review of the current levels of nutrient loadings at a specific location. Typically, densely populated areas may be eutrophic already, implying that only more remote locations would be available for aquaculture. Second, depending upon the conditions at a particular location, nutrient controls may involve restrictions on the total number and size of individual farms, as well as limits on stocking densities.[3] Further, various technologies may be used to improve the efficiency by which cultured fish convert feed into biomass (*i.e.*, to lower the feed conversion ratio [FCR]), thereby

[3] Reducing stocking densities can lead to other benefits, such as reduced risks of disease and increased harvest sizes.

reducing the quantity of unused food in the aquaculture operation. The U.S. Environmental Protection Agency recently has proposed regulations to monitor feed rates and to reduce feed inputs (USEPA). Lastly, different biocontrol techniques have been considered. For example, Neori *et al*. report that seaweed can be effective as a biofilter in an integrated fish-seaweed culture operation. Similarly, Folke and Kautsky propose a method for the polyculture of seaweeds, mussels, and salmon.

The effectiveness of technology-based pollution control measures in Norwegian salmon aquaculture has been examined by Asche, Guttormsen, and Tveteras and by Tveteras independently. Data from Norway between 1980 and 2000 exhibited a declining trend in FCR[4] and in the applications of antibiotics and chemicals,[5] even as production was expanding. Because feed often is the most costly input, constituting around 50 percent of production costs, gains in feed efficiency lead to both increased productivity and reduced effluents. Tveteras argues that industry growth can be achieved together with pollution reductions by encouraging technological innovations in industry-specific, pollution-reducing inputs. In the case of the salmon aquaculture industry, growth in supply has been associated with reduced environmental problems in both relative and absolute senses.

2.2. Measurement of Environmental Cost

The worldwide expansion of aquaculture production has been matched by growing concerns about its environmental impacts. Public pressure is mounting now for the aquaculture industry to account for its use of public resources and to demonstrate its

---

[4] The FCR has declined for salmon from nearly 3:1 in 1980 to just over 1:1 in 2000. In laboratory experiments, it has been possible to achieve FCRs as low as 0.6:1.

[5] Vaccines have been found to reduce substantially the incidence of fish diseases. Antibiotic applications can be minimized through a shift from curative to preventative disease treatment.

environmental sustainability (Muir *et al*.). Economic assessments of social and environmental costs and benefits might provide different and possibly more critical guidance for aquaculture development. Typically, total external costs are calculated as the sum of costs arising from specific externalities, such as impacts on water quality, local fisheries, and neighboring mariculture operations (Brennan; Stanley). Existing studies of the economic benefits of water quality improvements may provide insights for aquaculture management (Freeman 1979, 1995; Lyon and Farrow). The interactions between aquaculture and commercial fisheries in the market have been examined by Anderson (1985a, 1985b), who considers the implications for fishery management and for ocean ranching of salmonids. Hoagland, Jin, and Kite-Powell examine interactions between aquaculture and fisheries in both the seafood market and in the allocation of ocean areas.

It can be difficult to construct an accurate cost measure of environmental damages from pollution discharges, because marine resources provide a variety of tangible and intangible goods and services to the public. Although most economists would argue that marine resources generate both use and non-use values, there is little consensus among specialists about which damage assessment methodologies are appropriate in any given situation (*viz*., Kahneman and Knetsch; Smith; Arrow *et al*.). Muir *et al*. review the relevant issues and propose ways in which valuation techniques may be applied more effectively in strategic and local decision-making for aquaculture development. For example, in the case of salmon farming in Scottish sea lochs, these authors suggest that contingent valuation ought to be used to value an environmental amenity (e.g., the habitat characteristics of the loch), the travel cost approach ought to be used to capture the value of recreation at a specific location, and hedonic pricing ought to be used to estimate changes in property values due to the negative impacts of aquaculture facilities or the positive impacts of a well-managed development.

Smearman, D'Souza, and Norton estimate the external costs of aquaculture production in West Virginia. The authors suggest that total external costs may be measured as the sum of pollution prevention (*e.g.*, the costs of pollution control technologies), pollution avoidance (*e.g.*, the costs associated with activities taken by parties affected by pollution), and pollution damages. The first two components typically are engineering costs, and they can be relatively easy to quantify. Pollution damages are more difficult to measure, and they must be quantified using willingness to pay estimates based upon expressions of contingent values or calculations of travel costs. The authors estimate that, for the open type production system used in trout farming, pollution control costs are six percent and pollution damages are 25 percent, respectively, of private production costs.

Using survey results, Tran, Le, and Brennan estimate external costs in the shrimp farming industry located in the rice-growing regions of the Mekong Delta. In their study, external costs are defined to include sedimentation and salinization of fresh waters, leading to losses in rice production, the taking of preventative measures (*e.g.*, dike construction), delays in rice planting, and long term losses of farm land. Kitabatake models production losses caused by eutrophication in the farming of carp in Japan's Lake Kasumigaura, using a framework that integrates production, damage, and cost functions. Empirical results are developed using data from aquaculture producers, showing that about four percent of annual carp production in the lake is lost due to eutrophication. Pollution-related losses are primarily of fish cultured with an automatic feeding technology.

3. Methods

3.1. Framework

Our general analytical framework is depicted as a flow chart in figure 2. The chart illustrates the interactions among the key components of the framework, and it serves as a blueprint for our model of aquaculture environmental policy analysis. The future scale of aquaculture operations is influenced by the supply and demand for seafood. In turn, aggregate seafood demand is a function of population, income, and protein substitutes. Income levels are affected by changes in economic conditions. Aggregate seafood supply comes from three sources: fisheries, net imports (wild-harvest and cultured seafood), and aquaculture. The future supply from fisheries depends upon future stock sizes, which are influenced by current and future fisheries management efforts to allocate quotas and to protect and rebuild fish stocks. The level of imports is affected by supply and demand in international markets and by relevant trade policies.

For given levels of seafood supplies from fisheries and imports, we can estimate the demand (*i.e.*, price and quantity) for aquaculture products. Together, the demand for aquaculture products and its production technologies (and costs) determine the size of the aquaculture industry, which in turn determines the potential level of pollution.

3.2. Model

We assume that aquaculture produces the same species as a commercial fishery and that the product is undifferentiated in the market. We consider a linear demand function for fish:

$$p = (p_0 - kh)e^{\theta t} \qquad (1)$$

where p_0 is the choke price, k is the slope, h is the landings of fish or production from aquaculture supplied to the market, and θ is an exogenous parameter. The price is increasing in θ. In the analytical model, we do not explicitly model fish imports, and equation (1) is the net demand for domestic fish supplies. With this demand, we can compute the social benefit (B) at a given level of supply, h, to be:

$$B(h) = e^{\theta t}\int_0^h (p_0 - k\eta)d\eta = e^{\theta t}(p_0 h - kh^2/2) \qquad (2)$$

The production function for the wild harvest fishery is:

$$h_f = qxE \qquad (3)$$

where h_f is the level of landings from the harvest fishery, q is a catchability coefficient, x is the size of the natural fish stock, and E is an aggregate variable that represents fishing effort.

A variety of models of aquaculture production are extant in the literature (Hatch and Kinnucan; Bjorndal; Allen *et al.*; Shang). We assume that one type of unchanging aquaculture technology is used. As a consequence, capital and labor are proportional to acreage. A production function for aquaculture takes the following form:

$$h_a = ws \qquad (4)$$

where h_a is the total farmgate output, w is the output per farm, and s is the total number of farms. According to this model, a larger number of farms are needed if aquaculture is to increase its supply to the market.

Total benefits from the supply of fish are the sum of the revenues from the harvest of fish from a wild stock and the production of fish by aquaculture. From equations (3) and (4), benefits are a function of *E, x* and *s*:

$$B(E,x,s) = B(h_f + h_a) \qquad (5)$$

The cost of fishing, C_f, is modeled as a function of fishing effort:

$$\frac{\partial C_f}{\partial E} > 0 \qquad (6)$$

The cost of aquaculture, C_a, also is a function of the total number of farms *s*; and the cost of investment in new farms (*I*) is a function of the increment, *z*, to the total *s*.

$$\frac{\partial C_a}{\partial s} > 0, \qquad \frac{\partial I}{\partial z} > 0 \qquad (7)$$

The environmental damage from aquaculture is a function of the scale of production:

$$\frac{\partial D}{\partial s} > 0 \qquad (8)$$

A hypothetical regional manager chooses a level of investment in aquaculture, *z*, and a level of fishing effort, *E*, to maximize the net benefits of fish production from both the wild harvest fishery and aquaculture:

$$max \int_0^{\infty} \{ B(E,x,s) - C_f(E) - C_a(s) - I(z) - D(s) \} e^{-\delta t} dt \qquad (9)$$

subject to

$$\dot{x} = f(x) - qxE \qquad (10)$$

$$\dot{s} = z \qquad (11)$$

The two constraints describe the growth of the wild stock and changes in the scale of aquaculture production. The current-value Hamiltonian is:

$$H = B(E, x, s) - C_f(E) - C_a(s) - I(z) - D(s) + \lambda[f(x) - qxE] + \beta z \quad (12)$$

The marginal conditions for an interior solution include:

$$\frac{\partial H}{\partial E} = \frac{\partial B}{\partial E} - \frac{\partial C_f}{\partial E} - \lambda qx = 0 \quad (13)$$

$$\frac{\partial H}{\partial z} = -\frac{\partial I}{\partial z} + \beta = 0 \quad (14)$$

$$\dot{\lambda} - \delta\lambda = -\frac{\partial H}{\partial x} = -\frac{\partial B}{\partial x} - \lambda\frac{\partial f}{\partial x} + \lambda qE \quad (15)$$

$$\dot{\beta} - \delta\beta = -\frac{\partial H}{\partial s} = -\frac{\partial B}{\partial s} + \frac{\partial C_a}{\partial s} + \frac{\partial D}{\partial s} \quad (16)$$

Substituting (3) and (4) into (5), the benefit function becomes:

$$B = e^{\theta t}[p_0(qxE + ws) - k(qxE + ws)^2 / 2] \quad (17)$$

We employ a surplus production model to describe the growth, *f*, of the wild stock:

$$f(x) = rx - \frac{rx^2}{K} \quad (18)$$

where *r* is an intrinsic growth rate, and *K* represents the ecosystem's carrying capacity.

We specify the cost and investment functions as

$$C_f = cE \quad (19)$$

$$C_a = vs \quad (20)$$

$$I = bz \quad (21)$$

$$D = ms \quad (22)$$

Equations (13) through (16) become

$$\lambda = e^{\theta t}[p_0 - k(qxE + ws)] - c/(qx) \quad (23)$$

$$\beta = b \quad (24)$$

$$\dot{\lambda} - \lambda(\delta - r + qE + 2rx/K) + e^{\theta t} qE[p_0 - k(qxE + ws)] = 0 \qquad (25)$$

$$\dot{\beta} - \delta\beta + e^{\theta t} w[p_0 - k(qxE + ws)] - v - m = 0 \qquad (26)$$

From (24) and (26), we can solve for the optimal steady-state production scale of aquaculture:

$$s^* = \frac{p_0 - kh_f - e^{-\theta t}(\delta b + v + m)/w}{kw} \qquad (27)$$

The number of aquaculture farms is positively related to fish price (p_0) and the growth in demand over time and is negatively related to production cost (v), the cost of investment in farms (z), environmental damages (m), average farm productivity (w), and landings from the harvest fishery (h_f).

Assuming that the price of fish is not appreciating over time ($\theta = 0$) and a steady-state equilibrium is feasible, we use equations (23) through (26) to derive the following expressions for the marginal benefit (MB), the marginal cost of aquaculture with respect to fish yield (MC_a), and the marginal cost of fishing with respect to yield (MC_f)[6]:

$$MB = p_0 - k(qxE + ws) \qquad (28)$$

$$MC_a = \frac{\delta b + v + m}{w} \qquad (29)$$

$$MC_f = mc_f\left[1 + \left(\frac{qE}{\delta - \frac{df}{dx}}\right)\right] \qquad (30)$$

---

[6] We substitute for λ using equation (23) and β using equation (24). Then we solve both (25) and (26) for MB.

where we define $mc_f = c/(qx)$ to be the marginal cost of fishing with respect to yield, h_f, for the current period.[7] The market-clearing quantity is $h_f + h_a$ and the price is *MB*. Equations (25) and (26) indicate that, at market equilibrium, the marginal cost of production from both activities must equal *MB* (= $MC_a = MC_f$).

In our problem, the regional manager maximizes the benefits of fish production from both (either) the wild harvest fishery and (or) aquaculture. As shown in figure 3, this is the area below the demand curve and above the supply (*i.e.*, marginal cost) curve(s). When $MC_a < MC_f$ is always true over the entire range of aquaculture production levels (MC_a is always below MC_f in figure 3), we have a corner solution in which the entire market is supplied by aquaculture. In contrast, when $MC_a > MC_f$ is always true, the fishing industry is the sole supplier. In an interior solution (see figure 3), the wild harvest fishery is more competitive than aquaculture ($MC_f < MC_a$) within a certain range of production (h_f), and when market demand is greater than h_f, aquaculture becomes less costly ($MC_f > MC_a$). In this case, the rest of the market is supplied by aquaculture (h_a).

With $\theta = 0$, we can solve the steady-state fish stock (x^*), using equations (10), (18), (23) through (26).

$$x^* = \frac{cr/(qK) + (r-\delta)MC_a \pm \sqrt{[cr/(qK) + (r-\delta)MC_a]^2 + 8\delta crMC_a/(qK)}}{4rMC_a/K} \quad (31)$$

The corresponding aquaculture production scale (s^*) is

$$s^* = \frac{p_0 - kf(x^*) - (\delta b + v + m)/w}{kw} \quad (32)$$

The amount of pollution produced at an aquaculture facility is a function of the fish species, the production system, and the type and quality of feed. How much a

[7] Because $h_f = qxE$, we can write the total cost of fishing as $cE = c[h_f/(qx)]$.

facility is actually polluting, in turn, depends on factors such as location, whether or not a pollution control system is used, the characteristics of the water flow, and water temperature (Beveridge; Midlen and Redding). Using farm-level pollution estimates described in the Appendix, we can calculate the total annual pollution from the aquaculture industry (N_i):

$$N_i = s^* Q_i \tag{33}$$

where Q_i with i = [*BOD, TN, TP, TSS*] are farm-level annual pollution quantities (see (A24)).

3.3. Data

In order to project future growth in open-ocean aquaculture and the interactions between aquaculture and a commercial fishery, we consider the New England groundfish fishery and the potential aquaculture of Atlantic cod (*Gadus morhua*). The growout of cod in floating netpens (on the surface or submerged) has been proposed as a potential aquaculture activity along the New England coast. Open-ocean operations can be stocked with juvenile cod produced at an onshore hatchery. We assume that the cost of juveniles from the hatchery is part of the operating costs of the aquaculture operation. The product would be sold in the market for whitefish.

We employ published estimates of parameters for the groundfish fishery and the market (table 2). Edwards and Murawski develop a surplus production model for New England groundfish. Using their model coefficients, we estimate an intrinsic growth rate (r) of 0.3715 year^{-1} for our logistic growth function. Similarly, we calculate a carrying capacity for all groundfish species of 1.681 million metric tons. We use an estimate of the catchability (q) of cod at 0.000007 days^{-1}, also published in the same study.

We employ the groundfish demand function estimates from Edwards and Murawski, and we calculate a choke price (p_0) of $2,546 per mt and a slope (k) of 3.82 $/$10^{-3}$ mt. We employ an average estimate of unit fishing costs (c) of $3,300 day^{-1} for two intermediate size trawlers, based upon unpublished data compiled by the NOAA Northeast Fisheries Science Center.

To describe aquaculture production in the model, we develop a firm-level submodel of the operations of an open-ocean aquaculture facility for growing cod (this model is described in detail in the Appendix).

The firm-level model can be used to evaluate the effects of the implementation of pollution-control measures. The pollution-control measures are designed to reduce feed inputs, which leads to a lower FCR. A lower FCR is reflected in the submodel by an increase in an adjustment factor ψ (A11). The pollution control measures include feed management and BMPs for the control of solids. Feed management involves variable costs, and BMPs involve both fixed and variable costs. Although the implementation of these measures is costly, they result in a savings in feed costs, thereby lowering annual production costs.

We do not have specific estimates for ψ. Instead, we consider three sets of parameter results in table 3 to illustrate three different levels of the effectiveness of pollution control measures. In the baseline case, feed cost = $0.50/kg, ψ = 1.00, and *FCR* = 1.365, the farm level annual yield (w) is 2,115 mt, annual aquaculture production cost (v) is $3.62 million, the cost of new investment (b) is $7.51 million, and the total N input is 83 mt per year. If the pollution control measures are effective, *FCR* is lowered to 1.239 and the annual production cost falls to $3.49 million. Pollution loading declines as well, as reflected in total N releases of 76 mt per year. Note that production and investment costs are very sensitive to feed costs. For a feed price of \$0.60/kg, the production costs (in parentheses) are significantly higher than the baseline values, thereby affecting the competitiveness of cod aquaculture.

4. Simulations and Results

Our model is an extension of the classical fishery bioeconomic model (Clark). It can be used to assess a number of important policy variables. We examine first the steady-state (long-run equilibrium) level of aquaculture with respect to different levels of environmental damages, using the baseline parameter values described in the last section.

When waste discharges do not cause measurable environmental damage ($m = 0$),[8] the optimal scale of the aquaculture industry includes 11 farms[9] producing a total of 23.18 thousand mt of cod. The harvest fishery lands 156.11 thousand mt of groundfish, slightly below MSY (156.123 thousand MT). The total fish supply is 179 thousand mt per year (see figure 3). The aquaculture industry releases 910 mt of total N (see table 4).

To simulate the effects of a greater social cost of aquaculture, we arbitrarily set the farm-level environmental damage (m) to \$100 thousand per year; the socially optimal number of farms is then reduced to four. Although there is a slight increase in the supply from the traditional fishery,[10] the total fish supply declines to 165 thousand mt. As a result, the total N input is lowered to 344 mt per year.

To examine the impact of rising imports on the steady-state results, we change the slope parameter (k) to 3.608, representing a 10% increase in imports (decline in demand

[8] This is possible in offshore waters where currents disperse effluents quickly.

[9] This is calculated from Equation (32).

[10] This is because the supply curve of traditional fishery is nearly vertical when it approaches MSY.

for local fish). The result suggests that, in this case, imports will displace farmed fish (only three farms needed) and landings from the harvest fishery will not change.

If the feed conversion ratio (FCR) is lowered from our baseline estimate (1.365), the optimal size of the aquaculture industry will be significantly larger. As shown in figure 4, at $m = 0$, the number of farms increases from 11 to 20 and 23, when FCR is lowered from 1.365 to 1.286 and 1.239, respectively. In all cases, the number of farms declines as the environmental damage per farm (m) rises.

To link environmental damage to effluent quantity, we express unit environmental damage in terms of dollars per mt of feed. Remember that in our firm-level model, quantities of different effluents (e.g., TN and TP) from each farm are all proportional to feed quantity. The optimal industry size for different levels of unit environmental damage is depicted in figure 5. Unlike figure 4, the number of farms declines with respect to unit damage more rapidly and in a nonlinear fashion. This result may be explained as follows. In figure 4, the number of farms grows as the damage per farm declines (*i.e.*, moving from right to left). As the number of farms grows, the total feed quantity also rises. For a constant damage value per unit feed quantity, the number of farms grows more slowly initially as we move from right to left in figure 5.

Next, we examine the optimal scale of open-ocean aquaculture with expanding demand. The industry size is calculated using Equation (27). Although we do not have an analytical solution for landings from the harvest fishery (h_f), our steady-state estimate of 156.10 thousand MT is quite close to MSY and cannot be increased significantly (see figure 3). In order to consider a range of projections of population and income growth, we simulate the increase in the number of farms over a 30-year period with three different demand growth schedules. According to the U.S. Bureau of Census, the population growth rate in New England will be about 0.5% per year from 2005 to 2025 (Campbell). From 2002-2012, the projected personal consumption expenditures in the United States are increasing at a rate of 2.8 percent per year (BLS). As shown in figure 6, if demand rises at one, two, and three percent per year over 30 years, the industry size will expand respectively from 11 to 84, 138, and 178 farms.

Using the cod production and cost data, we show that the optimal level of landings from the traditional fishery is 156 thousand mt. Currently, the total groundfish landings in New England are only about 60 thousand mt, after two decades of decline due to overfishing (figure 7). During the 1990s, a wide variety of effort control measures were implemented in this fishery. Groundfish stocks are now beginning to recover. According to projections (figure 7), New England groundfish landings will reach 106, 136, and 146 thousand mt in 2012, 2015, and 2026, respectively. Nevertheless, prior to 2015, landings from the harvest fishery will still be significantly below 156 thousand mt. In order to bridge this supply gap, and in the absence of increasing levels of imports, additional aquaculture farms might enter the market. For example, an additional 20 farms could supply over 40 thousand mt of cod.

5. Conclusions

Existing studies project the future expansion of the marine aquaculture industry based on the assimilative capacity of the coastal environment, using water quality assessment models. In this article, we present a market-oriented approach for projecting future industrial expansion based upon equilibria in the seafood market. We consider supplies from both wild-harvest fisheries and open-ocean aquaculture. In our framework, the net demand for farmed fish determines the size of the aquaculture industry and, in turn, its level of pollution discharges. The socially optimal industry size is constrained by the environmental damages associated with effluent discharges. We illustrate our analytical approach using a case study of the New England groundfish fishery and proposed open-ocean aquaculture of Atlantic cod. Our results suggest that, in the case of New England groundfish market, the socially optimal solution involves a combination of the wild-harvest fishery and aquaculture. Aquaculture and the fishery are not mutually exclusive. It makes economic sense to rebuild and protect the groundfish stock, while also pursuing the industrial development of aquaculture.

The future size of the open-ocean aquaculture industry depends upon its costs and productivity. We use a detailed simulation model of firm-level investment and production to develop cost and production estimates for open-ocean aquaculture of cod. Based on these cost estimates, our analysis indicates that the optimal industry size implies 11 farms producing 23 thousand mt per year, after the groundfish stock has been rebuilt to yield annual landings of 156 thousand mt. The industry size will be much smaller (fewer than ten farms) if effluent discharges cause significant damage to the marine environment (see figure 5). Indeed, at present, the cost of cod farming is relatively high with respect to the harvest fishery. If the actual production costs (e.g., feed cost) are higher than our baseline estimates, cod aquaculture may not yet be economically feasible, given the projected growth in future landings from the groundfish fishery (figure 7).

Although the present analysis suggests that proposed cod aquaculture in New England is likely to remain secondary to harvest fishery production in terms of volume, the scale of the industry may be significant if pollution control measures can be shown to be effective (figure 4) or if there is significant growth in fish demand in the future (figure 6). Because there will be regulatory limits to landings from the wild-harvest fishery, future growth in demand is likely to be met only with contributions to supply from imports and from aquaculture operations.

Appendix: A Model of Firm-Level Investment and Production

Our firm-level model assumes that a growout operation produces a fixed amount of fish each month, following pre-determined stocking and harvesting schedules (*cf*., Kite-Powell *et al*.; Jin *et al*.). The model simulates fish growth and projects costs for each month in a 15-year period. It calculates the amount of up-front investment required, annual operating cost, and fish production. Several biological and environmental variables (*e.g*., mortality and water temperature) may be specified as stochastic variables to capture random effects in fish growth.

Fish Growth

To ensure a year-round fish yield, a certain number of fingerlings are stocked each month. Generally, for a particular cohort, fish growth may be modeled in continuous time as (see Arnason):

$$\frac{dx(\tau)}{d\tau} = G[f_d(\tau), x(\tau), \tau] \qquad \text{(A1)}$$

where x is the fish biomass at time τ, τ denotes time within a growout period [$\tau = 0$ (stocking), …, T (harvesting)], $G(\bullet)$ is the growth function, and f_d is the quantity of feed at τ. To control density, we model G following the Beverton-Holt approach (Ricker) and specify

$$x(\tau) = n(\tau)\omega(\tau) \qquad \text{(A2)}$$

where n is the number of fish in thousand and ω is the weight of a fish in grams. Without intervention,

$$n(\tau) = n(0)e^{-\alpha\tau} \qquad \text{(A3)}$$

where α is the mortality rate (Allen *et al.*). This relationship says that the number of fish will decrease while the weight grows. In discrete time (τ = month), (A3) becomes

$$n(\tau) = n(\tau - 1)(1 - \alpha) \quad \text{(A4)}$$

For cod, we model mortality as:

$$\alpha(\tau) = 0.01 - 0.000001\omega(\tau) \quad \text{(A5)}$$

The growth rate of individual fish weight (ω) in continuous time is

$$\frac{d\omega(\tau)}{d\tau} = g(\tau) \quad \text{(A6)}$$

In discrete time, (A6) may be rewritten as:

$$\omega(\tau) = \omega(\tau - 1) + g(\tau - 1) \quad \text{(A7)}$$

where $g(\cdot)$ is the weight growth function of an individual fish. For cod, we specify the monthly growth as a function of fish weight and water temperature (Jobling):

$$g(\tau) = 0.37223\omega(\tau)^{0.559} e^{0.297\gamma - 0.000538\gamma^3} \quad \text{(A8)}$$

where g is in grams per month, ω is weight in grams, and γ is the temperature in degrees Celsius. The feed conversion ratio (*FCR*) is defined as:

$$FCR(\tau) = \frac{f_0(\tau)}{g(\tau)} \quad \text{(A9)}$$

where f_0 is the quantity of feed per fish. Thus, the total feed quantity in kg at τ is:

$$f_d(\tau) = f_0(\tau)n(\tau) = FCR(\tau)g(\tau)n(\tau) \quad \text{(A10)}$$

For cod, we have *FCR* as a function of fish weight:

$$FCR(\tau) = [1.5 - 0.00035\omega(\tau)] / \psi \quad \text{(A11)}$$

where $1 \le \psi \le 1.1$ is an adjustment factor that allows us to reduce the baseline FCR to reflect the effect of pollution control measures (discussed below).

Fish Production

For specific stocking and harvesting schedules, the model calculates the factor inputs, associated costs, and fish production month-by-month over 15 years [t = 1, 2, …, 180 (month)]. For cod, the growout period is two years. There are 24 cohorts. Cohort 1 is initially stocked at $t = 1$ ($\tau = 1$), harvested at $t = 24$ ($\tau = T$), and restocked at $t = 25$ ($\tau = 1$). Total fish biomass at harvest time $x(T=24)$ in kg can be calculated from (A2). Note that $x(T) = 0$ for $t = 1 – 23$.

Costs of Investment and Production

For open-ocean aquaculture, the total cost includes expenditures on cages, a boat, fingerlings, feed, and shore-based operations (e.g., administration and marketing). In the model, we assume a sequential cage installation schedule. For each of the first 24 months, there is one new cage added to the farm. The cost of each cage is

$$c_k(t) = \mu(acq + inst) + efix \qquad t=1,2,\ldots,24 \qquad \text{(A12)}$$

where c_k is the cost of each cage in \$, μ is the cage volume in m^3, *acq* is the cage acquisition cost in \$/m^3, *inst* is the cage mooring and installation cost[11] in \$/m^3, and *efix* is the fixed cost associated with environmental compliance in \$/cage. For cage maintenance in subsequent months, the cost is

$$c_m(t) = \mu \cdot cn(t) \cdot cm(t) + evar(t) \qquad t=25, 26,\ldots,180 \qquad \text{(A13)}$$

where *cn* is the number of cages in the farm, *cm* is the cage operating and maintenance cost in \$/m^3/year, and *evar* is the variable cost of environmental compliance in \$/month.

[11] This parameter may be modeled as a function of water depth.

Each month, feed and fingerlings are transported to the farm and harvest is transported back to shore by boat. Aggregating cage-level feed quantity [$f_d(\tau)$ from (A10)], we have the farm-level monthly feed quantity (*fq*) in kg:

$$fq(t) = \sum_{\tau=1}^{cn(t)} f_d(\tau) \qquad \text{(A14)}$$

For each month, the quantity of fingerlings and water transported for stocking (*sq*) in kg is:

$$sq(t) = stock \cdot sg \cdot \varphi \qquad \text{(A15)}$$

where *stock* [= *n(0)*] is the number of fingerlings in thousands, *sg* is the fingerling weight in gram/fish, and φ is ratio of water weight to fingerling weight during transport to farm. For each month, the number of boat days (*bd*) is calculated as either the number of days necessary for transporting harvest from the farm or the number of days needed for transporting feed and fingerlings to the farm, whichever is greater.

$$bd(t) = max\{ x(T) / ld, [fq(t) + sq(t)] / ld \} / trip \qquad \text{(A16)}$$

where *x(T)* is the fish harvest in kg, *ld* is the boat payload in kg, *fq* is the feed quantity in kg, *sq* is the quantity of fingerlings in kg, and *trip* is the number of round-trips per day.[12]

For each month, boat cost (c_b) is

$$c_b(t) = bfix / 12 + bvar \cdot bd(t) \qquad \text{(A17)}$$

where *bfix* is the vessel fixed cost in \$/year, and *bvar* is the variable and crew cost in \$/day. Fingerling cost (c_r) is

$$c_r(t) = 1000 \cdot stock \cdot sp \qquad \text{(A18)}$$

where *sp* is the fingerling cost in \$/fish. Feed cost (c_f) is

[12] This parameter may be modeled as a function of distance to shore.

$$c_f(t) = fq(t) \cdot fp \qquad \text{(A19)}$$

where *fp* is the feed cost in \$/kg. Shore cost (c_s) is

$$c_s(t) = (sh + ins)/12 \qquad \text{(A20)}$$

where *sh* is the on shore cost (e.g., dock, facilities, management administration, marketing and distribution) in \$/year and *ins* is the insurance cost in \$/year.

From Equations (14), (15), and (19) through (22), we can calculate the total cost (C) in each month

$$C(t) = \sum_i c_i(t) \qquad \text{(A21)}$$

Note that $i = [k, m, b, r, f, s]$. We define the total investment in the first three years as:[13]

$$Inv = \sum_{t=1}^{24} C(t) \qquad \text{(A22)}$$

The average annual operating cost over the next 13 years is:

$$C_{op} = \sum_{t=25}^{180} C(t)/13 \qquad \text{(A23)}$$

As noted, several key economic and biological variables in the model may be specified as stochastic. We attach a normally distributed random element, $\xi_j \sim (0, \sigma_j^2)$, to each of the four variables: mortality rate ($\alpha + \xi_\alpha$), fish weight growth ($g + \xi_g$), and water temperature ($\gamma + \xi_\gamma$). We run the stochastic version of the firm model by setting the variances as: $\sigma_m^2 = \sigma_g^2 = 0.05$ and $\sigma_\gamma^2 = 0.5$).

Pollution

Using the monthly farm-level feed quantity (*fd*) from (A14) we can estimate the average yearly feed quantity and associated pollutant quantity (Q_i):

[1313] Discounting is not included here, because it has been incorporated into the general model.

$$Q_i = \Phi_i \cdot 12 \cdot E(fq) \quad \text{(A24)}$$

where Φ_i with i = [*BOD, TN, TP, TSS*] are the feed-to-pollutant factors.

We apply the models to Atlantic cod. Cod can be stocked and harvested year-round in southern New England waters. The growout site is assumed to be located 6 km from the shore station or dock used by the support vessel. The water depth is 50 m. Monthly water temperatures are shown in table A1. Table A2 summarizes other model input parameters describing cage system, stocking, feed cost, boat, etc. We use a set of biological parameters for cod published by Best.

As shown in table A2, the cage capacity per cohort is 5000 m^3. The fixed cost for the growout support vessel, which stocks the cages, carries feed to the cages, supports maintenance, and carries out harvesting, is $100,000/year. Operating costs are $1,500/day for fuel and other consumables, and personnel costs are another $1,500/day. The vessel has an operating speed of 15 km/h and a payload capacity of 30 metric tons. On a typical round trip carrying feed, it spends 3 hours on site. The maximum length of a work day is 12 hours; and due to weather constraints and maintenance requirements, the vessel is at sea a maximum of 25 days per month. Onshore costs include $30,000/year for dock use and other onshore facilities, $70,000/year for management and administrative costs, and $50,000/year for marketing and distribution.

Environmental compliance costs are also included in the lower portion of table A2. These cost data are based on EPA (USEPA) estimates for four pollution control measures for offshore cage aquaculture: (1) Feed Management (*fmv* is the cost associated with extra time for record keeping); (2) Solid Control BMP Plan (*scf* covers the cost associated with developing three 5-year plans and *scv* is the cost for monthly review of the plans); (3) Drug and Chemical Control BMP Plan (*dcf* is the cost to develop three 5-year plans and *dcv* is the cost for monthly review of the plans); and (4) Active Feed Monitoring (*aff* is the cost of one set of underwater cameras and *afv* is the cost associated with feeding control). These pollution controls measures are cumulative and designed to lower feed and drug inputs. Note that *efix* in (A12) is calculated using *scf*, *dcf*, and *aff*, and *evar* in (A13) is based on *fmv*, *scv*, *dcv*, and *afv*. Feed-to-pollutant factors are in table A3. They are also from EPA (USEPA).

References

Allen, P.G., L.W. Botsford, A.M. Schuur, and W.E. Johnson. *Bioeconomics of Aquaculture*. New York: Elsevier, 1984.

Anderson, J.L. “Market Interactions between Aquaculture and the Common-property Commercial Fishery.” *Marine Resource Economics* 2(1985a):1-24.

Anderson, J.L. “Private Aquaculture and Commercial Fisheries: Bioeconomics of Salmon Ranching.” *Journal of Environmental Economics and Management* 12(1985b):353-370.

Arnason, R. “Optimal Feeding Schedules and Harvesting Time in Aquaculture.” *Marine Resource Economics* 7(1992):15-35.

Arrow, K., R. Solow, P.R. Portney, E.E. Leamer, R. Radner and H. Schuman. “Report of the NOAA Panel on Contingent Valuation.” *Federal Register* 58(1993):4601-4614.

Asche, F., A.G. Guttormsen and R. Tveteras. “Environmental Problems, Productivity and Innovations in Norwegian Salmon Aquaculture.” *Aquaculture Economics and Management* 3(1999):19-29.

Barbier, E.B. and M. Cox. “An Economic Analysis of Shrimp Farm Expansion and Mangrove Conversion in Thailand.” *Land Economics* 80(2004):309-387.

Best, N.A. “Preliminary Design of a Recirculating Aquaculture System in Boston Harbor.” MS thesis, Massachusetts Institute of Technology, 1995.

Beveridge, M. *Cage Aquaculture*, 2nd ed. Ames, IA: Iowa State Press and Blackwell Publishers, 1996.

Bjorndal, T. *The Economics of Salmon Aquaculture*. Boston: Blackwell Scientific Publications, 1990.

Brennan, D. “Pollution Control Options for Australian Prawn Farms.” *Aquaculture Economics and Management* 6(2002):325-338.

Campbell, P. *Population Projections: States, 1995-2025*. Washington, DC: U.S. Department of Commerce, Bureau of the Census, Curr. Pop. Rep. P25-1131, May 1997.

Clark, C.W. *Mathematical Bioeconomics: the Optimal Management of Renewable Resources*, 2nd ed. New York: John Wiley & Sons, Inc., 1990.

Edwards, S.F. and S. A. Murawski. “Potential Economic Benefits from Efficient Harvest of New England Groundfish.” *North American Journal of Fisheries Management* 13(1993):437-449.

Folke C. and N. Kautsky. "Aquaculture with its Environment: Prospects for Sustainability." *Ocean and Coastal Management* 17(1992):5-24.

Folke, C., N. Kautsky, and M. Troell. "The Costs of Eutrophication from Salmon Farming: Implications for Policy." *Journal of Environmental Management* 40(1994):173-182.

Freeman, A.M. *The Benefit of Environmental Improvement: Theory and Practice.* Baltimore: John Hopkins University Press, 1979.

Freeman, A.M. "The Benefits of Water Quality Improvements for Marine Recreation: A Review of the Empirical Evidence." *Marine Resource Economics* 10(1995):385-406.

Gillibrand, P.A. and W.R. Turrell. "The Use of Simple Models in the Regulation of the Impact of Fish Farms on Water Quality in Scottish Sea Lochs." *Aquaculture* 159(1997):33-46.

Group of Experts on the Scientific Aspects of Marine Environmental Protection (GESAMP). *Planning and Management for Sustainable Coastal Aquaculture Development*. Rep. Stud. GESAMP 68, Rome, 2001.

Hatch, U. and H. Kinnucan. *Aquaculture: Models and Economics*. Boulder, CO: Westview Press, 1993.

Hoagland, P., D. Jin, and H.L. Kite-Powell. "The Optimal Allocation of Ocean Space: Aquaculture and Wild-Harvest Fisheries." *Marine Resource Economics* 18(2003):129-147.

Ibrekk, H.O., H. Kryvi, and S. Elvestad. "Nationwide Assessment of the Suitability of the Norwegian Coastal Zone and Rivers for Aquaculture (LENKA)." *Coastal Management* 21(1993):53-73.

Jin, D., H.L. Kite-Powell, and P. Hoagland. "Risk Assessment in Open-Ocean Aquaculture: A Firm-Level Investment-Production Model." *Aquaculture Economics and Management* 9(2005):369-387.

Jobling, M. "A Review of the Physiological and Nutritional Energetics of Cod, *Gadus morhua* L., with Particular Reference to Growth under Farmed Conditions." *Aquaculture* 70(1988):1-19.

Kahneman, D. and J.L. Knetsch. "Valuing Public Goods: the Purchase of Moral Satisfaction." *Journal of Environmental Economics and Management* 22(1992):57-70.

Kitabatake, Y. "Welfare Cost of Eutrophication-Caused Production Losses: a Case of Aquaculture in Lake Kasumigaura." *Journal of Environmental Economics and Management* 9(1982):199-212.

Kite-Powell, H.L., P. Hoagland, D. Jin, and K. Murray. "Open Ocean Grow-Out of Finfish in New England: a Bioeconomic Model." In C.J. Bridger and B.A. Costa-Pierce, eds., *Open Ocean Aquaculture: From Research to Commercial Reality*. Baton Rouge, LA: The World Aquaculture Society, 2003, pp. 319-324.

Lyon. R.M. and S. Farrow. "An Economic Analysis of Clean Water Act Issues." *Water Resources Research* 31(1995):213-223.

Mathis, M.L. and P.B. Baker. "Assurance Bonds: a Tool for Managing Environmental Costs in Aquaculture." *Aquaculture Economics and Management* 6(2002):1-17.

Midlen, A. and T.A. Redding. *Environmental Management for Aquaculture*. Dordrecht, The Netherlands: Kluwer Academic Publishers, 1998.

Muir, J.F., C. Brugere, J.A. Young, and J.A. Stewart. "The Solution to Pollution? The Value and Limitations of Environmental Economics in Guiding Aquaculture Development." *Aquaculture Economics and Management* 3(1999):43-57.

Naylor, R.L., R.J. Goldburg, J.H. Primavera, N. Kautsky, M.C.M. Beveridge, J. Clay, C. Folke, J. Lubchenco, H. Mooney, and M. Troell. "Effect of Aquaculture on World Fish Supplies." *Nature* 405(2000):1017-1024.

Neori, A., M.D. Krom, S.P. Ellner, C.E. Boyd, D. Popper, R. Rabinovitch, P.J. Davison, O. Dvir, D. Zuber, M. Ucko, D. Angel, and H. Gordin. "Seaweed Biofilters as Regulators of Water Quality in Integrated Fish-Seaweed Culture Units." *Aquaculture* 141(1996):183-199.

Ricker, W.E. *Computation and Interpretation of Biological Statistics of Fish Populations*. Ottawa, ON: Canada Department of the Environment, Fisheries and Marine Service, Bull. Fish. Res. Board Can. 191, 1975.

Shang, Y.C. *Aquaculture Economics: Basic Concepts and Methods of Analysis*. Boulder, CO: Westview Press, 1981.

Silvert, W. "Assessing Environmental Impacts of Finfish Aquaculture in Marine Waters." *Aquaculture* 107(1992):67-79.

Smearman, S.C., G.E. D'Souza, and V.J. Norton. "External Cost of Aquaculture Production in West Virginia." *Environmental and Resource Economics* 10(1997):167-175.

Smith, V.K. "Arbitrary Values, Good Causes, and Premature Verdicts." *Journal of Environmental Economics and Management* 22(1992):71-89.

Stanley, D.L. "The Economics of the Adoption of BMPs: the Case of Mariculture Water Management." *Ecological Economics* 35(2000):145-155.

Sylvia, G., J.L. Anderson, and D. Cai. "A Multilevel, Multiobjective Policy Model: the Case of Marine Aquaculture Development." *American Journal of Agricultural Economics* 78(February 1996):79-88.

Tran, T.B., C.D. Le, and D. Brennan. "Environmental Costs of Shrimp Culture in the Rice-Growing Regions of the Mekong Delta." *Aquaculture Economics and Management* 3(1999):31-42.

Tveteras, S. "Norwegian Salmon Aquaculture and Sustainability: the Relationship between Environmental Quality and Industrial Growth." *Marine Resource Economics* 17(2002):121-132.

U.S. Department of Labor, Bureau of Labor Statistics (BLS). "Economic growth." *Occupational Outlook Quarterly*. Washington DC, Winter 2003-04, pp. 36-41. [Found at: http://www.bls.gov/opub/ooq/2003/winter/art04.pdf (last accessed on 6 October 2004).]

U.S. Environmental Protection Agency (USEPA), Office of Water. *Development Document for Proposed Effluent Limitations Guidelines and Standards for the Concentrated Aquatic Animal Production Industry Point Source Category*. EPA-821-R-02-016, Washington DC, August 2002.

Table 1. Typology of Economic and Ecological Effects

	Positive	Negative	Indeterminate
Direct Economic Effects	• Increase in seafood output • Decrease in seafood price • Increase in demands for factors from other industries • R&D and technology investments	• Administrative costs of providing access • Ineffective regulations • Industry concentration (if monopolistic)	• Employment for currently unemployed workers • Increase in seafood quality
External Effects	• Organic nutrient inputs (up to a threshold) • Nutrient removal (shellfish)	• Displacement of more productive ocean uses • Eutrophication • Chemical pollution • Pharmaceutical pollution • Escapement • Ecosystem disruption • Protected species takings • Growth overfishing of ranched stocks	• Bioaccumulation of carcinogens in fish • Overexploitation of forage fish stocks
Distributional Effects	• Employment opportunities in a new industry • Redeployment of unused capital from the fishing industry • Rents accrue to the public as the owner of "ocean space"	• Local communities left out of industry • Reorganization of local market structure • Loss of access to local seafood protein (forage fish)	• Reduction of trade deficit

Table 2. Parameters for the Market and the Fishery

Variable	Description	Unit	Value
p_0	intercept of fish demand function	\$/MT	2,546
k	slope of fish demand function	$\$10^{-3}/MT^2$	3.28
r	Intrinsic growth rate	$time^{-1}$	0.3715
K	carrying capacity	10^3 MT	1,681
q	catchability coefficient	day^{-1}	0.000007
c	unit cost of fishing effort (*E*)	10^3\$/day	3.3
δ	discount rate		0.07

Table 3. Parameters for Open-Ocean Aquaculture

Variable	Description	Unit	Value		
			$\psi = 1.00$	$\psi = 1.05$	$\psi = 1.10$
FCR	average feed conversion ratio		1.365	1.286	1.239
w	aquaculture production output per farm	MT/farm	2,115	2,158	2,143
v	aquaculture production operating cost [a]	10^3 $/year/farm	3,615 (3,913)	3,556 (3,842)	3,487 (3,760)
b	investment cost [a]	10^3 $/farm	7,514 (7,792)	7,464 (7,732)	7,442 (7,706)
$12 \cdot E(fq)$	feed quantity	MT/year/farm	2,765	2,660	2,544
Q_{BOD}	biochemical oxygen demand (BOD)	MT/year/farm	968	931	890
Q_{TN}	total nitrogen (TN)	MT/year/farm	83	80	76
Q_{TP}	total phosphorus (TP)	MT/year/farm	14	13	13
Q_{TSS}	total suspended solids (TSS)	MT/year/farm	830	798	763

Notes:
a. Values are associated with feed cost (*fp*) = $0.50/kg and $0.60/kg (in parentheses), respectively.

Table 4. Simulation Results

Output Variables	Description	Unit	Without Damage[a]	With Damage[b]	Rising Imports[c]
x	fish stock	10^3MT	847.51	843.81	847.51
E	fishing effort	10^6 days	26.314	26.431	26.314
h_f	fishing landings	10^3MT	156.11	156.12	156.11
s	aquaculture industry size	farms	10.96	4.14	3.25
h_a	aquaculture production	10^3MT	23.18	8.76	6.88
h	total fish supply	10^3MT	179.30	164.88	163.00
N_{BOD}	total BOD[d]	MT	10,609	4,008	3,146
N_{TN}	total TN	MT	910	344	270
N_{TP}	total TN	MT	153	58	46
N_{TSS}	total TSS	MT	9,097	3,436	2,698

Notes:
a. $m = 0$.
b. m = $100,000 per farm per year.
c. Imports account for 10% of total fish supply and $m = 0$.
d. All total pollutant estimates (N_i) are based on baseline values ($\psi = 1.00$ in table 3).

Table A1: Monthly Average Temperatures

Month	Water Temperature
	C^0
Jan	2
Feb	2
Mar	3
Apr	5
May	10
Jun	17
Jul	21
Aug	22
Sept	22
Oct	18
Nov	10
Dec	5

Table A2: Firm Model Input Parameters.

Parameter	**Description**	**Unit**	**Value**
μ	cage volume per cohort	m^3	5,000
acq	cage purchase cost	$\$/m^3$	15.00
inst	cage mooring and installation cost	$\$/m^3$	3.00
cm	cage operating and maintenance cost	$\$/m^3/year$	1.00
stock	number of fingerlings stocked per cohort	1,000 fish	150
sg	stocking weight	gram/fish	50
φ	ratio of water weight to fingerling weight during transport to farm		5
sp	fingerling cost	$/fish	0.85
fp	feed cost	$/kg	0.50
bfix	vessel fixed cost	$/year	100,000
bvar	vessel variable and crew cost	$day	3,000
ld	vessel payload	MT	30
trip	round trips per day		3
sh	on shore cost	$/year	150,000
ins	insurance cost	$/year	50,000
fmv	feed management variable cost	$/cohort/month	33.32
scf	solid control BMP plan fixed cost	$/farm	1615.20
scv	solid control BMP plan variable cost	$/month	21.15
dcf	drug and chemical control BMP plan fixed cost	$/farm	1615.20
dcv	drug and chemical control BMP plan variable cost	$/month	21.15
aff	active feed monitoring fixed cost	$/farm	10,000
afv	active feed monitoring fixed cost	$/cohort/month	33.32

Table A3: Feed-to-Pollutant Conversion Factors

Parameter	**Pollutant**	**Conversion Factor**
Φ_{BOD}	biochemical oxygen demand (BOD)	0.35
Φ_{TN}	total nitrogen (TN)	0.03
Φ_{TP}	total phosphorus (TP)	0.005
Φ_{TSS}	total suspended solids (TSS)	0.3

Note: all effects are negative unless preceded by "+". "Z" = zero, "M" = moderate, "S" = significant.	Offshore Finfish	NearshoreFinfish	Land Based Finfish	Nearshore Mollusks	Offshore Mollusks	Offshore Fish Ranching	Nearshore Fish Ranching	Coastal Marine Shrimp	Polyculture
Organic Pollution and Eutrophication	M	S	M	Z	Z	Z	M	S	M
Chemical and Pharmaceutical Pollution	Z	M	M	Z	Z	Z	Z	S	Z
Habitat Modification	Z	Z	Z	Z	Z	Z	Z	S	Z
Disease Transmission to Wild Stocks	S	S	Z	M	M	Z	Z	Z	M
Escapements and Interbreeding	S	S	Z	M	M	Z	Z	Z	M
Exploitation of Forage Fish Stock	S	S	S	Z	Z	S	S	Z	Z
Takings of Protected Species	M	M	Z	Z	M	M	M	Z	M
Direct Depletion of Natural Stocks	Z	Z	Z	Z	Z	S	S	Z	Z
Bioaccumulation of Carcinogens	S	S	S	Z	Z	M	M	Z	Z
Increased Productivity from Nutrient Input	+M	+S	Z	Z	Z	Z	Z	Z	+M
Nutrient Removal	Z	Z	Z	+S	+M	Z	Z	Z	+M

Significant negative effect (S)
Significant positive effect (+S)
Moderate negative effect (M)
Moderate positive effect (+M)
Neutral or No effect (Z)

Figure 1. Preliminary qualitative assessment of environmental effects

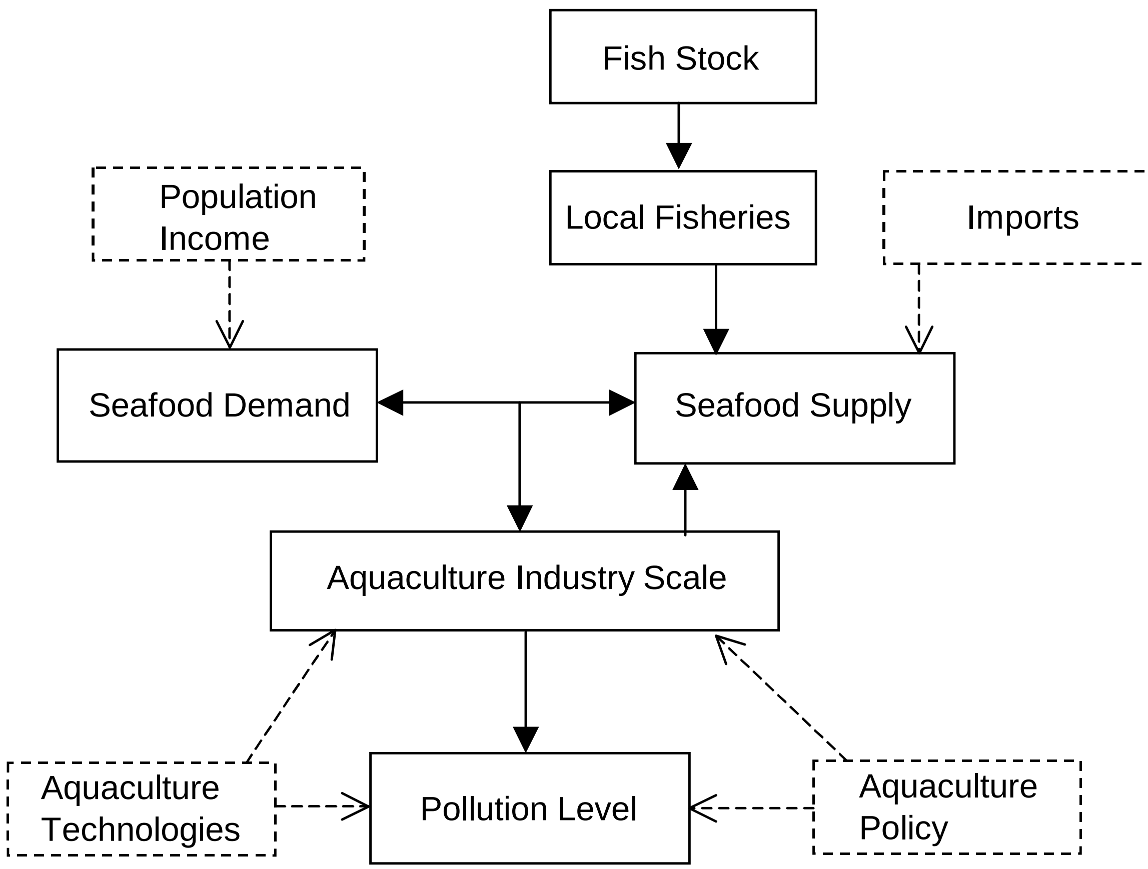


Figure 2: Environmental quality and aquaculture growth

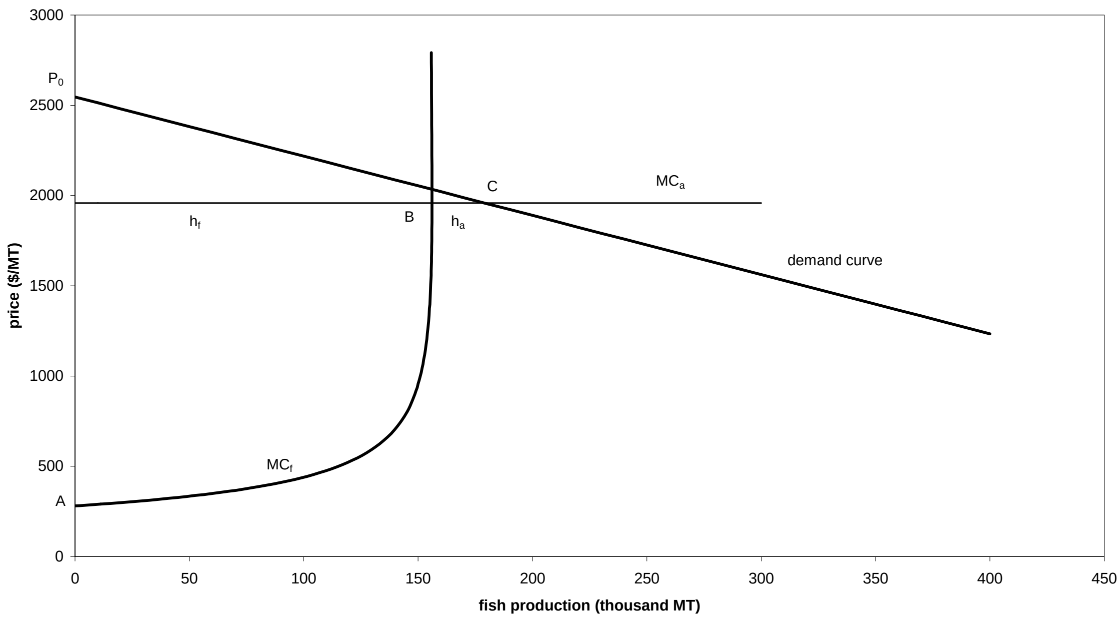


Figure 3: Market demand and supply

The marginal costs of fishing (MC_f), the marginal costs of aquaculture (MC_a), and the demand curve. Total fish production equals the sum of supplies from the wild fishery, h_f, and aquaculture, h_a. A regional manager's objective is to maximize net surpluses, represented by the area ABCP$_0$.

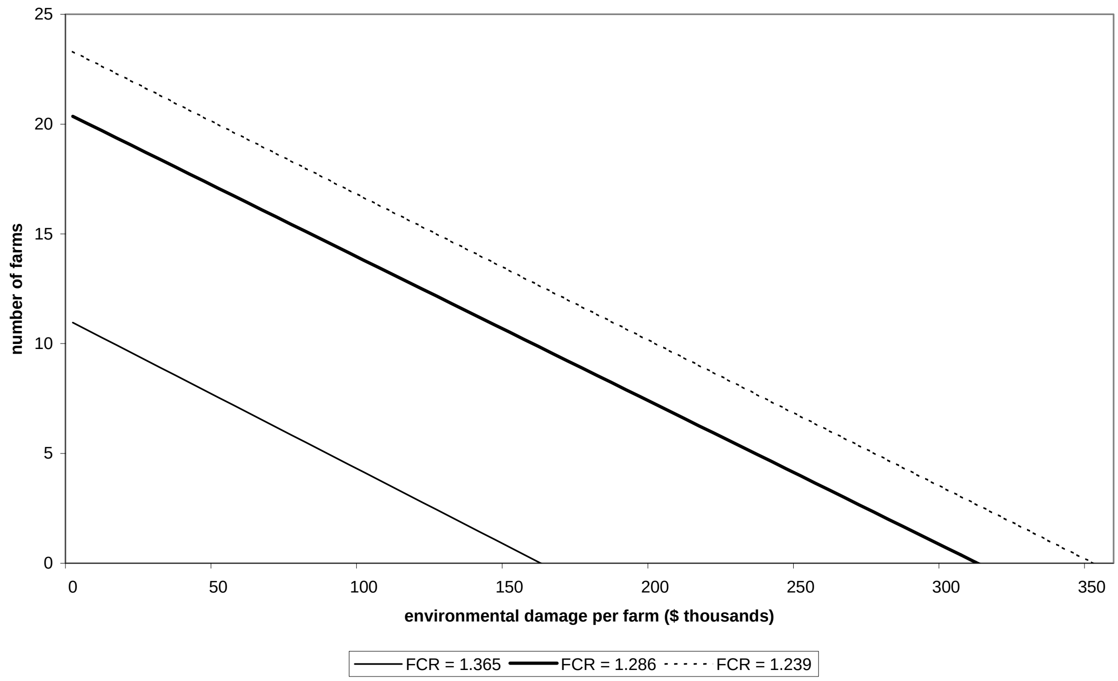


Figure 4: Farm-level environmental damage and aquaculture industry size

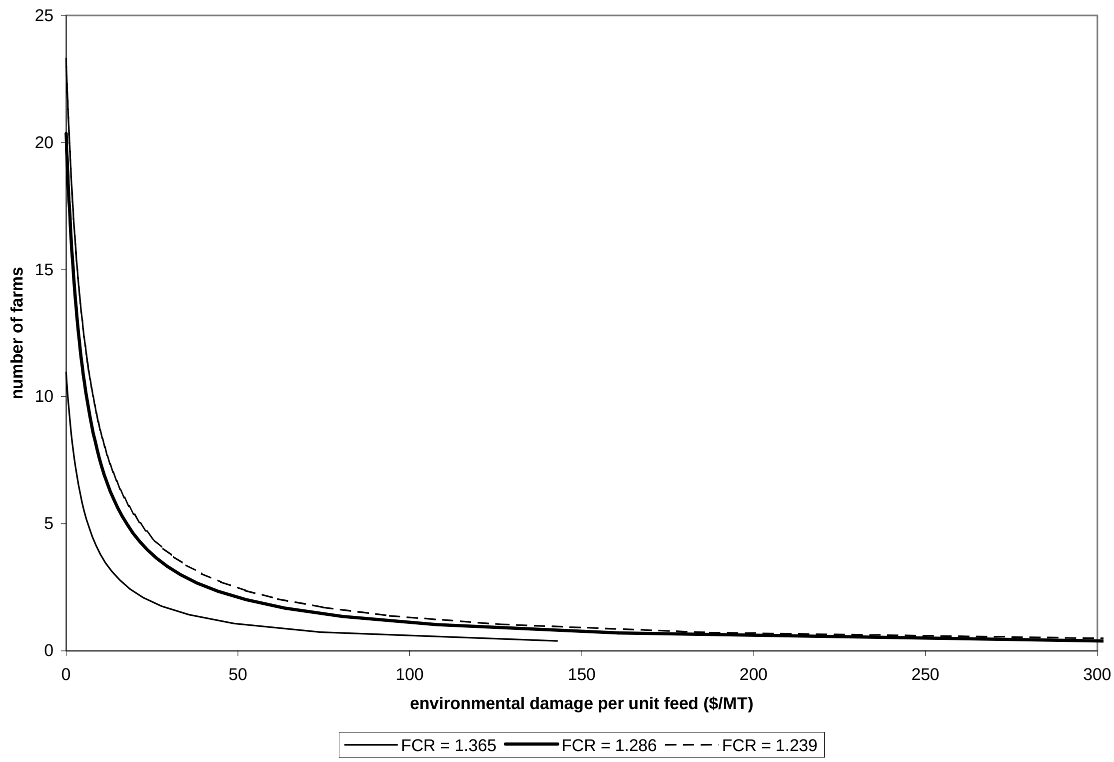


Figure 5: Unit environmental damage and aquaculture industry size

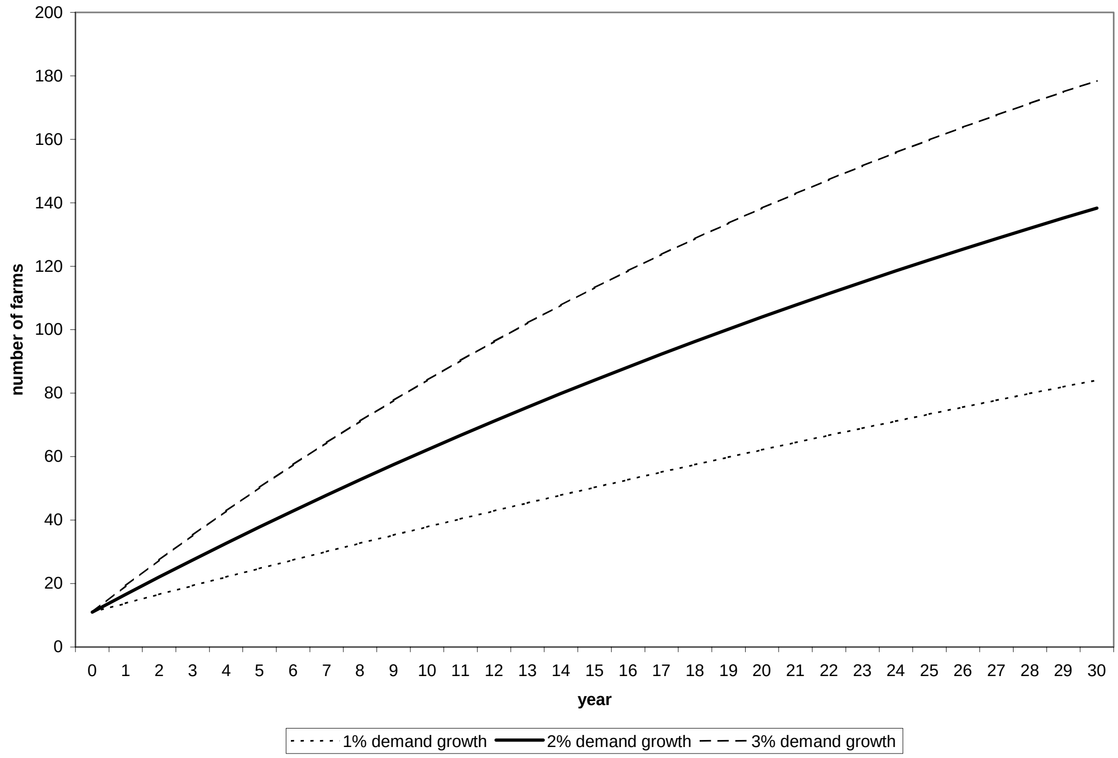


Figure 6: Future expansion of the open-ocean aquaculture industry

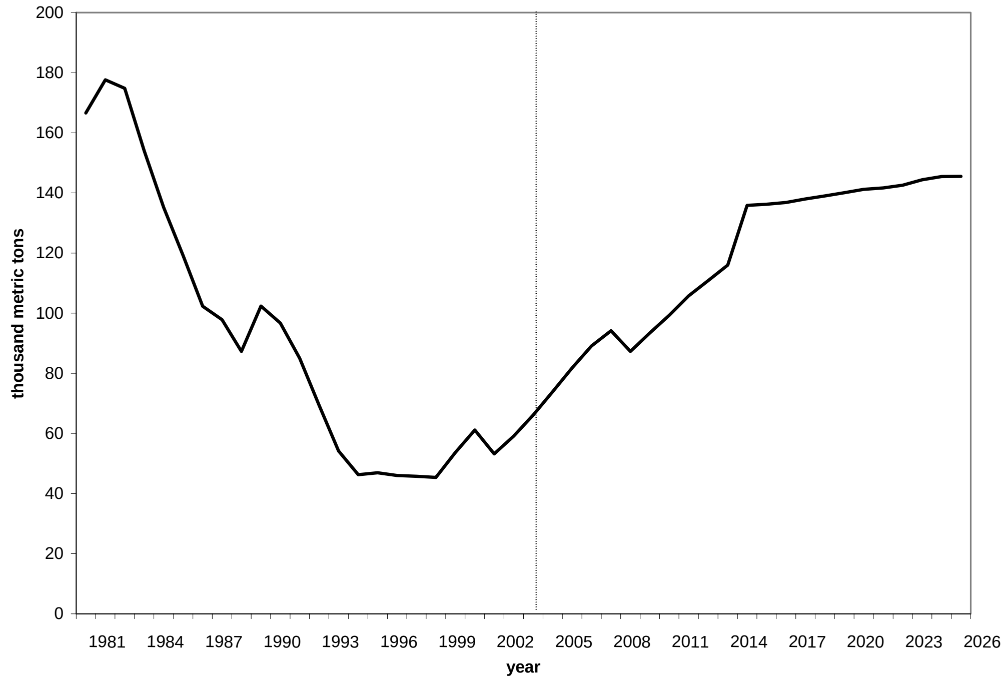


Figure 7: New England groundfish landings and projection

International Institute for
Applied Systems Analysis
Schlossplatz 1
A-2361 Laxenburg, Austria

Tel: +43 2236 807 342
Fax: +43 2236 71313
E-mail: publications@iiasa.ac.at
Web: www.iiasa.ac.at

Interim Report **IR-05-025**

Population Aging and Future Carbon Emissions in the United States

Michael G. Dalton (michael_dalton@csumb.edu)
Brian C. O'Neill (oneill@iiasa.ac.at)
Alexia Fuernkranz-Prskawetz (Alexia.Fuernkranz-Prskawetz@oeaw.ac.at)
Leiwen Jiang (Leiwen_Jiang@brown.edu)
John Pitkin (john_pitkin@earthlink.net)

Approved by

Leen Hordijk (hordijk@iiasa.ac.at)
Director

April 25, 2005

Contents

Abstract

Changes in the age composition of U.S. households over the next several decades could affect energy use and carbon dioxide emissions. This article incorporates population age structure into an energy-economic growth model with multiple dynasties of heterogeneous households. The model is used to estimate and compare effects of population aging and technical change on baseline paths of U.S. energy use and emissions. Results show that population aging reduces long-term carbon dioxide emissions, by almost 40% in a low population scenario, and effects of aging on emissions can be as large, or larger than effects of technical change in some cases.

Acknowledgments

The PET model was developed at Stanford University, with support from the U.S. Department of Energy, under the direction of Larry Goulder, Paul Ehrlich, Steve Schneider, and Don Kennedy. We are grateful to Jae Edmonds, Son Kim, and Ron Sands for providing production data for the United States. We thank Warren Sanderson, Ross Guest, and others at the Symposium on Population Ageing and Economic Productivity, Vienna Institute for Demography, December 2004 for helpful comments and suggestions. Work described in this article was supported in part by the U.S. Environmental Protection Agency (EPA) through grant/cooperative agreement # R-82980101, and the Office of Science (BER), U.S. Department of Energy, Grant No. DE-FG02-01ER63216, both to Brown University. This research has not been subjected to the EPA's required peer and policy review and therefore does not necessarily reflect the views of the Agency and no official endorsement should be inferred.

This paper was submitted to Energy Economics in April 2005.

About the Authors

Dr. Michael G. Dalton is an Assistant Professor of the California State University Monterey Bay, CA, USA, and a Guest Research Scholar in the Population and Climate Change Program at IIASA.

Dr. Brian O'Neill is the Leader of the Population and Climate Change Program at IIASA.

Dr. Alexia Fuernkranz-Prskawetz is the Leader of the Population Economics Research Group at Vienna Institute for Demography.

Dr. Leiwen Jiang is an Assistant Professor (Research) in the Global Environment Program at the Watson Institute for International Studies, Brown University, Providence, USA, and a Guest Research Scholar in the Population and Climate Change Program at IIASA.

Dr. John Pitkin is a consultant and president of Analysis and Forecasting, Inc., a demographic research firm located in Cambridge, Massachusetts; he is also a Senior Research Associate at the University of Southern California.

Population Aging and Future Carbon Emissions in the United States

Michael G. Dalton
Brian C. O'Neill
Alexia Fuernkranz-Prskawetz
Leiwen Jiang
John Pitkin

Introduction

Population growth and technical change are among the most important factors to consider in projections of future carbon dioxide (CO_2) emissions and other greenhouse gases (Schelling, 1992). These emissions, primarily from burning fossil fuels for energy but also other sources such as land use, contribute to the trend of global warming that could cause earth's climate to change in unpredictable and potentially dangerous ways (O'Neill and Oppenheimer, 2002; Mastrandrea and Schneider, 2004). The role of technical change has been the focus of several studies that estimate baselines for future emissions (e.g. Weyant, 2004). The treatment of population in these projections has been limited mainly to direct scale effects from changes in population size alone. However, other demographic factors may be important. Indirect scale effects can arise through compositional changes in the population due to aging, urbanization, or other determinants of economic growth (Birdsall et al., 2001). In addition, population composition can affect consumption patterns, which vary in their indirect energy requirements because of the energy embodied in different consumer goods (Schipper, 1996; Bin and Dowlatabadi, 2005). Compositional changes in population will occur over the next several decades in many parts of the world, and effects of these changes on energy demand and emissions are currently unknown.

This article estimates potential effects of population aging on energy use and CO_2 emissions for the United States (U.S.). Our approach differs in two important ways from existing energy and emissions projections: First, we use households, rather than individuals, as the demographic unit of analysis, and second, we incorporate demographic heterogeneity by introducing the age structure of households into an energy-economic growth model. The empirical energy studies literature has identified household characteristics, such as size and age structure, as key determinants of direct residential energy demand (Schipper, 1996), and has shown that changes in the composition of U.S. households could have substantial effects on national energy demand (O'Neill and Chen, 2002). A few studies have included household characteristics in projections of future energy demand, but these have been limited to short time horizons and simple household projections (Lareau and Darmstadter, 1983; Weber and Perrels, 2000). Household characteristics have not been incorporated into energy-economic growth models, which are among the most widely used tools for making long-term CO_2 projections and analyzing climate change policies (Weyant and Hill, 1999). To frame the development of our own methodology, we give an overview of the two families of models, infinitely lived agent (ILA) and overlapping generations (OLG), which have been used for long-term emissions projections and climate change policy analysis. We focus on the treatment of savings decisions, and assumptions implicit in solution methods, two key issues for judging a model's applicability to introducing heterogeneity in households.

Infinitely lived agent models

Most energy-economic growth models used for climate change policy analysis have a dynamic structure that is based on a variant of the infinitely lived agent in Ramsey's (1928) savings model, and are the typical approach for comparing costs and benefits of alternative emissions abatement strategies (Manne, 1999; Cline, 1992; Peck and Teisberg, 1992; Nordhaus, 1994; Manne, Mendelsohn, and Richels, 1995; Nordhaus and Yang, 1996). In such models, population is treated as a single representative household that is infinitely lived. The economy is analyzed as though there were a benevolent planner acting as a trustee on behalf of both present and future generations. Schelling (1995) and others (e.g., Azar and Sterner, 1996) have criticized the strong welfare assumptions implicit in the representative agent, planner-based ILA approach. Nonetheless, ILA models have been developed with detailed production sectors for energy and other intermediate goods, have a transparent dynamic structure to describe capital accumulation, and can be calibrated to historical data. In other words, ILA models are broadly consistent with economic theory, and currently provide the most detailed empirical tools for evaluating the costs, and perhaps benefits, of controlling greenhouse gas emissions.

While these models have many similarities, they also exhibit important differences. Many models adopt a recursive, or backwards-looking, formulation of investment decisions, and are based on a variation of the Solow (1956) growth model that assumes some type of fixed savings rule, usually a constant fraction of income in each period. Fixed savings rules are usually a simplification that avoids solving a dynamic optimization problem. Nonetheless, models with fixed savings rules often compensate for this simplification with detailed energy sectors, and other realistic features such as land-use and demographic change (e.g., MacCracken, et al., 1999).

Other models in the energy economics literature adopt a forward-looking approach to capital accumulation that assumes perfect foresight about the future productivity of capital, prices, and other variables (e.g., Goulder, 1995). The properties of a dynamic competitive equilibrium with forward-looking behavior are substantially different from models based on fixed savings rules. In fact, a dynamic equilibrium with fixed savings rules is not an authentic competitive equilibrium because households are not, strictly speaking, utility maximizers. While the assumption of perfect foresight may not be realistic, it does incorporate information about the future into current decisions, and is thus an improvement over fixed savings rules from the point of view of economic theory. Moreover, perfect foresight can be interpreted as a first-order approximation to rational expectations (Fair and Taylor, 1983). Some economic growth models mix different types of savings behavior by assuming a proportion of the population solves a dynamic optimization problem, while others follow a fixed savings rule (McKibbin and Vines, 2000).

Overlapping generations models

Overlapping generations (OLG) models provide an alternative to ILA models for dealing with sustainability and other intergenerational welfare issues (Howarth and Norgaard, 1992; Farmer and Randall, 1997). The OLG models have an explicit demographic structure to describe key life-cycle stages. Like their ILA counterparts, OLG models come with a variety of structural assumptions and solution techniques. In general, OLG models have dynamic properties that are different from ILA models (Auerbach and Kotlikoff, 1987; Geanakoplos and Polemarchakis, 1991; Kehoe, 1991). However, these differences depend critically on the assumption that savers in OLG models plan only for their own retirement, and do not care about future generations. For example if parents care about the welfare of their children, a bequest motive exists that influences savings behavior, and leads to an OLG model that is similar to ILA models in terms of discounting (Barro, 1974).

The Blanchard-Yaari-Weil model of perpetual youth provides a set of conditions under which OLG and ILA approaches are equivalent (Blanchard, 1985, Blanchard and Fischer, 1987). Marini and Scaramozzino (1995) use a version of this model to show that solving a social planner's problem with overlapping generations collapses to the representative agent framework as a special case only when there is an absence of heterogeneity among generations. In other words, the suitability of the planner-based ILA approach to environmental policy analysis reduces to an empirical issue of whether there is significant heterogeneity in the savings and consumption decisions of different generations.

Recently, several OLG models have been used to re-examine the climate change policy implications derived from the planner-based ILA models cited above. In some cases, OLG models yield results that are similar to corresponding ILA models (Stephan, et al., 1997; Manne, 1999). However, other studies find substantial differences between results with OLG and ILA models. Howarth (1996, 1998) matches a two-period OLG model to assumptions in Nordhaus (1994), and finds that modest to aggressive reductions in greenhouse gas emissions are justifiable in terms of economic efficiency. Howarth shows that, in general, ILA models can be represented as reduced-form OLG models without qualitatively important demographic features. He concludes that Nordhaus' (1994) model, in particular, is strongly sensitive to changes in the intergenerational weights used in the social welfare function. Gerlagh and van der Zwaan (2000, 2001) reach stronger conclusions, and question whether ILA models are appropriate for analysis of climate change policies. Differences in their results from other OLG models, notably Stephan et al. (1997) and Manne (1999), are attributed to an explicit representation of longer life expectancy and population aging in their three-period OLG model.

Multiple dynasty approach

We develop an energy-economic growth model that shares features of ILA and OLG approaches. We introduce demographic dynamics into the Population-Environment-Technology (PET) model, a computable general equilibrium model of the economy with detail in the energy sector, by using household projections to construct "cohorts" of households, where household age is defined by the age of the household head (Deaton, 1997). These projections, carried out with the ProFamy model (Zeng et al., 1998), represent a substantial improvement over previous household projection models, which have typically relied on simple headship rate methods that have several serious shortcomings (Jiang and O'Neill, 2004). Household cohorts from the ProFamy model are grouped into three infinitely lived dynasties in the PET model. Each dynasty contains households separated in age by the average length of a generation, taken to be thirty-years. For example, eighty-year-old, fifty-year-old, and twenty-year-old households are grouped in a single dynasty, based on the assumption that the younger households are, on average, descendents of the older households. Note that by increasing the length of a generation, the number of dynasties increases and our approach converges to the simplest OLG framework, with each dynasty represented by only one cohort, excluding any altruistic behavior. Conversely, a shorter generational length reduces the number of dynasties and is closer to a typical ILA framework. Therefore, heterogeneity in dynasties increases with generational length.

To calibrate the PET model, estimates of consumption expenditures, savings, asset accumulation, labor supply, and other variables for households in each age group were derived from the U.S. Consumer Expenditure Survey (CES). The PET model has seventeen consumer goods, including energy intensive goods like utilities and fuels, and less intensive goods such as education or health (Goulder, 1995). Households in different age groups are associated with distinct income and consumption levels, based on the CES data. Differences among age groups imply that each dynasty is associated with a specific pattern of income and consumption, based on its age distribution at each point in time. These differences have implications for energy demand, both directly and indirectly.

In our results, the most important effects are caused by differentials in labor income across age groups that create complex dynamics for consumption and savings. These dynamics, and other relationships implied by the household projections and CES data, create interacting effects that influence each dynasty's current and future consumption and savings decisions. A dynamic general equilibrium model is required to analyze these interacting effects on behavior, including how price changes for individual consumer goods affect tradeoffs between consumption and savings at the level of individual households.

Using the PET model, we are able to decompose and analyze these general equilibrium effects. We use the model to analyze how household-level variables respond to plausible changes in the age composition of U.S. households over the next several decades. We also use the model to estimate how changes in household-level variables affect the whole economy, and whether projected changes in the age composition of U.S. households could have a substantial influence on total energy demand and CO_2 emissions. Our results show that combining ILA and OLG approaches creates complicated dynamics for the age structure of each dynasty, which cause cycles in labor income that affect savings and consumption directly, and also have indirect effects on energy demand. We find that including heterogeneity among U.S. households reduces long-term emissions, by almost 40% in our low population scenario. Effects of heterogeneity are less extreme in other scenarios, and our results estimate that emissions are around 15% lower. We also find that effects of aging on emissions can be as large, or larger than effects of technical change in some cases.

The following section describes the PET model and household economic data. The population and household projections are described in the third section, and results of simulations with the PET model are presented afterwards. We conclude with a discussion of our analysis, results, and directions for future research.

Population-Environment-Technology Model

The PET model is a global-scale dynamic computable general equilibrium model designed to analyze economic tradeoffs associated with production and use of fossil fuels, and carbon dioxide emissions. A separate document, available from the authors, gives mathematical descriptions and data sources of the PET model (Dalton and Goulder, 2001). An overview is given here, and schematic diagram of the model is provided in Figure 1. The production component of the PET model has industries with many perfectly competitive firms that produce intermediate goods, including energy and materials, and final goods. Consumption and investment are final goods, and a government sector produces a final good. Production functions for each industry in the model have a capital-labor-energy-materials (KLEM) structure, with a nested constant elasticity of substitution form. There is a separate nest for energy inputs with oil and gas, coal, refined petroleum, and electricity. Other intermediate goods are aggregated, and produced by a single materials industry. Exogenous technical change is included in the PET model using separate productivity coefficients that change over time for each input of each production function in the model. Growth in the productivity coefficients for different inputs include patterns of labor, capital, and energy augmenting technical change.

Each production function in the PET model has a substitution parameter for energy inputs that is assumed to be greater than the substitution parameter for KLEM inputs, implying that energy inputs are more substitutable in production with one another, than energy is with other inputs. Estimating or assigning appropriate values for substitution parameters is an important topic in applied general equilibrium analysis, and has been the subject of past work with the PET model. We assign values here based on a standard configuration of the model, with the substitution elasticity for energy inputs set equal to 2.0 for all industries, implying modest substitutability of energy inputs, and an elasticity for KLEM inputs of 0.4, so that demand for these inputs is relatively inelastic. Different assumptions regarding the structure of production functions and substitution elasticities appear in the energy and climate change literature (e.g. Weyant and Hill, 1999). The substitution elasticities given above are consistent with this literature. Because oil and gas, and coal industries produce primary energy from fossil fuels, outputs of these industries account for CO_2 emissions in the model.

The consumption component of the PET model is based on a population with many households that take prices as given. Each consumer good in the model is produced by a different industry, and one industry produces investment goods.

Households demand consumer goods, and receive income by supplying capital and labor to producers. Households save by purchasing investment goods, and in the model, savings behavior is determined by solving an infinite horizon dynamic optimization problem for the dynasty to which the household belongs. Consumption and savings are described in more detail below.

The following sections present parts of the PET model related to household consumption and savings, and the data used to calibrate the household component of the model. These parts of the model are central to our general equilibrium analysis of demographic factors that affect energy use and CO_2 emissions. The PET model includes international trade, and can analyze different countries and world regions, but currently we have household economic data and projections for the U.S. only. Therefore, we are primarily interested in interactions between household consumption and factor supply within the U.S. economy. We have omitted trade from work in this article to simplify the model, and isolate effects of demographic factors. We recognize that results are likely to be affected by this omission, but an initial assessment without effects of trade provides a useful benchmark against which further work can be compared, and still allows an informative comparison of results with demographic heterogeneity.

Household consumption and savings

Using age of the household head, we classify individual households in the population into three separate dynasties, indexed by i. Each dynasty consists of a large number of identical households, extending a standard assumption in neoclassical growth models that the population consists of a large number of identical households. Our extension to multiple dynasties is consistent with neoclassical growth theory, and from the point of view of general equilibrium analysis, is more natural and interesting than assuming all households are the same.

Let n_{it} denote the total number of people living in each household type at time $t \geq 0$. Each household is endowed with labor l_{it}, and an initial stock of assets $\overline{k}_i$, which are expressed in average per capita terms. Likewise, other variables are expressed in per capita terms, except where noted. Capital owned by different households is homogeneous, and perfectly substitutable in production. Households save by purchasing investment goods x_{it}, at price q_t. Investment is added to a stock of household assets, or capital k_{it}, which depreciates at rate $\delta > 0$ that is the same for all households, according to the law-of-motion

$$k_{it+1} = (1-\delta)k_{it} + x_{it}. \qquad (1)$$

Household capital income is determined by the rental rate of capital, r_t, which is the same for all households. Labor's wage rate, w_t, is also assumed to be equal across households, so that differences in labor income are from variations in per capita labor supply or productivity. Labor is assumed, without loss of generality, to be the numeraire good in our analysis, and $w_t = 1$ for all t.

The PET model has 17 consumer goods, indexed by j. Per capita consumption for households of type i, of good j, at date t is denoted by c_{ijt}. The price of each consumer good is denoted by p_{jt}. Households have a common discount factor $0 < \beta < 1$, and intertemporal substitution parameter $-\infty < \rho < 1$. Preferences for different consumer goods are characterized by a substitution parameter $-\infty < \sigma < 1$ that is also assumed to be the same for all households. The expenditure share parameters μ_{ijt} are differentiated for households, and can vary over time.

This article evaluates the importance of demographic factors during a transition period of one hundred years, and does not address possible effects on the long run equilibrium. Therefore, we assume that households are identical in the long run. The rationale for this assumption is to establish consistency for comparing results in cases with and without demographic heterogeneity. In cases with demographic heterogeneity, values for per capita labor supply, l_{it}, and expenditure shares, μ_{ijt}, tend over time to equal values for all i. These long run conditions imply the terminal or long run balanced growth path equilibrium with demographic heterogeneity is the same as the reference case with representative households.

Simulations with the PET model start at 2000. The transition period in the model is one hundred years, the time span of the demographic projections described below. Simulations continue for another hundred years, during which we assume that demographic heterogeneity gradually disappears so that all households are identical at 2200. Even without these long run restrictions on l_{it} and μ_{ijt}, if capital income tax rates ϕ_{it} are the same for each i, then other assumptions in the model, described below, imply that asset stocks of each dynasty, k_{it}, expressed in per capita terms, converge endogenously to equal values. In other words, per capita asset holdings are the same across dynasties in the long run, even if labor income or consumption patterns are different. This result depends on the tax rates for capital income being the same for each dynasty, but is not directly affected by the tax rate on labor income θ_{it}.

In the model, households receive per capita lump-sum transfers from the government, g_{it}, which is a net value so that negative values represent net payments by households. Private transfers, among households, are represented in the model, but are not distinguished here to save notation. The budget constraint for a household in dynasty i at date t is

$$\sum_{j=1}^{17} p_{jt}c_{ijt} + q_t x_{it} = (1-\theta_{it})w_t l_{it} + (1-\phi_{it})r_t k_{it} + g_{it}. \qquad (2)$$

Demand for consumption goods is influenced by tradeoffs across goods at each t, and by dynamic factors related to savings and investment. Households take prices as given, are rational with forward-looking behavior, and in particular have perfect foresight of future values for all variables that affect their investment decisions. These variables include relevant prices, such as q_t and r_t, and future asset holdings by other households. Forward-looking behavior implies that equilibrium conditions in the model are dynamically consistent. Although the assumption of perfect foresight is restrictive in terms of the information structure of the model, this approach is preferable to an even more restrictive information structure, such as ignoring the value of future information altogether, which is true of models that use fixed savings rules to drive investment. Perfect foresight may be justified either by appealing to some type of certainty equivalence, or as the first step in an algorithm that converges to a rational expectations equilibrium (Fair and Taylor, 1983).

Tradeoffs across goods are described with a constant elasticity of substitution expenditure function, and over time by a constant elasticity of substitution intertemporal utility function. The PET model does not include leisure in household utility functions. Therefore, labor supply is inelastic, and given by each household's labor endowment, l_{it}, which is determined by the CES data described below.

Given prices, and subject to constraints (1) and (2), each household of type i chooses sequences of consumption $\{c^*_{ijt}\}$, for all j, and investment $\{x^*_{it}\}$, to maximize

$$\frac{1}{\rho}\sum_{t=1}^{\infty}\beta^t n_{it}\left(\sum_{j=1}^{17}\mu_{ijt}c_{ijt}^{\sigma}\right)^{\frac{\rho}{\sigma}}. \tag{3}$$

We describe two steps in the solution algorithm for each household's optimization problem to aid explanation of results below. Other parts of the dynamic algorithm are described in detail in the PET model's technical document (Dalton and Goulder, 2001). In the first step, demand for each consumer good is determined from prevailing prices by minimizing total expenditures, subject to a given level of utility, at each date t. A dual price index is used to calculate the marginal cost of consumption for each household, which varies across households because of heterogeneity in expenditure shares. The price index dual to the expenditure function in (3) has a closed-form expression for each household type,

$$\overline{p}_{it}=\left(\sum_{j=1}^{17}\mu_{ijt}^{\frac{1}{1-\sigma}}p_{jt}^{\frac{\sigma}{\sigma-1}}\right)^{\frac{\sigma-1}{\sigma}}. \tag{4}$$

Each price index includes a weighted sum that depends on expenditure shares for each household, and the prices of consumer goods faced by all households. In the general equilibrium PET model, prices of consumer goods are influenced in complex ways by changes in factor supply, including effects on labor of an aging population. The dual price index (4) summarizes price changes across goods to indicate overall effects on the marginal cost of consumption for each household. The marginal cost of consumption $\overline{p}_{it}$ is compared to the price of investment goods q_t to determine optimizing tradeoffs for households between consumption and savings at each t.

The second step in each household's problem is solving for paths of consumption expenditures and investment, for all t, that maximize (3). While price changes for consumer goods have static effects on the pattern of consumption, the tradeoff between consumption and savings affects model dynamics. The model's solution algorithm uses the Euler equations that are first-order conditions from maximizing (3), subject to (1) and (2), which after manipulation imply

$$\frac{q_t}{\overline{p}_{it}}\left(\sum_{j=1}^{17}\mu_{ijt}c_{ijt}^{\sigma}\right)^{\frac{\sigma-1}{\sigma}} = \beta\left(\frac{r_{t+1}+(1-\delta)q_{t+1}}{\overline{p}_{it+1}}\right)\left(\sum_{j=1}^{17}\mu_{ijt+1}c_{ijt+1}^{\sigma}\right)^{\frac{\sigma-1}{\sigma}}. \quad (5)$$

The Euler equations (5), capital law-of-motion (1), budget constraint (2), and transversality conditions

$$\lim_{t\to\infty}\lambda_{it}k_{it} = 0 \quad (6)$$

are necessary and sufficient for maximizing (3). Moreover, a solution to (3) is unique (Stokey and Lucas, 1989). The transversality conditions ensure that each household's sequence of capital stocks is bounded. We use this fact to compute a steady state level of the capital stock that is the same for all households, k^*, which satisfies conditions assumed above.

The PET model allows labor augmenting and other types of technical change. Let γ denote the long run rate of labor augmenting technical change. The long run condition used to compute the steady state level of the capital stock is given by the steady state, or balanced growth path, ratio of the return on capital to the price of investment goods

$$(1-\phi_{it})\frac{r_t}{q_t} = \frac{1}{\beta}(1+\gamma)^{1-\rho} - (1-\delta). \quad (7)$$

By assumptions above, parameters on the right-hand side of (7) do not depend on time, and are the same across household types. Because households face the same prices on capital and investment, if capital income tax rates are the same across households, then per capita asset accumulation is equal in the long run, which was mentioned above in the description of long run conditions. The PET model uses the Euler equations (5), and a variation of the Fair-Taylor algorithm (Fair and Taylor, 1983), to compute the dynamic transition from $\overline{k}_i$ to k^* for each household.

Production, consumption, and income data

The pattern of expenditure shares on energy and other inputs varies across industries. Brenkert et al. (2004) describes the benchmark input-output data that are used in the PET model. These data are used to calibrate the PET model's production functions, and are derived from the U.S. National Income and Product Accounts (NIPA), and other sources. To calibrate the model's household demand system, we use data from the U.S. Consumer Expenditure Survey (CES). The CES is a nationally representative survey composed of two parts: An Interview survey, and a Diary survey. In some cases, CES survey results are different from NIPA data. To resolve differences in the consumption and production data, we use CES data to determine aggregate expenditure shares of each consumer good at the economy-wide level, and apply these economy-wide shares to total consumption expenditures in order to determine the output of each consumer good industry. Conditional on the CES-determined output levels, demands for energy and other inputs of each industry are determined using input-output ratios derived from NIPA data. Additional details on the calibration procedure are described in Dalton and Goulder (2001).

The CES Interview survey has a sample size of approximately 5,500 households and is based on recall of expenditures over the past three months and income over the past year. It is aimed at capturing relatively large expenditures and those that occur on a regular basis. The Interview survey has a rotating panel design: Each panel is interviewed for five consecutive calendar quarters and then dropped from the survey. A new panel is then introduced. Therefore, about 20% of the addresses are new to the survey each quarter. The Diary survey is based on a written account of expenditures over the past two weeks, and is aimed at better capturing small, frequent purchases.

The CES data are used for economic analyses of consumption (e.g., Paulin, 2000; Schmitt, 2004). Details of our work with the CES data are described in a separate document (O'Neill, 2005). In brief, data are integrated by choosing for each consumption category whether the Interview or Diary data are more reliable according to the Bureau of Labor Statistics. The CES categories are then aggregated into the 17 consumer good categories used in the PET model (Goulder, 1995). Mean annual per capita expenditures for these goods are calculated by household type. Household types are defined by characteristics of the "reference person" in the household, defined in the CES data as the first member mentioned by the respondent when asked to "Start with the name of the person or one of the persons who owns or rents the home." We use the reference person as our "householder" or "household head".

Values in Table 1 show how consumption of the 17 consumer goods varies across age groups using expenditure shares, or fraction of total expenditures, for each good. We use these expenditure shares as benchmark data for the PET model, which are converted to share parameters μ_{ijt} that calibrate the model's household demand system. To summarize key differences in expenditure patterns, we distinguish between younger versus older households. As discussed below, the household projections show that future compositional changes are driven by shares of the population at opposite ends of the age range in Table 1. As seen in the table, older households spend a substantially larger share of income than younger households on utilities, services, and health care, and a substantially smaller share on clothing, motor vehicles, and education.

Since the most energy intensive goods are utilities and fuels, expenditure patterns in Table 1 imply that aggregated consumption in older households is more energy intensive than consumption in younger households. The utilities category is about two-thirds electricity, with the remaining third split between natural gas, and payments for water and sewer services. Electricity demand is driven principally by appliance use, and natural gas consumption by space conditioning (EIA, 2004). Although older households spend a larger fraction of income on utilities, absolute levels of expenditures on utilities are roughly the same across the younger and older households when income differences are taken into account, which is consistent with previous work on patterns in residential energy use (Bin and Dowlatabadi, 2005). The fuels category is 80-90% gasoline, and is therefore influenced mainly by car use. The remainder is split primarily between fuel oil and natural gas. While old households spend a larger share of per capita income on fuels than young households, income differences imply the absolute level of fuel use is substantially smaller, which is consistent with other work (O'Neill and Chen, 2002).

Government transfers in Table 2 include social security, workers compensation, unemployment benefits, and other kinds of public assistance, and these favor older households in per capita terms by a wide margin. Savings includes retirement contributions, down payments on purchases of property, mortgage payments, capital improvements, and investments in own businesses or farms. Assets include the value of financial accounts and securities plus the equity share of property.

Household Projections and Dynasties

In Table 3, we present population and household projections from the ProFamy model for three scenarios. The ProFamy projections run from 2000 to 2100. For simplicity, population is assumed to stay constant after 2100 in our analysis. Values in the table give total population in each year of the projection, followed by percentage shares of the population living in households of different ages, in order to more clearly distinguish differences in both scale and composition across scenarios. Work with the ProFamy model, which jointly projects population and households, and methods for developing the U.S. household projections, are described in a separate paper (Jiang and O'Neill, 2005), and an overview is given here.

The scenarios we use are based on a set of plausible demographic assumptions for fertility, mortality, migration, and union formation and dissolution rates that span a wide range of outcomes in terms of population size, age structure, and household size. Assumptions for demographic rates, and how to combine them in each scenario, were chosen in order to produce one scenario with relatively small, old households (our low scenario), one scenario with relatively large, young households (our high scenario), and one scenario with moderate outcomes (our medium scenario). Population size varies among the three scenarios by more than a factor of four at 2100. An important property of the projections is that the age composition of households in the low scenario is markedly different from the pattern in high and medium scenarios, with people living in older households making up a much greater percentage of the population under conditions of low fertility and mortality.

We use the population distribution by household age to construct dynasties that consist of a series of cohorts of households of different ages at each point in time. The procedure for constructing cohorts and dynasties from the ProFamy projections is outlined in Figure 2. This procedure implies that each dynasty has a specific household age distribution at each point in time, based on the population size of each cohort.

We use benchmark data from the CES for households of different ages to derive weighted-mean per capita labor supply and expenditure shares for consumer goods for each dynasty over time. Per capita labor supply for each age group is derived from the CES data, and multiplied by the population living in households of different ages. The sum of these products determines total labor supply of each dynasty. Then for each dynasty, the ratio of total labor supply over the dynasty's total population size determines the mean per capita labor supply. Expenditure shares are translated into share parameters for the PET model's demand system during model calibration. In this way, the ProFamy projections are used to determine the changing composition of the population across household types within each dynasty. The CES data are used to calculate average per capita labor supply, and household expenditure shares within each dynasty that change over time to reflect the changing demographic composition.

Results

We conducted two sets of simulations with the PET model to analyze the effects on emissions of population aging in the United States over the next hundred years. To isolate effects of demographic factors, the first set does not include technical change. The second set includes technical change, and is organized in the same way as the first set of simulations, which is divided into three groups. The first group uses a configuration of the PET model with a single representative household and no aging. This group is considered the starting point for our analysis, and is similar to the typical approach used currently for many models in the climate change literature. The second group uses a configuration of the model with heterogeneous households that includes three dynasties with age-specific demographic heterogeneity in consumption patterns, initial capital, and labor supply. A comparison of results from the second group of simulations with those in the first group provides the basis for our main conclusions on whether the introduction of demographic heterogeneity can substantially affect emissions.

The third group of simulations also uses a representative household configuration of the PET model with a single dynasty, but aggregate labor supply changes over time to be consistent with a changing age structure. This "representative households with aging" configuration has the same total labor supply as the heterogeneous household configuration, and this comparison tests whether results obtained with heterogeneous households can be approximated using a simpler model, with a single dynasty. Each of the three groups consists of 12 simulations, based on the low, medium, and high household projections described above, and stratified by four combinations of household substitution parameters for sensitivity analysis. We use low, medium, and high household projections to test the effects of aging under alternative, but plausible, population scenarios of future demographic changes.

Heterogeneous versus representative households

The model configuration with heterogeneous households has three dynasties that follow the dynamics in Figure 2. For each dynasty, age-specific weights for consumption expenditures are derived from values in Table 1. Initial capital and weights for labor supply are derived from Table 2. The model configuration for representative households without aging has per capita expenditure shares that are equal to the mean values in Table 1. Labor supply, consumption expenditures, and other variables are equal in per capita terms, and are derived from mean values in Table 2. Benchmark values for transfers and income tax rates are set to zero to simplify the interpretation of results.

The multiple dynasty structure of the model configuration with heterogeneous households has interesting implications for the dynamics of labor income and capital. Graphs in Figure 3 show these dynamics. The top graph in Figure 3 shows per capita labor income for the three dynasties. Population aging causes the downward trends in per capita labor income for the dynasties, and the effects of aging are strongest in the low population scenario. In contrast, per capita labor income for a representative household is a flat line at $20,000 per year. The dynasties can be identified from their supply of labor in 2000. For example in 2000, dynasty 1 has a cohort in the 45-55 group, which has the largest per capita labor income. Thus, dynasty 1 has the largest labor income in 2000.

Labor income directly affects the dynamics of savings and capital, which are presented in the bottom graph of Figure 3. Capital for a representative household is illustrated with a flat line at about $70,000 per person. In Figure 3, the variation across dynasties in each year exceeds the variation across population scenarios within each dynasty until about 2050, after which variation across scenarios is larger. An implication is that age structure is important in the short run, but because of population momentum, effects of aging in the short run are similar across population scenarios. However in the long run, aging and the population scenario have differential effects.

The graphs in Figure 4 compare results for total CO_2 emissions, and per capita CO_2 emissions, over time for heterogeneous and representative households. Total emissions with heterogeneous households are driven by changes in age composition of the population. Results show that total emissions with heterogeneous households range from 0.9 to 5.1 billion metric tons per year at 2100. For representative households, changes in emissions over time are due to changes in the size of the population, and emissions range from 1.4 to 5.9 billion metric tons per year by 2100 in the three population scenarios.

The top graph in Figure 4 shows that heterogeneity leads to lower emissions in each population scenario. Differences between emissions in simulations with heterogeneous and representative households are a combination of direct effects from changes in labor supply due to aging, and indirect or general equilibrium effects from changes in capital accumulation, prices, or other factors. Aging implies fewer young workers, whose per capita labor contribution tends to be greater than the population mean. Hence, aging implies a reduction in aggregate labor supply for a given population size.

The bottom graph in Figure 4 shows per capita emissions for heterogeneous and representative households in each population scenario with no technical change. Because total population within each scenario is the same, differences in per capita emissions are caused exclusively by changes in total emissions. Per capita growth in output, measured by gross domestic product (GDP) per person, is essentially zero with representative households, and changes in carbon intensity, represented by CO_2 emissions per dollar of GDP, are also minor. Consequently, per capita emissions with representative households are essentially constant over time and across population scenarios, around 5.3 tons per person.

The bottom graph in Figure 4 shows that demographic heterogeneity in the low population scenario reduces per capita emissions by about two metric tons per person by 2100. Per capita labor supply, which is a weighted average over different age groups, is similar in medium and high population scenarios, which is why per capita emissions are relatively close. The scarcity of young workers drives results in the low population scenario, which has substantial effects on per capita emissions. The range of per capita emissions between low and high population scenarios is about one ton per person by 2100, but because of population momentum, these effects are not apparent until after 2050.

Population aging and representative households

A model configuration with identical households is used to evaluate whether the main effects of population aging can be incorporated into the model simply by scaling the labor supply of representative households. This representative household configuration with aging has the same level of aggregate labor as the model with heterogeneous households. In comparison to the model with representative households and no aging, the long-term emissions reductions for representative households with aging are about 85% of those associated with heterogeneous households for our reference values of the household substitution parameters. Thus, much of the effect of population aging in our reference case can be captured in a representative household model with dynamic labor supply. However, whether a representative household model is adequate in other cases is unclear. For example in simulations with alternative values of the household substitution parameters, described next, the direction of these effects changes.

Sensitivity analysis of household substitution parameters

The substitution parameters ρ and σ in each household's utility function from (3) directly affect results. Our reference value for households' intertemporal substitution parameter is $\rho = 0.5$, or an elasticity of $1/(1-\rho) = 2.0$. This value is taken from Goulder (1995), who reports it is in the range of estimates obtained by Hall (1988), and Lawrance (1991). Our reference value for the substitution elasticity of consumer goods is also 2.0, or $\sigma = 0.5$. We conduct a sensitivity analysis to examine how results with inelastic values for ρ and σ differ.

Values for the intertemporal substitution elasticity are important in macroeconomic models (Guvenen, 2003), and obtaining reliable and consistent estimates has been a problem. Beudry and van Wincoop (1996) use panel data for U.S. states, and report estimates close to a value of one, and significantly different from zero. Note that an elasticity of one implies a ρ of zero, which is equivalent in the limit to the natural log utility function. An elasticity of zero implies $\rho \to -\infty$, which is the Leontief case of perfect complements. A recent study, using a new econometric approach, estimates intertemporal substitution elasticities less than one, but not significantly different from zero (Yogo, 2004). Therefore, negative values for ρ seem plausible. Inelastic values for σ are also plausible. To represent inelastic demand for different consumption goods, we use an alternative value for the consumption substitution parameter of $\sigma = -3.0$, or an elasticity of 0.25. To represent inelastic consumption over time, we use an alternative value for the intertemporal substitution parameter of $\rho = -3.0$. The reference and alternative values for these parameters are intended to span a plausible range that includes both substitutes and complements in consumption.

Values in Table 4 summarize comparisons among the model configurations, substitution parameters, and population scenarios. Our primary comparison is between the two model configurations that consider population aging. Values in the table for the reference case with $\rho = 0.5$ and $\sigma = 0.5$ are taken from the simulations shown in Figure 4. In this case, for the low population scenario, emissions are about 37% less in 2100 with heterogeneous households relative to the representative household configuration without aging. Most of this difference is due directly to scale effects from changes in labor supply associated with population aging because emissions at 2100 for the representative household configuration with aging are about 31% less than for representative households without aging. The remaining difference occurs through capital dynamics and general equilibrium effects. The effects of population aging on emissions are smaller for medium and high population scenarios, about 18% and 13% respectively, because the effects of population aging are not as strong.

For each population scenario, values in Table 4 for the representative household configuration with aging do not vary much for different substitution parameters. The reason is that variation in exogenous labor supply alone has neutral scale effects on the PET model, which is a standard property of neoclassical growth models. Therefore, baseline emissions for the single dynasty cases are scaled by the size of the labor force, but are not sensitive to the choice of household substitution parameters. Results in Table 4 for heterogeneous households are also insensitive to the consumption substitution parameter σ for cases with the reference value of $\rho = 0.5$ for the intertemporal substitution parameter.

However, most energy-economic growth models include only a single consumer good, and this type of aggregation is equivalent to assuming perfect complements, $\sigma \to -\infty$, for different consumer goods. In Table 4, reductions in baseline emissions with the inelastic value of $\rho = -3.0$ are smaller than for the reference case. In this case, compared to representative households with no aging, reductions in baseline emissions for heterogeneous households are smaller than representative households with aging in corresponding population scenarios. As noted above, the implication is that simply scaling the labor supply of a single, representative dynasty to account for future aging gives ambiguous results that either underestimates or overestimates, depending on true values of household substitution parameters, the emissions reductions associated with an aging population.

According to Table 4, emissions reductions for heterogeneous and representative households with aging are similar for cases with the inelastic value of $\sigma = -3.0$ for the consumption substitution parameter. However, substitutability of different consumer goods seems plausible in a developed country like the U.S. With $\sigma = 0.5$ and $\rho = -3.0$, differences in emissions reductions between heterogeneous and representative households with aging are substantial in early years of the simulations, for each population scenario, and differences remain large, throughout the simulation horizon, for the low scenario.

Demography and technical change

Technical change is expected to be an important factor in future CO_2 emissions, and is a prominent feature of current energy-economic growth models (Weyant, 2004). The flexible production structure of the PET model can simulate different patterns of technical change. For comparison, the SRES scenarios provide a logical framework for organizing alternative assumptions about future technical change (IPCC, 2000). Our second set of simulations uses the SRES A1 scenario to compare emissions with representative and heterogeneous households in the presence of a plausible pattern of future technical change according to the SRES methodology. The simulations with technical change are based on the representative household configuration of the PET model, with our medium population projection to be consistent with the A1 scenario, and our reference values of 0.5 for both household substitution parameters. Productivity growth rates for labor and energy were selected so that variables related to GDP and CO_2 emissions in the PET model match averages for different models used in the SRES A1 scenario for the OECD region, as seen in Figure 5.

The SRES A1 scenario uses medium population projections for the OECD countries, but on average, these differ in growth rates by about 0.5% per year from our medium projection for the U.S. Therefore, we match the PET model to average growth rates for per capita GDP from SRES. To match these growth rates in the PET model, labor productivity measured in efficiency units is assumed to grow at 1.6% per year through 2160, and then gradually falls to zero at 2200. Growth in labor productivity increases the scale or size of the economy, but does not affect the carbon intensity of output, which is measured by the ratio of CO_2 emissions over GDP. To match average rates of decline in carbon intensity for OECD countries in A1, we assume productivity growth rates of 2.9% per year through 2160 in the use of refined petroleum and electricity by the energy and materials producing industries in the PET model. After 2160, we assume these growth rates gradually fall to zero at 2200, and the economy reaches a steady state. The top graph in Figure 5 shows the relative growth rate over time of per capita U.S. GDP from the PET model under these assumptions, compared to the SRES models for this scenario in the OECD region. The bottom graph in Figure 5 shows the relative annual rate of change over time in carbon intensity. Note the PET model resembles the AIM model in both graphs, which is the "marker" for the A1 emissions scenario.

The graphs in Figure 6 compare results for U.S. GDP and CO_2 emissions with and without technical change for representative and heterogeneous households. The top graph shows the effects of population aging on U.S. GDP as the difference between curves for representative and heterogeneous households. The upward trend in the pair of curves without technical change is attributed to population growth in our medium household projection. For the upper pair of curves, the scale of the economy grows with technical change, and the absolute difference in GDP with representative and heterogeneous households is close to $20 trillion by 2100, expressed in year 2000 dollars, compared to about $4 trillion without technical change. However, the relative difference in GDP is about the same in both cases, around 16% less with heterogeneous households.

The bottom graph in Figure 6 shows the effects of demographic heterogeneity and technical change on CO_2 emissions. The results of these comparisons are interesting. As also seen in Figure 4, CO_2 emissions exhibit a roughly linear increase over time with the medium household projection and representative households. Changes in the composition of the population with heterogeneous households affect emissions relatively soon in the simulation horizon, reducing emissions almost 10% by 2030, compared to the corresponding case with representative households. In contrast, differences in emissions between representative households with and without technical change are relatively minor before 2060, and the effects of technical change on emissions do not catch up to the effects of population aging until 2086. The explanation for this result derives from the fact that both population growth and economic growth have scale and composition effects.

In the medium household projection, the composition effect from population aging is relatively strong compared to the scale effect from population growth. The scale effect for technical change is due primarily to increases in labor productivity. The composition effect for technical change comes from productivity improvements in the use of refined fuels and electricity, relative to the use of more carbon intensive energy sources such as oil and coal. The process of fuel switching induced by this type of technical change causes a steady decline over time in the carbon intensity of output. Other things being equal, the decline in carbon intensity would reduce emissions. However in Figure 6, emissions reductions induced by the composition effect of declining carbon intensities are neutralized for several decades by the contemporaneous increase in emissions caused by the scale effects of labor augmenting technical change.

While the comparison of effects on emissions from technical versus demographic change is interesting, Figure 6 shows the combined effects are also important, and close to additive in the long run for this particular group of simulations. The population composition effect in the absence of technical change reduces emissions by about 18% by 2100. Effects of energy and labor augmenting technical change reduce emissions by another 24%, relative to emissions with heterogeneous households and no technical change. In comparison, effects of both aging and technical change in the bottom curve on the graph reduce emissions by 38% relative to the top curve with representative households and no technical change.

Results in Figure 6 are derived from a single group of simulations, and are not conclusive. Simulations using the SRES A1 scenario are intended to illustrate the interesting possibilities of combining effects of demography and technical change in the PET model. The results of sensitivity testing in Table 4 imply the relative strengths of scale and composition effects depend on the parameter values, population scenario, and model configuration used for analysis. For example in other groups of simulations with our low household projection and reference values for the household substitution parameters, the effects of technical change in A1 do not catch up to the effects of aging on emissions before 2100. This case is interesting because the average population growth rate for OECD countries in the A1 scenario, 0.2%, is in fact closer to the average population growth rate in our low projection, -0.1%, than to the average growth rate in our medium projection, 0.7%. On the other hand, emissions are much closer with our inelastic value for the consumption substitution parameter, and effects of technical change on emissions surpass the effects of aging at 2045, instead of 2086 with the reference value for this parameter. Of course, these results will vary across SRES scenarios, which is a topic for future research.

Discussion

Demographic factors are usually treated implicitly in energy-economic growth models. This article describes a modeling framework, household projections, and economic data to estimate the effects of population aging on U.S. energy use and CO_2 emissions. Our framework is based on the Population-Environment-Technology (PET) model, a standard neoclassical growth model with detail in energy inputs and consumer goods that is extended to incorporate population age structure and other demographic features. The PET model is decentralized, there is no social planner, and the dynamic competitive equilibrium in each simulation is solved directly from market clearing conditions, and the maximizing behavior of households and firms.

For the model to be consistent with the interpretation of decentralized forward-looking households over an infinite planning horizon, we assume intergenerational altruism in the form of parents caring about the welfare of their children. While this form of altruism is implicit in the dynastic structure of neoclassical growth models, we developed an explicit procedure for linking cohorts into three heterogeneous infinitely lived dynasties. Each dynasty contains households separated in age by the average length of a generation, which is about thirty-years, so that on average, younger households are descendents of the older households. Taken together, the three dynasties combine features of existing infinitely lived agent (ILA) and overlapping generations (OLG) models, and this approach offers several advantages.

To populate the three dynasties, we use household projections from the ProFamy model, which is a major improvement over previous household projection methods. We develop low, medium, and high population scenarios with the ProFamy model. The influence of population aging is strongest in our low scenario, which exhibits large compositional changes in the age structure of the population over time. Compositional changes due to aging are present in the medium and high scenarios, too, but to a lesser degree. We developed age profiles of expenditure patterns, labor income, asset holdings, and other economic variables for each dynasty from the U.S. Consumer Expenditure Survey (CES). These age profiles have measurable differences across age groups both in the levels and composition of labor and capital income, and expenditure shares for the seventeen consumer goods in the PET model. Age-specific heterogeneity in factor incomes, consumption patterns, and population composition create interacting effects that flow back and forward through the economy. A decentralized general equilibrium framework, such as the PET model, is needed to decompose and analyze these interacting micro and macroeconomic effects. Scarcity of labor and capital at a point in time, as well as expected future changes in these factors, are signaled by market prices that are observed by households. These price signals are incorporated directly into consumption and savings decisions of households in the PET model.

The OLG structure of household cohorts in the PET model implies that per capita labor income and capital accumulation within each dynasty are cyclical, with a general downward trend from the effects of aging on per capita labor supply. Labor income for each dynasty follows the same thirty-year pattern, increasing for ten-years after a young cohort enters the workforce, followed by a steady twenty-year decline that is caused by other cohorts aging. Capital accumulation of each dynasty is influenced by labor income, but the general pattern is qualitatively different. Capital is accumulated by each dynasty for the ten-year period that labor income rises, but then is relatively stable for a decade, followed by a ten-year decline. This general pattern implies that dynasties save during periods of high labor income when there are many young or middle-age households, and spend down their capital stocks when households are older and labor income is lower. This general pattern is consistent with the life-cycle savings behavior found in OLG models.

We use the PET model to estimate effects of population aging by comparing emissions baselines from simulations with age-specific heterogeneity to baselines without aging and representative households. To isolate demographic effects, the first set of simulations does not include technical change. Our results compare two types of heterogeneous households to representative households. The first type has heterogeneity only in expenditure shares for different consumer goods that depends on age of the household head. The second type has heterogeneity in expenditure shares, and also in sources of household income, including capital and labor.

The first type of heterogeneity affects only the composition of demand, but our results show these effects are negligible. In contrast, age-specific heterogeneity in labor income reduces CO_2 emissions by 11%, 18%, and 37% per year by 2100 in the high, medium, and low population scenarios, respectively. In our reference case, a labor scale effect accounts for about 85% of these reductions, and the other 15% is from capital dynamics and general equilibrium effects. However, sensitivity analysis indicates that simply scaling labor supply of a single representative dynasty to account for population aging has ambiguous effects that either underestimate or overestimate emissions reductions from population aging, depending on values of household substitution parameters, about which we are uncertain.

A second set of simulations compares emissions baselines with population aging to representative households in the presence of technical change. Assumptions about technical change are based on the SRES A1 Scenario for OECD countries. For our reference values of household substitution elasticities, effects on emissions from aging and decreases in carbon intensity from technical change are additive in the long run. The most interesting result is that effects of aging on emissions are as large, or larger, than effects of technology in some cases.

Results in this article support further consideration of demographic factors in emissions projections, and suggest these factors may be critical to the development of new emissions scenarios, particularly those based on low population projections for the U.S., because effects of aging are most important in this scenario. However, our model and current approach are based on several simplifying assumptions that ignore feedbacks, which could dampen, or deepen, economic effects of an aging population. For example, this article considers population age structure, but changes in household size, the proportion of immigrant households, or other demographic factors are probably also important. In addition, labor participation by older households has been increasing over the past decade, and this trend seems likely to continue, particularly if wages rise in response to changes in aggregate labor supply. We have ignored these effects by treating labor supply as an exogenous variable.

Resolving these issues is beyond the scope of this article, the aim of which is to present a new method for isolating effects of population heterogeneity for age, the most widely recognized demographic factor, in a dynamic general equilibrium setting, and establish an initial set of empirical bounds on these effects. This initial assessment provides an informative comparison of results with and without demographic heterogeneity, in the absence of some potentially confounding factors such as international trade, and thus provides a useful benchmark against which further work can be compared. Results in this article suggest that demographic factors have the potential to substantially affect long-term emissions for the U.S., and motivate further study of relationships between demographic change, economic growth, and energy use.

Future work could address some limitations of the work described in this article. First, our analysis of technical change could be extended to other SRES scenarios.

Second, household size and nativity could be included as additional demographic factors. Third, empirical estimates are needed for the household substitution elasticities used in this article. These values are associated with the substitutability of consumption over time, and across different goods, including energy intensive goods like utilities and fuels, and less intensive goods such as education or health. Some results in this article are sensitive to these values. Data from the U.S. Consumer Expenditure Survey (CES) could be used to estimate substitution elasticities for consumer goods, and test hypotheses about whether these vary among age groups and other demographic categories.

An important limitation of our current approach is that labor supply is inelastic, and does not respond to changes in real wages or other variables. Clearly, increasing labor supply is a plausible response by older age groups to changes in real wages, policy, life expectancy, or other factors that provide an incentive to delay retirement, or otherwise continue working. A thorough analysis of household economic data should be done to infer a reasonable range of alternatives for age profiles of labor supply, and to develop a set of scenarios for future labor force participation by different demographic groups.

Another important restriction is that results in this article are for the U.S. only, under assumptions of a closed economy. Several models, including the PET model, have the structure to include multiple countries or regions, and international trade, but demographic projections for other countries to support the type of analysis in this article do not currently exist. The data required for future work on these countries are extensive, including household projections, household survey data, and production data for different consumer good industries. Results with international trade are difficult to predict *a priori*, and will depend on the countries being compared. Countries that differ in age distribution will gain from trade, since labor intensive goods can be exported by the country with the younger population. International trade might be expected to diminish the effects of aging on energy use and CO_2 emissions, relative to an autarky situation without trade. However, population aging is a global event (O'Neill, MacKellar, and Lutz, 2001). Extrapolating results in this article suggests there may be a general upward bias in current global emissions projections, which should provide additional motivation for research in this area.

References

Auerbach, A., and L. Kotlikoff, 1987, Dynamic fiscal policy (Cambridge University Press, Cambridge, MA).

Azar, C., and T. Sterner, 1996, Discounting and distributional considerations in the context of global warming, Ecological Economics 19, 169-184.

Barro, R., 1974, Are government bonds net wealth? Journal of Political Economy 82, 1095-1117.

Beaudry, P., and E. van Wincoop, 1996, The intertemporal elasticity of substitution: an exploration using a U.S. panel of state data, Economica, New Series 63, 495-512.

Bin, S., and H. Dowlatabadi, 2005, Consumer lifestyle approach to US energy use and the related CO_2 emissions, Energy Policy 33, 197-208.

Birdsall, N., A. Kelley, and S. Sinding, 2001, Population matters: demographic change, economic growth, and poverty in the developing world (Oxford University Press, Oxford, UK).

Blanchard, O., 1985, Debt, deficits, and finite horizons, Journal of Political Economy 93, 223-247.

Blanchard, O., and S. Fischer, 1987, Lectures on macroeconomics (MIT Press, Cambridge MA).

BLS (Bureau of Labor Statistics), U.S. Department of Labor, 1998, Consumer Expenditure Survey. http://www.bls.gov/cex/home.htm.

Brenkert, A., R. Sands, S. Kim, and H. Pitcher, 2004, Model documentation for the SGM, Pacific Northwest National Laboratory, PNNL-14256.

Cline, W., 1992, Global warming: the economic stakes (Institute for International Economics, Washington D.C.).

Dalton, M., and L. Goulder, 2001, An intertemporal general equilibrium model for analyzing global interactions between population, the environment and technology: PET model structure and data. Unpublished document, California State University Monterey Bay.

Deaton, A., 1997, The Analysis of Household Surveys (The World Bank, Washington, D.C.).

EIA, 2004, Annual energy review 2003 (Energy Information Administration, U.S. Department of Energy, Washington, D.C.).

Fair, R., and J. Taylor, 1983, Solution and maximum likelihood estimation of dynamic nonlinear rational expectations models, Econometrica 51, 1169-1185.

Farmer, M., A. Randall. 1997. Policies for sustainability: Lessons from an overlapping generations model, Land Economics 73, 608-622.

Geanakoplos, J., and H. Polemarchakis, 1991, Overlapping generations, Ch. 35 in: W. Hildenbrand and H. Sonnenschein, eds., Handbook of Mathematical Economics IV (North-Holland, Amsterdam).

Gerlagh, R., and B. van der Zwaan, 2000, Overlapping generations versus infinitely-lived agent the case of global warming, in: R. Howarth and D. Hall, eds., The Long-Term Economics of Climate Change, Vol. 3 (JAI Press, Stamford CT) 301-327

Gerlagh, R., and B. van der Zwaan, 2001, The effects of ageing and an environmental trust fund in an overlapping generations model on carbon emissions reduction, Ecological Economics 36, 311-326.

Goulder, L., 1995, Effects of carbon taxes in an economy with prior tax distortions: an intertemporal general equilibrium analysis, Journal of Environmental Economics and Management 29, 271-297.

Guvenen, F., 2003, Reconciling conflicting evidence on the elasticity of intertemporal substitution: a macroeconomic perspective. RCER Working Paper No. 491, University of Rochester, January.

Hall, R., 1988, Intertemporal substitution in consumption, Journal of Political Economy 96, 339-357.

Howarth, R., 1996, Climate change and overlapping generations, Contemporary Economic Policy 14, 100-111.

Howarth, R., 1998, An overlapping generations model of climate-economy interactions, *Scandinavian Journal of Economics* 100, 575-591.

Howarth, R., and R. Norgaard, 1992, Environmental valuation under sustainable development, American Economic Review 82, 473-477.

Intergovernmental Panel on Climate Change (IPCC), 2000, Special report on emissions scenarios (Cambridge University Press, Cambridge UK). http://www.grida.no/climate/ipcc/emission/

Jiang, L., and B.C. O'Neill, 2004, Towards a new model for probabilistic household forecasts, International Statistical Review 74, 51-64.

Jiang, L., and B.C. O'Neill, 2005, Impact of demographic events on household formation and dissolution in the United States, Working Paper, Brown University.

Kehoe, T., 1991, Computation and multiplicity of equilibria, Ch. 38 in: W. Hildenbrand and H. Sonnenschein, eds., Handbook of Mathematical Economics IV (North-Holland, Amsterdam).

Lareau, T., and J. Darmstadter, 1983, Energy and household expenditure patterns, (Resources for the Future, Washington, D.C.).

Lawrance, E., 1991, Poverty and the rate of time preference: evidence from panel data, Journal of Political Economy 99, 54-77.

MacCracken, C., J. Edmonds, S. Kim, and R. Sands, 1999, The economics of the Kyoto Protocol, Energy Journal, Kyoto Special Issue, vii-xiv.

Manne, A., 1999, Equity, efficiency, and discounting, Ch. 12 in: P. Portney and J. Weyant, eds., Discounting and Intergenerational Equity (Resources for the Future, Washington D.C.).

Manne, A., R. Mendelsohn, and R. Richels, 1995, MERGE: A model for evaluating regional and global effects of GHG reduction policies, Energy Policy 23, 17-34.

Marini, G., and P. Scaramozzino, 1995, Overlapping generations and environmental control, Journal of Environmental Economics and Management 29, 64-77.

Mastrandrea, M., and S. Schneider, 2004, Probabilistic integrated assessment of "dangerous" climate change, Science 304, 571-575.

McKibbin, R., and D. Vines, 2000, Modelling reality: the need for both inter-temporal optimization and stickiness in models for policy-making, Oxford Review of Economic Policy 16, 106-137.

Nordhaus, W., 1994, Managing the global commons: the economics of climate change (MIT Press, Cambridge MA).

Nordhaus, W., and Z. Yang, 1996, A regional dynamic general equilibrium model of alternative climate change strategies, American Economic Review 86, 741-765.

O'Neill, B.C., 2005, Household expenditure patterns by demographic characteristics based on the 1998 U.S. Consumer Exependiture Survey data, Working Paper, Brown University.

O'Neill, B.C., and B. Chen, 2002, Demographic determinants of household energy use in the United States, in: Methods of Population-Environment Analysis, Supplement to Population and Development Review 28, 53-88.

O'Neill, B.C., and M. Oppenheimer, 2002, Dangerous climate impacts and the Kyoto Protocol, Science 296, June 14, 1971-1972.

O'Neill, B.C., L. MacKellar, and W. Lutz, 2001, Population and climate change (Cambridge University Press, Cambridge, UK).

Paulin, G., 2000, Expenditure patterns of older Americans, 1984-1997, Monthly Labor Review, May, 3-28.

Peck, S., and T. Teisberg, 1992, CETA: A model for carbon emissions trajectory assessment, Energy Journal 13, 55-77.

Ramsey, F., 1928, A mathematical theory of saving, Economic Journal 38, 543-559.

Schelling, T., 1992, Some economics of global warming, American Economic Review 82, 1-14.

Schelling, T., 1995, Intergenerational discounting, Energy Policy 23, 395-401.

Schipper, L., 1996, Lifestyles and the environment: the case of energy, Daedalus 125, 113-138.

Schmitt, J., 2004, Estimating household consumption expenditures in the United States using the Interview and Diary portions of the 1980, 1990, and 1997 Consumer Expenditure Surveys, DEMPATEM Working Paper No. I, available at http://www.uva-aias.net/lower.asp?id=186.

Solow, R., 1956, A contribution to the theory of economic growth, Quarterly Journal of Economics 70, 65-94.

Stephan, G., G. Muller-Furstenberger, and P. Previdoli, 1997, Overlapping generations or infinitely-lived agents, Environmental and Resource Economics 10, 27-40.

Stokey, N., and R. Lucas, 1989, Recursive methods in economic dynamics (Harvard University Press, Cambridge MA).

Weber, C., and A. Perrels, 2000, Modelling lifestyle effects on energy demand and related emission, Energy Policy 28, 549-566.

Weyant, J., 2004, Introduction and overview, EMF 19 alternative technology strategies for climate change policy, Energy Economics 26, 501-515.

Weyant, J., and J. Hill, 1999, Introduction and overview, costs of the Kyoto Protocol: a multimodel evaluation, Energy Journal, Kyoto Special Issue, vii-xiv.

Yogo, M., 2004, Estimating the elasticity of intertemporal substitution when instruments are weak, Review of Economics and Statistics 86, 797-810.

Zeng, Y., J. Vaupel, and W. Zhenglian, 1998, Household projection using conventional demographic data, in: W. Lutz, J. Vaupel, and D. Ahlburg, eds., Frontiers of

Population Forecasting, supplement to Population and Development Review 24, 59-87.

Figure 1: Overview of the PET model. Households demand consumption and investment goods (C and I), and supply capital and labor (K and L). Final good producers supply C, I, and a government good (G). Intermediate goods producers supply energy and materials (E and M). The primary energy producers, which are coal, oil and gas industries, create CO_2 emissions.

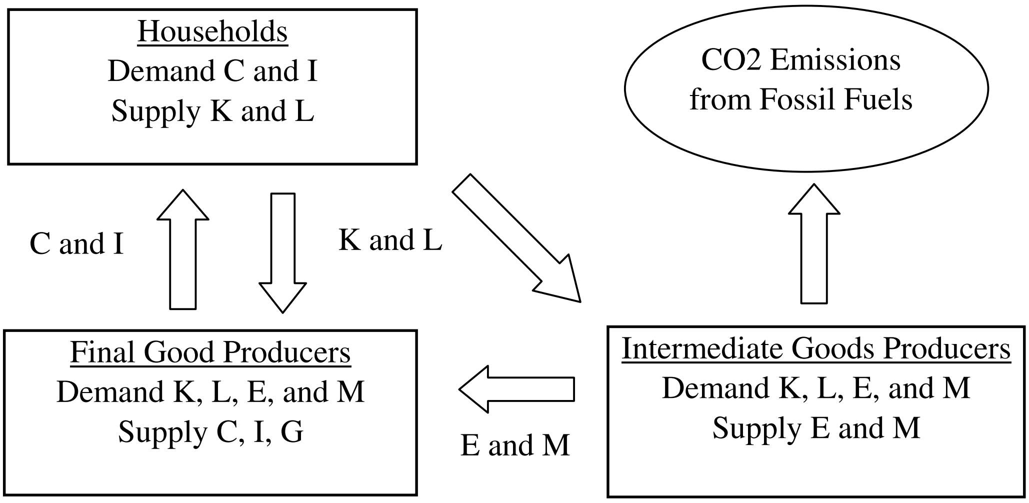


Figure 2: Cohort structure of dynasties in the PET model. Dynasty 1 consists of cohorts 1a-f (boxes). Dynasty 2 consists of cohorts 2a-f (circles). Dynasty 3 consists of cohorts 3a-e (triangles).

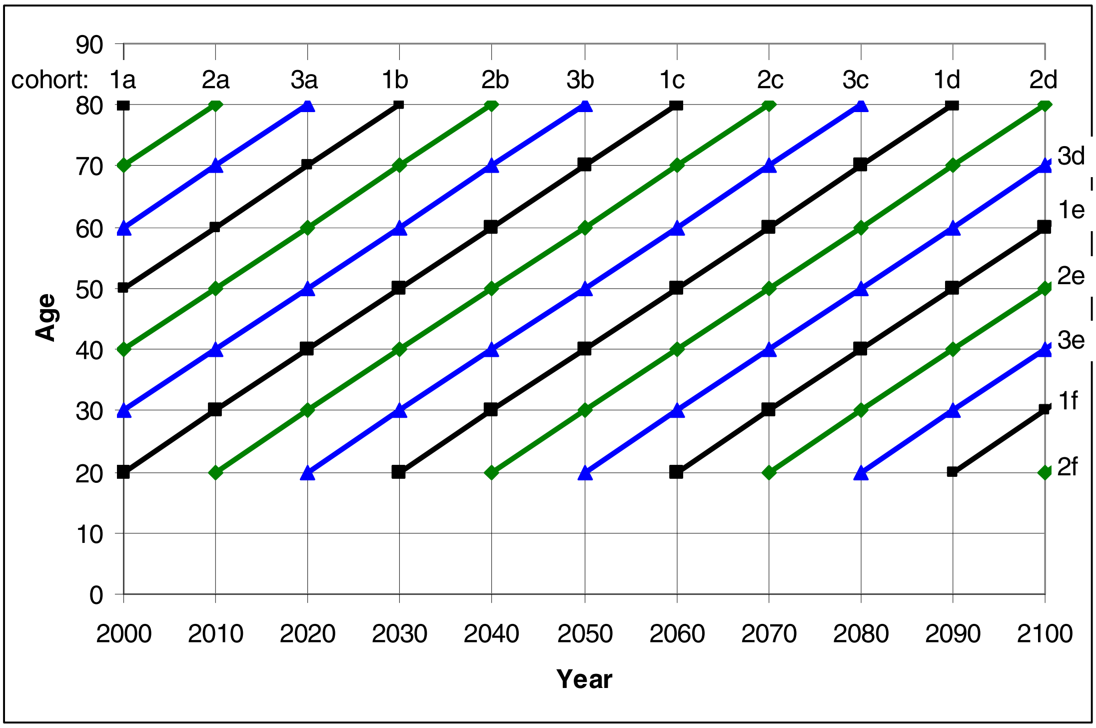
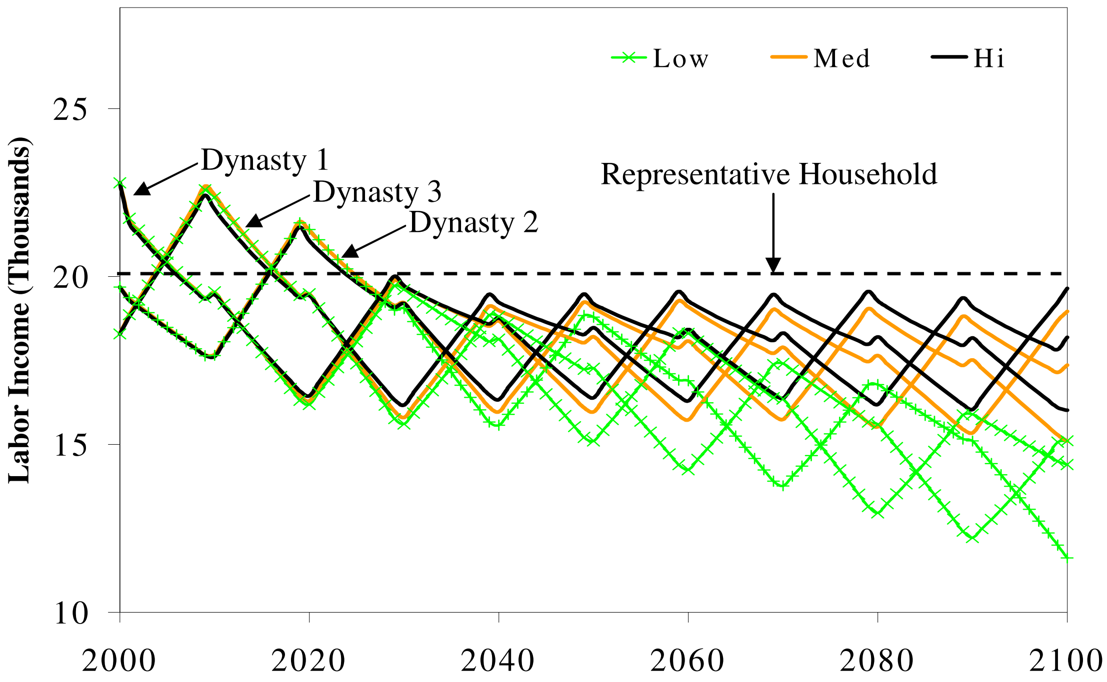


Fig. 3: Per capita dynamics for labor income (top) and capital stock (bottom) in thousands of year 2000 dollars for the 3 dynasties in the low (hatched), medium (light solid), and high (dark solid) population scenarios.



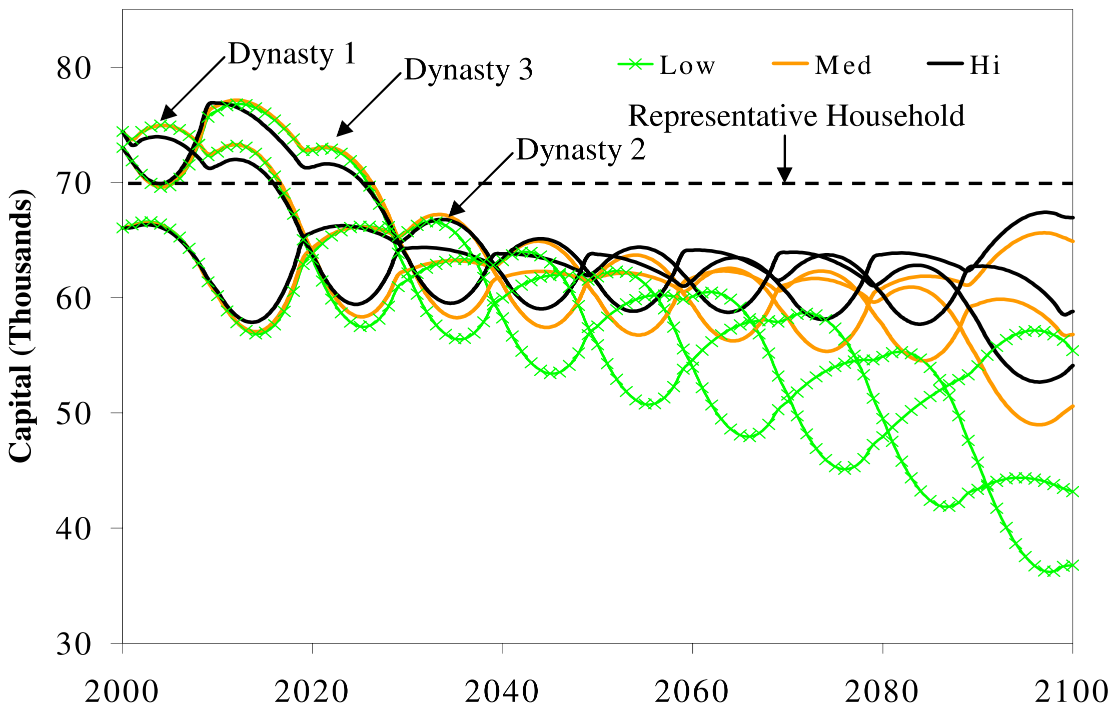
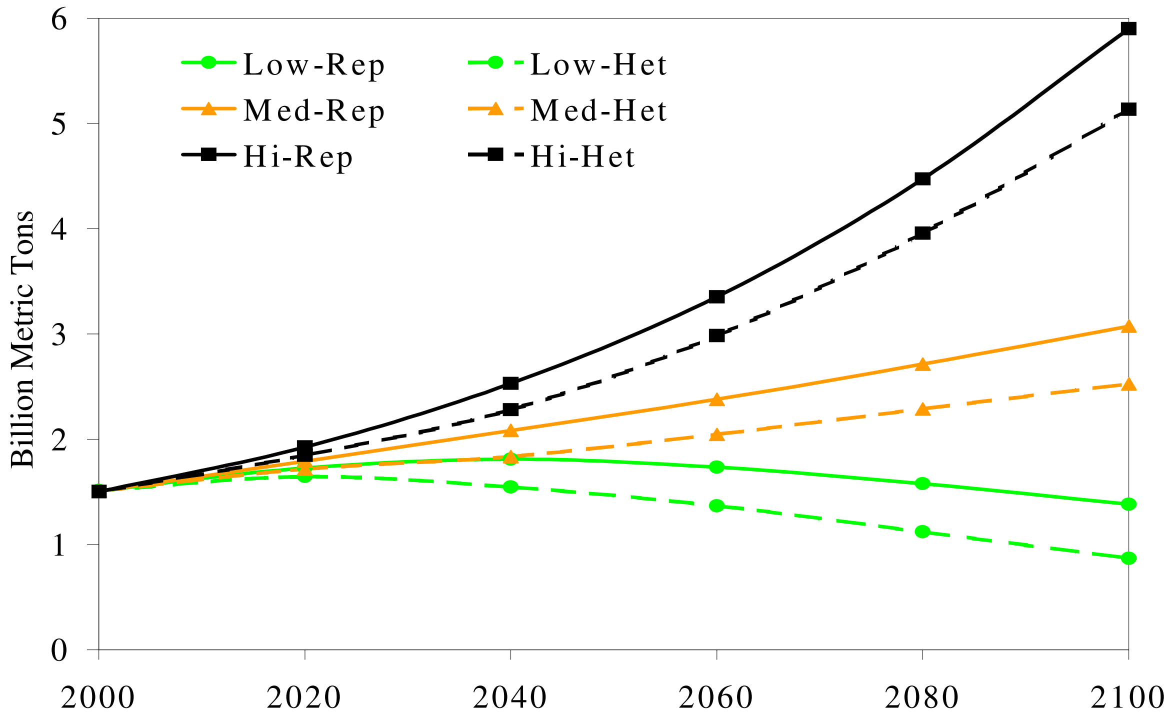


Figure 4: Range of CO_2 emissions and per capita CO_2 emissions for heterogeneous (Het) and representative (Rep) households in low, medium, and high population Scenarios.



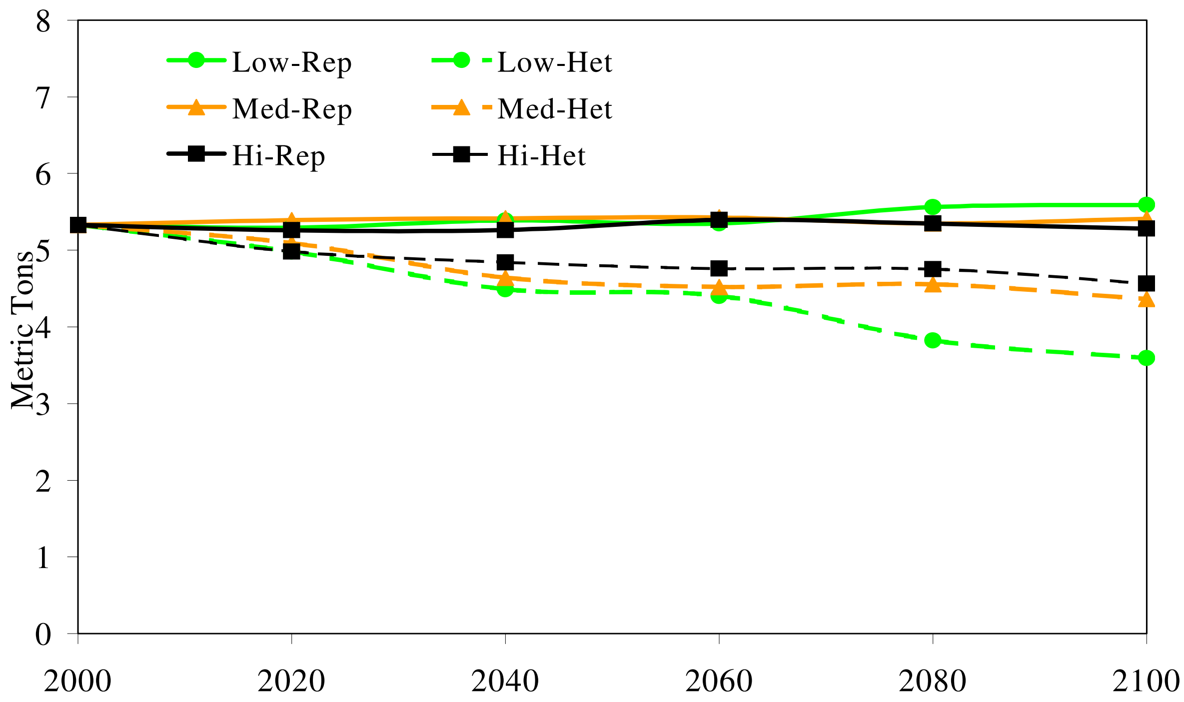
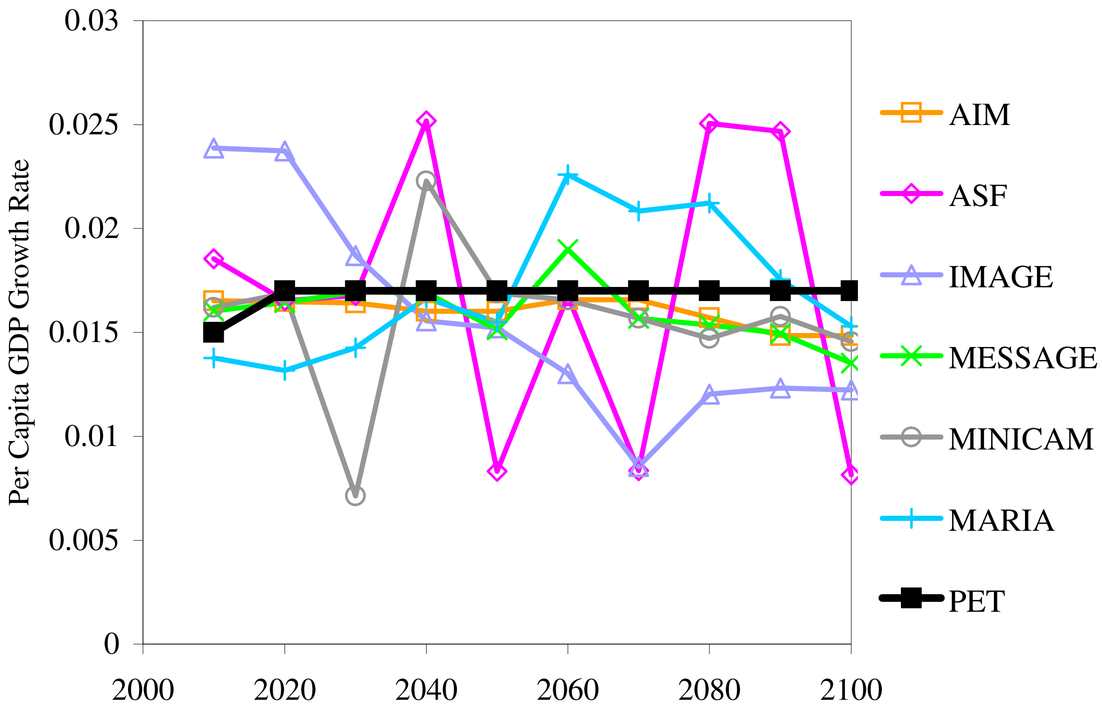


Figure 5: Rates of change for models in SRES A1 scenario for OECD countries compared to the PET model for per capita GDP (top) and carbon intensity of GDP (bottom).



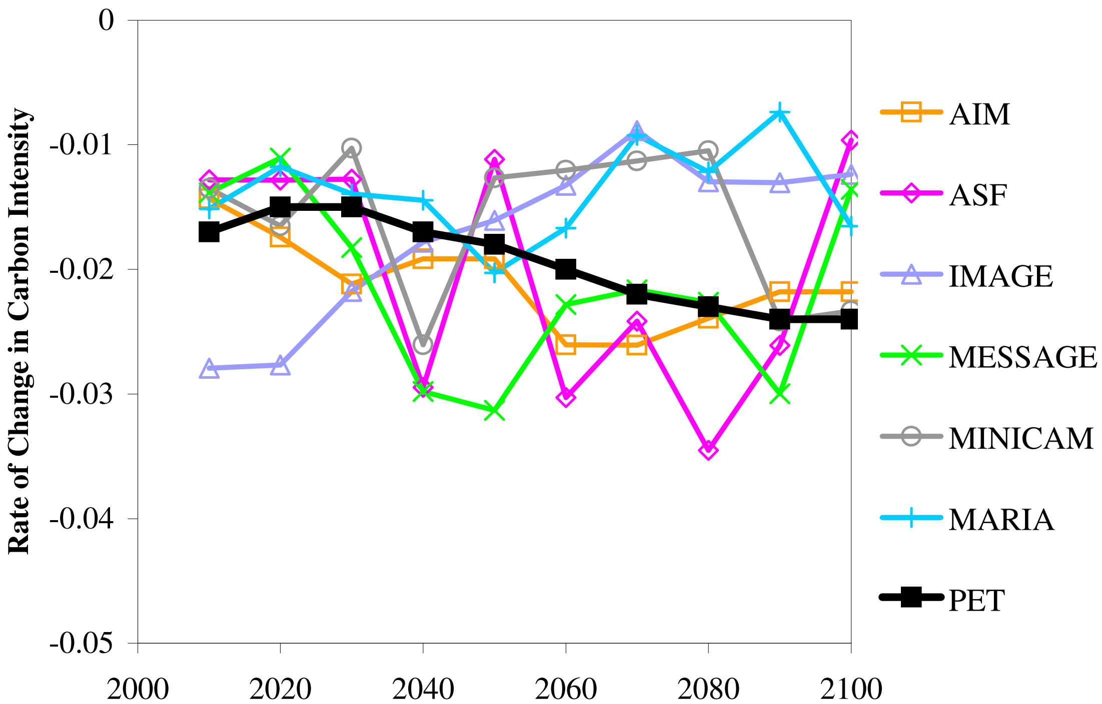
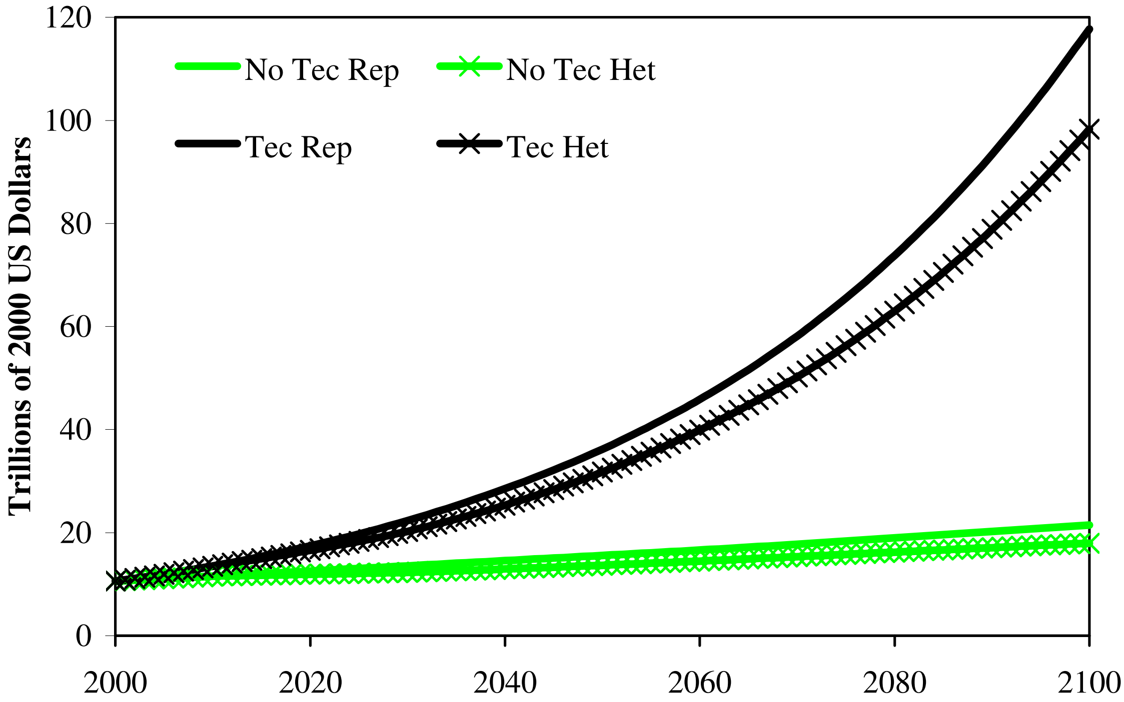


Figure 6: GDP and CO_2 emissions under technical change assumptions consistent with the SRES A1 emissions scenario (Tec) compared to no technical change (No Tec) for representative (Rep) and heterogeneous (Het) households.



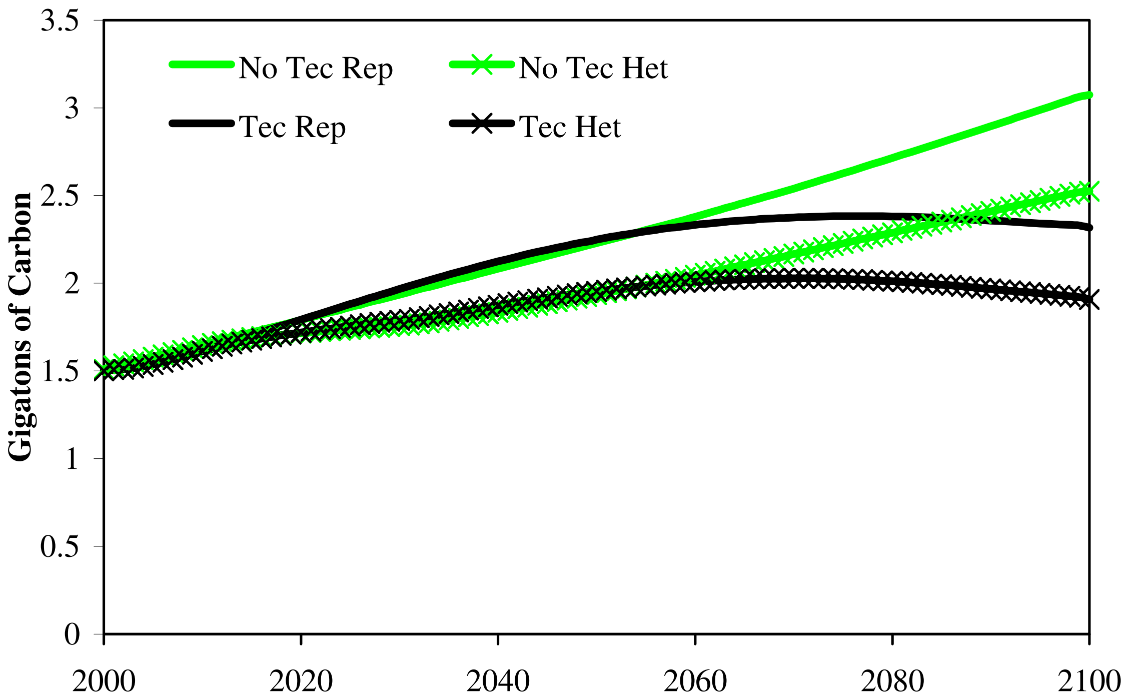


Table 1: Expenditure shares for different age groups (%). Source: BLS 1998.

		Age of Household Head							
Good	Mean	15-25	25-35	35-45	45-55	55-65	65-75	75-85	85-95
1. Food	15.29	15.41	14.71	15.55	15.29	15.31	15.55	16.43	12.43
2. Alcohol	1.02	1.69	1.22	0.96	0.84	1.02	0.87	0.99	0.24
3. Tobacco	0.85	0.93	0.83	0.89	0.86	0.98	0.76	0.43	0.37
4. Utilities	4.22	2.90	3.74	4.01	3.98	4.69	5.53	6.71	6.07
5. Housing Services	20.50	21.54	23.80	21.69	18.82	17.80	16.19	17.63	33.63
6. Furnishings	4.48	3.76	4.29	4.35	4.84	5.07	4.66	4.16	1.21
7. Appliances	1.35	1.65	1.25	1.41	1.33	1.49	1.21	1.19	0.87
8. Clothing	4.93	5.35	5.31	5.28	5.40	4.07	4.00	2.85	1.59
9. Transportation	8.25	7.71	8.33	7.99	8.68	8.90	8.25	6.78	4.70
10. Motor Vehicles	12.01	14.47	13.06	12.65	12.57	11.20	9.42	5.08	5.12
11. Services	7.22	5.48	6.25	6.53	7.31	8.35	9.53	10.04	9.19
12. Financial Service	2.99	1.93	2.95	3.20	2.80	3.55	2.88	3.26	1.58
13. Recreation	3.75	3.38	3.67	3.65	4.02	3.70	3.99	3.88	2.07
14. Nondurables	1.98	2.12	2.16	2.09	2.07	1.76	1.74	1.06	0.70
15. Fuels	3.40	3.50	3.29	3.40	3.50	3.59	3.42	3.02	2.25
16. Education	1.76	5.50	1.29	1.75	2.41	1.14	0.50	0.19	0.37
17. Health	5.99	2.69	3.84	4.60	5.28	7.39	11.51	16.30	17.62

Table 2: Total consumption expenditures, savings, income, government (Gov.) and household (HH) transfers, and income tax rates for different age groups (per capita values in 1998 dollars). Source: BLS 1998.

		Age of Household Head							
	Mean	15-25	25-35	35-45	45-55	55-65	65-75	75-85	85-95
Consumption	13,214	11,355	11,824	12,175	15,987	15,336	14,156	12,555	12,084
Savings	3,316	1,080	2,253	3,442	4,674	5,020	2,299	3,036	6,808
Labor income	14,198	9,659	14,753	15,278	21,583	14,440	4,014	1,324	1,325
Capital income	2,020	192	769	1,336	2,081	4,115	4,998	5,019	3,777
Capital	33,377	3,076	5,894	17,040	43,867	66,295	95,910	87,351	83,277
Gov. transfers	371	-440	-882	-811	-1,066	1,270	6,098	7,957	7,384
HH transfers	48	342	210	32	7	65	-244	-364	-474
Capital tax rate	0.23	0.39	0.34	0.31	0.30	0.17	0.16	0.15	0.17
Labor tax rate	0.09	0.06	0.08	0.08	0.10	0.10	0.18	0.26	0.18

Table 3: U.S. population (millions) and shares (%) living in households of different ages in high, medium, and low population scenarios. Source: Jiang and O'Neill (2005).

		Population Shares (%) by Age of Household Head								
Year	Population	15-25	25-35	35-45	45-55	55-65	65-75	75-85	85-95	95+
High Population Scenario										
2000	281.4	6.5	23.0	30.5	19.7	9.4	6.5	3.6	0.9	0.1
2010	316.6	7.3	21.7	25.0	20.7	13.6	7.0	3.6	1.0	0.1
2020	361.2	6.2	21.8	24.5	17.5	14.6	10.1	4.2	1.0	0.1
2030	414.3	6.4	19.9	24.9	17.4	12.5	11.2	6.3	1.3	0.2
2040	475.0	6.7	20.5	23.3	17.7	12.4	9.6	7.3	2.3	0.2
2050	546.3	6.9	20.8	23.9	16.5	12.5	9.5	6.5	3.0	0.4
2060	630.2	6.9	20.6	24.0	16.9	11.7	9.6	6.6	3.0	0.6
2070	728.3	7.0	20.5	23.7	17.0	12.0	9.1	6.7	3.3	0.7
2080	841.5	6.9	20.4	23.5	16.8	12.1	9.3	6.5	3.6	0.9
2090	970.4	6.9	20.2	23.3	16.7	12.0	9.4	6.8	3.6	1.1
2100	1117.0	6.8	20.1	23.1	16.6	11.9	9.4	7.0	3.8	1.2
Medium Population Scenario										
2000	281.4	6.5	23.0	30.5	19.7	9.4	6.5	3.6	0.9	0.1
2010	307.8	6.7	21.0	25.2	21.3	13.9	7.1	3.6	1.1	0.1
2020	333.8	5.8	20.6	23.9	18.0	15.4	10.6	4.4	1.1	0.2
2030	360.6	5.8	18.9	23.9	17.4	13.2	12.2	6.9	1.4	0.2
2040	387.8	5.6	19.2	22.5	17.7	12.9	10.7	8.5	2.6	0.3
2050	414.5	5.4	19.0	22.9	16.8	13.2	10.7	7.8	3.7	0.5
2060	442.3	5.3	18.6	22.7	17.2	12.6	11.1	7.9	3.9	0.7
2070	472.3	5.2	18.4	22.2	17.0	13.0	10.7	8.4	4.3	0.8
2080	504.9	5.0	18.1	22.1	16.8	12.9	11.0	8.2	4.8	1.1
2090	538.3	4.9	17.7	21.8	16.8	12.8	11.1	8.7	5.0	1.4
2100	573.0	4.7	17.4	21.5	16.6	12.8	11.1	8.9	5.4	1.7
Low Population Scenario										
2000	281.4	6.5	23.0	30.5	19.7	9.4	6.5	3.6	0.9	0.1
2010	303.7	6.8	21.0	24.9	21.1	14.0	7.2	3.7	1.1	0.1
2020	321.2	5.3	20.3	23.6	17.9	15.7	11.1	4.7	1.2	0.2
2030	331.4	4.5	17.6	23.6	17.5	13.7	13.1	7.8	1.8	0.3
2040	334.1	3.9	16.4	21.8	18.0	13.8	12.0	10.0	3.7	0.4
2050	328.5	3.3	14.9	21.0	17.2	14.8	12.6	9.7	5.6	0.9
2060	317.9	2.9	13.4	19.8	17.0	14.6	14.1	10.7	6.0	1.6
2070	305.0	2.5	12.0	18.4	16.5	15.0	14.2	12.3	7.0	2.0
2080	287.7	2.3	10.7	16.9	15.7	15.0	15.1	12.9	8.5	2.9
2090	269.9	2.1	10.1	15.5	14.8	14.7	15.5	14.0	9.4	3.9
2100	250.5	2.0	9.5	14.9	13.7	14.1	15.5	14.8	10.7	4.8

Table 4: Percentage differences in U.S. CO_2 emissions with population aging compared to the first representative household configuration in low (L), medium (M), and high (H) population scenarios, and for alternative values of the intertemporal (ρ) and consumption (σ) substitution parameters.

	Rep. W/Aging			Heterogeneous			Rep. W/Aging			Heterogeneous		
Year	L	M	H	L	M	H	L	M	H	L	M	H
	$\rho = 0.5, \sigma = 0.5$						$\rho = 0.5, \sigma = -3.0$					
2000	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.1	0.1
2020	-4.9	-4.4	-4.1	-4.8	-4.2	-4.1	-4.9	-4.4	-4.1	-5.1	-4.5	-4.3
2040	-12.7	-10.1	-8.3	-14.6	-11.9	-9.8	-12.7	-10.2	-8.3	-14.8	-12.0	-9.9
2060	-18.3	-11.8	-9.2	-21.2	-14.0	-11.0	-18.2	-11.8	-9.2	-21.4	-14.0	-11.0
2080	-25.0	-13.2	-9.7	-29.0	-15.7	-11.5	-24.9	-13.2	-9.7	-29.3	-15.7	-11.5
2100	-31.5	-14.9	-10.8	-37.2	-17.9	-13.0	-31.6	-14.9	-10.8	-37.4	-17.9	-13.0
	$\rho = -3.0, \sigma = 0.5$						$\rho = -3.0, \sigma = -3.0$					
2000	0.2	0.2	0.2	-0.1	0.1	0.0	0.3	0.2	0.2	0.1	0.1	0.1
2020	-5.5	-4.8	-4.3	-1.0	-0.8	-1.0	-5.3	-4.7	-4.3	-2.6	-2.2	-2.2
2040	-12.6	-9.8	-8.1	-8.6	-7.3	-6.3	-12.6	-9.9	-8.1	-10.5	-8.7	-7.3
2060	-18.4	-11.7	-9.1	-13.7	-10.0	-8.0	-18.3	-11.7	-9.1	-16.2	-11.2	-8.9
2080	-25.1	-13.3	-9.8	-19.0	-11.3	-8.4	-25.1	-13.2	-9.7	-22.3	-12.6	-9.3
2100	-31.1	-14.8	-10.7	-25.3	-13.0	-9.5	-31.3	-14.8	-10.8	-29.0	-14.4	-10.5

Comments of Tim Eichenberg, The Ocean Conservancy
Re: WHOI Aquaculture Paper (Jin et. al)
Nov. 16, 2005

<u>There is no longer any doubt that the oceans are in trouble</u>

- Two national commissions recently arrived at the same conclusion
- Overfishing and destructive fishing from longlining and bottom trawling have devastated world fish stocks
    - Total landings have leveled off and are declining
    - 25% of the world's catch (27M mts) is wasted as bycatch
    - 9 of the world's 17 major fishing zones are in serious decline
    - 75% of world's fisheries are fully/over-exploited
    - 90% of large pelagic species have been wiped out in past 50 years (sharks, swordfish, marlin, tuna)
    - Species diversity has declined 50% in ocean hotspots
    - The cod fishery has collapsed in the Atlantic
    - The entire continental slope from Canada to Mexico has been closed to bottom fishing to rebuild groundfish populations

<u>Aquaculture is viewed as the answer to declining seafood production</u>

- Aquaculture is the fastest growing segment of the world food economy
- It currently produces 40% of all seafood products (marine aquaculture is a smaller but growing portion of the aqua industry)
- Feds called for 5-fold increase ($5B yr.) over next 20 years to supplement declining fisheries and reduce US $8B seafood trade deficit (78% of US seafood imported)
- Compared with Asia and Europe, the US aquaculture industry is in its infancy. Current marine farmed species in the US include:
    - Caribbean: cobia, snapper
    - Gulf: red drum, pompano, amberjack, cobia
    - Pacific: salmon, halibut, tuna
    - New England: salmon, halibut, haddock, cod
    - Hawaii: moi

<u>Both Ocean Commissions acknowledge that marine fish farming entails significant risks/"externalities":</u>

- Conflicts with fishing and public trust uses
- Impacts on marine wildlife
- Escapes spread disease/parasites, compete with and biologically pollute wild fish stocks
- Ecosystem effects
    - Fish farms use of 48% of world's fishmeal, 78% of the fish oil, and farmed fish are fed 12% of the world's catch
    - 4:1 production ratio for wild/farmed marine finfish
    - Unless these ratios are reduced, fish farming will result in a net loss of fish to the world's oceans
- Pollution:
    - The wastes of 200,000 fish produce nutrients of 20,00 - 65,000
    - Fish farms use a variety of chemicals: hormones, antibiotics, pesticides, herbicides, pigments, parasiticides, anesthetics

<u>Authors undertake a market-based forecast of industry growth:</u>

- They acknowledge that the industry can not realize its full potential if external effects are ignored, but state that in open-ocean environments assimilative capacity is unlikely to be a serious constraint
- They cite studies showing that industry growth can actually achieve pollution reductions
- Yet their model assumes that the scale of production depends upon environmental damage measured by the release of N
- They conclude that optimal industry scale (11 farms producing 23K mt of cod) is achieved when waste discharges do not cause measurable environmental harm
- They also show how fish farms and groundfish landings can increase together – this is subject to much debate

<u>Comments:</u>

- It would be useful for policymakers to know how the increase of fish farms affect wild harvest fisheries
- N is probably not a useful measure of environmental harm in the oceans – more serious consequences are likely from disease, genetic impacts, ecosystem impacts from the use of fishmeal/oils, and public trust conflicts. These issues need more examination.

- The assumption that the aquaculture industry is constrained by environmental damage assumes the existence of a robust regulatory program – such an assumption is misleading

<u>Currently a robust federal regulatory program does not exist</u>

- Code of Conduct for Responsible Aquaculture Development in the EEZ, drafted in 2002 but never finalized, provides only voluntary guidance to:
    - consolidate federal permit/leasing system;
    - BMPs and "precautionary" siting and management policies
- EPA Effluent Limitation Guidelines (2004)
    - Does not:
        - require numeric limits on pollutants (TSS, FC, nitrates, phosphates, BOD, metals, drugs, pesticides);
        - limit use of non-native/GM species;
        - require WET testing or water quality monitoring
    - Relies instead on BMPs to minimize feed inputs, properly store and dispose chemicals, inspect and maintain production systems, and train personnel
- New federal legislation being considered is weak: S1195 (Stevens, Inouye)
    - Contains no environmental standards
    - "Encourages" responsible development, and protection of wild stocks and marine ecosystems
    - Exempts OOA permits from MSA
    - Amendments being considered to defer to state policies

<u>Weak federal policies have forced some states to act (but states only regulate to 3 miles):</u>

- Alaska has banned all marine finfish aquaculture
- California:
    - Banned salmon, and GM and non-native species in 2003 (Sher Bill – SB 245)
    - Is currently considering a TOC sponsored bill to:
        - Develop PEIR to consider appropriate sites/designs, avoid conflicts with other uses, and evaluate impacts on fisheries, wildlife, and marine ecosystems;

- Provide specific leasing standards to:
  - Ensure that sites do not “unreasonably interfere” with fishing and other public trust uses;
  - Prevent escapes from adversely affecting marine wildlife, habitats, fishing and other uses;
  - Minimize the use of fish meal/oils, drugs and chemicals;
  - Control the density of farmed species;
  - Restore any damage to human health and marine environment;
  - Conduct baseline assessments, and regular monitoring;
  - Properly tag and marked farmed fish;
  - Charge reasonable fees to monitor, inspect, and enforce leases
- Issues to be resolved include: using matching industry funds for the PEIR; minimizing the use of use of fish meal/oil; preventing harm to marine mammals and other wildlife; tagging and marking farmed fish; and MOA with the CCC on OREHAP

Comments on “Future Growth of the US Aquaculture Industry and Associated Environmental Quality Issues”

by

Charles D. Kolstad
University of California, Santa Barbara

The subject paper has the objective of evaluating the potential expansion of open-ocean aquaculture and the constraints provided by pollution considerations and regulations. This is an important objective and one deserving of attention. Secondary objectives of the paper are to understand the wild vs. farmed fish markets and to understand pollution as a type of product degradation (making the fish less desirable). These are excellent objectives.

Given these objectives, it is somewhat perplexing that the authors chose open-ocean aquaculture where it is very difficult to determine the negative environmental effects, let alone the economic damages. As the authors state, effluents disperse quickly. The examples of damage they cite (mangrove swamps, fresh-water aquaculture) just do not apply in the case of open-ocean aquaculture. This is a real problem with the paper.

The method the authors use is to develop a bioeconomic model of wild fisheries and then assume farmed fish can be produced at constant cost and are perfect substitutes for wild fish. Unfortunately, the theoretical model has very little relevance to aquaculture and the assumption of perfect substitution between wild and farmed fish just isn’t appropriate (as indicated by the significant price differences between the two). The theoretical model focuses almost exclusively on the wild fishery, whereas aquaculture is what we are interested in. The authors then turn to a simulation model for real results. A major problem is that they will obtain little in the way of interesting results without environmental damage – so they simply assume damages at an arbitrary level.

The paper has potential though I have a few suggestions that might improve the paper. One is to focus on better defining the object of the study and then match the method to the objectives. If the objectives are a normative study of environmental constraints in an open ocean, the problem needs rephrasing for there to be substance. If the objective is a positive analysis of the effects of environmental regulations, de-emphasize the wild fishery. Another suggestion would be to focus on coastal or inland fisheries where environmental concerns are sharper. Alternatively, focus more attention to the demand side of the market.

Other suggestions include backing off on the theory since the main contribution of the paper is not in the theory but in the empirical dimensions. Another suggestion would be to specify some specific policy questions to explore, such as who bears the burden of regulations or can aquaculture reduce fish imports or simply evaluate some regulations that have been proposed.

Comments on "Population Aging and Future Carbon Emissions in the United States"

by

Charles D. Kolstad
University of California, Santa Barbara

This is an interesting paper with important objectives. The main goal as stated in the paper is to estimate the effects of population aging on US carbon emissions. An unstated objective of the paper seems to be to move away from the modeling framework of the infinitely-lived agent (ILA) to an overlapping generations (OLG) framework with population cohorts.

The approach of the paper is to add three "dynasties" (types of cohorts) to a standard computable general equilibrium (CGE) model (PET). Each dynasty is infinitely lived. What this amounts to is a different way of partitioning the set of consumers and it may indeed be a good way to do the partitioning.

There are a number of issues or questions that the paper suggests. One is it is unclear why this division/partition of consumers would change anything, holding everything else constant. For instance, as the length of time between generations changes, one can obtain two extreme models of every agent being separate or a single representative agent. In fact, the model seems to have little in common with an OLG framework.

Another question concerns what the reader should be focusing on. Should we be focusing on the CGE model PET? Or the dynastic enhancements? Furthermore, the big issue of old vs. young seems to be eliminated by essentially grouping the young with elders. Why are 20-somethings more concerned with 30-somethings than with 60-somethings?

A last point it why dividing the population into age/household size categories is preferred to income stratification, a more common way of disaggregating CGE models.

Although I have raised some issues and questions, the point remains that the basic questions posed in this paper are important one. In terms of recommendations for futher refinements, my main suggestion would be to focus on the effect of population in a simpler framework, moving away from the big model, at least in part. You might also focus on the output of ProFamy and compositional projections for the population.

Summary of the Q&A Discussion Following Session II

Michael Kleeman, (University of California at Davis)
Admitting that he is not a population modeler, Mr. Lehman noted that he reads a lot in the papers these days about pandemic possibilities and such things. He then commented that a lot of the modeling work presented assumes a nice, continuous growth and reproduction rate and so on, and he asked, "How do you handle the discontinuities, such as wars and pandemics? Odds are we have one of these things more frequently than once in a 100 years, and you're going out that far, so how do you handle that sort of complexity?"

Dr. Michael Dalton, (California State University)
Dr. Dalton replied, "The short answer is that we don't. It's an excellent point, but there's only so much one can do. Trying to predict wars may be more difficult than trying to predict global warming."

Jack Landy, (U.S. EPA Region 9)
Addressing Dr. Dalton, Mr. Landy asked whether he had factored temperature increase into itself as a feedback.

Dr. Michael Dalton
Acknowledging that it was a very good question, Dr. Dalton responded by saying, "No, at this point the modeling framework starts with this ProFamy model, which produces the population, and then we've gotten it up to the point where we're doing the emissions outcomes." He explained further that they then planned to link the PET (Population-Environmental Technology) model to produce emissions, and the emissions will then be fed into the ISAM (Integrated Science Assessment Model), which will "start to give us temperature outcomes so we can do stabilization runs and that sort of thing." In conclusion, Dr. Dalton stated, "At that point, it's a brand new model because it will have three pieces to it. That's the direction we're going in, but we're not there yet."

Dr. Ben Hobbs, (Johns Hopkins University)
Dr. Hobbs brought a question regarding Dr. Dalton's graphs of the growth of emissions over time, comparing scenarios that had no technological change versus those that did. He noted that "basically they tracked each other until 2050, with the scenarios *with* technological change actually being slightly higher [i.e., having greater emissions], and it was only after 2050 that they diverged and technological change started dampening emissions somewhat." His question was: "What's going on before 2050 that would make this so close or for scenarios with technological change to be a little higher?"

Dr. Michael Dalton
Dr. Dalton reiterated a point made in his presentation, and that is that technology is actually causing two effects. He clarified, "There's a scale effect—the whole economy is getting bigger, and that's causing emissions to go up. At the same time, there's this decreasing carbon intensity effect—the amount of carbon released per dollar of GDP is going down." He explained that "those two effects are roughly offsetting each other until

about 2050 or so,” at which point the curves with technology included really begin to taper off and population growth fuels the upswing in the non-technology curves.

END OF SESSION II Q&A

SOCIO-ECONOMIC CAUSES AND CONSEQUENCES OF FUTURE ENVIRONMENTAL CHANGES WORKSHOP

A WORKSHOP SPONSORED BY THE U.S. ENVIRONMENTAL PROTECTION AGENCY'S NATIONAL CENTER FOR ENVIRONMENTAL ECONOMICS (NCEE), NATIONAL CENTER FOR ENVIRONMENTAL RESEARCH (NCER)

November 16, 2005

EPA Region 9 Building

75 Hawthorne Street 1st Floor Conference Room San Francisco, CA

Prepared by Alpha-Gamma Technologies, Inc. 4700 Falls of Neuse Road, Suite 350, Raleigh, NC 27609

ACKNOWLEDGEMENTS

This report has been prepared by Alpha-Gamma Technologies, Inc. with funding from the National Center for Environmental Economics (NCEE). Alpha-Gamma wishes to thank NCEE's Cynthia Morgan and Jennifer Bowen and the Project Officer, Cheryl R. Brown, for their guidance and assistance throughout this project.

DISCLAIMER

U.S. Environmental Protection Agency
Socio-Economic Causes and Consequences of Future Environmental Changes Workshop

November 16, 2005
EPA Region 9
75 Hawthorne Street
1st Floor Conference Room
San Francisco, CA

8:45-9:15	**Registration**	
9:15 -9:30	**Introductory Remarks – Tom Huetteman, Deputy Assistant Regional Administrator, USEPA Pacific Southwest Region 9**	
9:30-11:30	**Session I:**	**Trends in Housing, Land Use, and Land Cover Change** Session Moderator: Jan Baxter, US EPA, Region 9, Senior Science Policy Advisor
	9:30 – 10:00	Determinants of Land Use Conversion on the Southern Cumberland Plateau **Robert Gottfried (presenter)**, Jonathan Evans, David Haskell, and Douglass Williams, University of the South
	10:00– 10:30	Integrating Economic and Physical Data to Forecast Land Use Change and Environmental Consequences for California's Coastal Watersheds Kathleen Lohse, David Newburn, and **Adina Merenlender (presenter)**, University of California at Berkeley
	10:30 – 10:45	**Break**
	10:45 – 11:00	Discussant: Steve Newbold, US EPA, National Center for Environmental Economics
	11:00 – 11:15	Discussant: Heidi Albers, Oregon State University
	11:15 – 11:30	Questions and Discussions
11:30 – 12:30	**Lunch**	
12:30 –2:30	**Session II:**	**The Economic and Demographic Drivers of Aquaculture and Greenhouse Gas Emissions Growth** Session Moderator: Bobbye Smith, U.S. EPA Region 9
	12:30 – 1:00	Future Growth of the U.S. Aquaculture Industry and Associated Environmental Quality Issues **Di Jin (presenter)**, Porter Hoagland, and Hauke Kite Powell, Woods Hole Oceanographic Institution

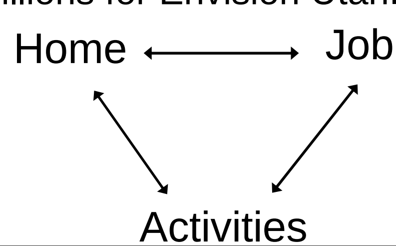
	1:00 – 1:30	Households, Consumption, and Energy Use: The Role of Demographic Change in Future U.S. Greenhouse Gas Emissions Brian O'Neill, Brown University, **Michael Dalton (presenter)**, California State University – Monterey Bay, John Pitkin, Alexia Prskawetz, Max Planck Institute for Demographic Research
	1:30 – 1:45	Discussant: Tim Eichenberg, The Ocean Conservancy
	1:45 – 2:00	Discussant: Charles Kolstad, University of California at Santa Barbara
	2:00 – 2:30	Questions and Discussion
2:30 – 2:45	**Break**	
2:45 - 4:55	**Session III:**	**New Research: Land Use, Transportation, and Air Quality** Session Moderator: Kathleen Dadey, US EPA, Region 9, Co-chair of the Regional Science Council
	2:45 - 3:10	Transforming Office Parks Into Transit Villages: Pleasanton's Hacienda Business Park **Steve Raney (presenter)**, Cities21
	3:10 – 3:35	Methodology for Assessing the Effects of Technological and Economic Changes on the Location, Timing and Ambient Air Quality Impacts of Power Sector Emissions Joseph Ellis and **Benjamin Hobbs (presenter)**, Johns Hopkins University, Dallas Burtaw and Karen Palmer, Resources for the Future
	3:35 - 4:00	Integrating Land Use, Transportation and Air Quality Modeling **Paul Waddell (presenter)**, University of Washington
	4:00- 4:25	Regional Development, Population Trend, and Technology Change Impacts on Future Air Pollution Emissions in the San Joaquin Valley Michael Kleeman, Deb Niemeier, **Susan Handy (presenter)**, Jay Lund, Song Bai, Sangho Choo, Julie Ogilvie, Shengyi Gao, University of California at Davis
	4:25 – 4:55	Questions and Discussion
4:55 – 5:00	**Wrap-Up and Closing Comments**	

Transforming Office Parks into Transit Villages: Vision

- Less auto-dominated suburbs
- Assumes global warming & peak oil are real
  - Least worst alternative
- Less than 50% of trips by solo driving
- Extreme sustainability, cut energy use
  - From 280 mBTU per HH per year to 97 mBTU
  - Smart Growth on steroids
    - Controversial
- Futuristic, complicated.

Disfunctional Human Settlement Patterns (Risse)

- Big required change: demand side. There's no quick transportation or energy supply fix.
  - Frustration: environment ⇔ smart growth links are weak
- For each person, minimize the distances in the triangle below. Miles ➔ feet
  - 50 DU/acre urbanist mixed use ➔ 50% of trips w/o car, mostly ped, not transit (GB Arrington, TCRP 102) – "walk to quart of milk"
- πr^2 :: pipes, wires, streets, distribution. Infrastructure cost savings in the billions for Envision Utah. (25% -TCRP74)



The Villain: Suburban Office Parks

- Main cause of sprawl & congestion for 30 years
  - Affordability decreasing, segregation increasing
  - 200 with ~ 30K workers ➔ 6M+ workers
- ULI's *Transforming Suburban Business Districts*
- Calthorpe "We didn't focus on office parks. Huge mistake. Need powerful strategies for these"
- Cervero: So bad they're easy to fix
- Shoup (*High Cost of Free Parking*) - Parking lots ➔ land bank. The new frontier: 5 spaces per car
- Duany: "Upper Rock" business park ➔ TOD
- Rail~Volution session: Tyson's ➔ edgy TOD
- 70% of tech workers want urban vitality.

steve_raney@cities21.org, slide 3

Villain 2: Housing Industry

- Problem: few innovative housing choices
- 1) Zimmerman / Volk. Home industry: "lumbering giants." No genuine innovations. No "meaningful improvement of the product offered to the consumer"
- 2) SG America: "Homes are like pork bellies, all the same, rather than as consumer products which vary greatly according to people's preferences." HPD #12i4
- New choice: vibrant, green suburban lifestyle: short commute apts and condos, mixed use, good schools.

(By John S. Pritchett www.pritchettcartoons.com)

steve_raney@cities21.org, slide 4

Transformational Tools

- Personal Rapid Transit (PRT)
  – Makes carpooling & transit more effective
- GPS cell phones to connect
- Safe Hitchhiking
- Better carpool "matchmaking"
- Small parking charges (automated)
- "Cool to be green" culture
- Parking lots ➔ housing with retail
  – "Walk to work" housing
  – Small parking charges
- Customer-centered design.

steve_raney@cities21.org, slide 5

PRT – Rapid Local Shuttle

- Feeder / Distributor / Circulator
  – Similar to a monorail. Video
- High service level, no waiting, faster than a car.
  – Non-stop, 30 MPH
  – Bypasses intermediate stations
  – Ride alone or with 1-2 people you choose
  – Convenient stops by buildings (not on street)
  – Comfortable, quiet, safe, no exhaust
  – 24x7.

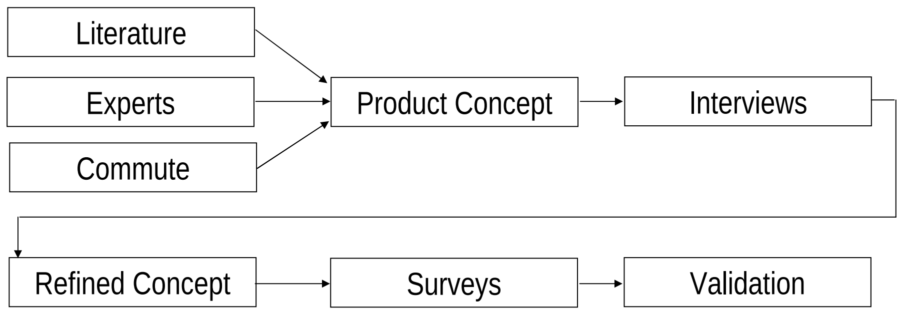
steve_raney@cities21.org, slide 6

5 PRT Development Efforts

- ULTra, Cardiff, Wales (1km track, 2 vehicles)
  - Won Heathrow System RFP
  - $10M investment by British Airport Authority
- Korean Posco for Uppsala, Sweden
  - Close clone of Skyweb design, more funding
- Korea Railroad Research Institute: $30M, 5 yr
- Skyweb Express / Taxi2000, MN
  - (60' track, 1 vehicle)
- Microrail, TX (60' track, 1 vehicle)
- Dubai procurement
  - no public review!.

steve_raney@cities21.org, slide 8

Customer-Centered Product Research



- Silicon Valley style
- New technology bias
  - High touch / community building is natural
  - Takes on personality of researching organization
- Start with rough business case in mind and refine.

steve_raney@cities21.org, slide 9

225 Surveys at Oracle

- Vulcan mind meld
- Teach suburban solo drivers about carpooling and transit (drawbacks)
- Customized for each commute
- + Low income worker interviews.

steve_raney@cities21.org, slide 10

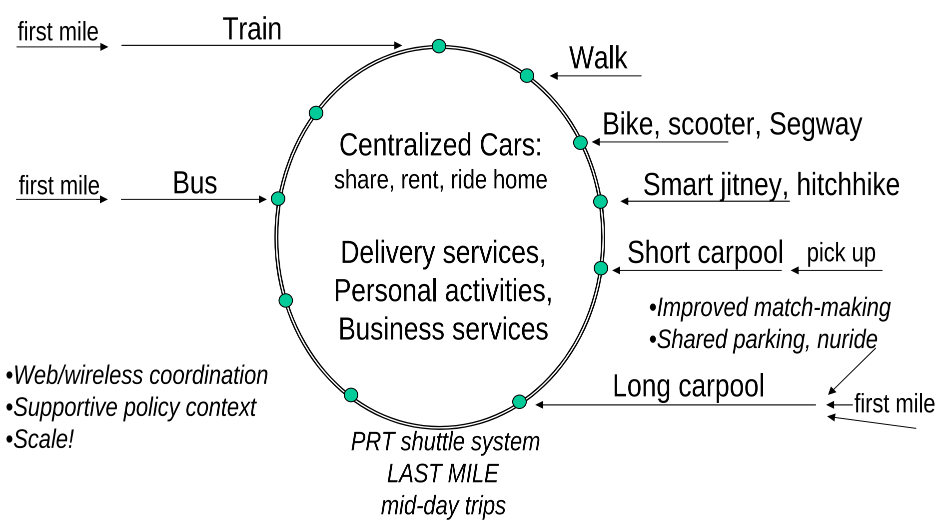
Promising Palo Alto Results

- Promising, but not definitive (62)
- Solo commutes: 89% ➔ 45%
  - Carpool: 9% ➔ 32%, train: 0% ➔ 15.5% train
  - For 20K people, removes 6,600 autos (roughly)
    - @ 350 s.f. per space ➔ 50 acres ➔ $326M hsng profit
- 1.32 PRT trips/day/person => 26K trips/day
  - PRT: profitable (capital, O&M)
- Huge transit village ➔ land value increase
- Apply to 6M workers in major emp. centers
  - 1.98M cars, 12B VMT, 424M gals, 8.4B lbs CO_2 .

steve_raney@cities21.org, slide 11

Comprehensive, Integrated Mobility

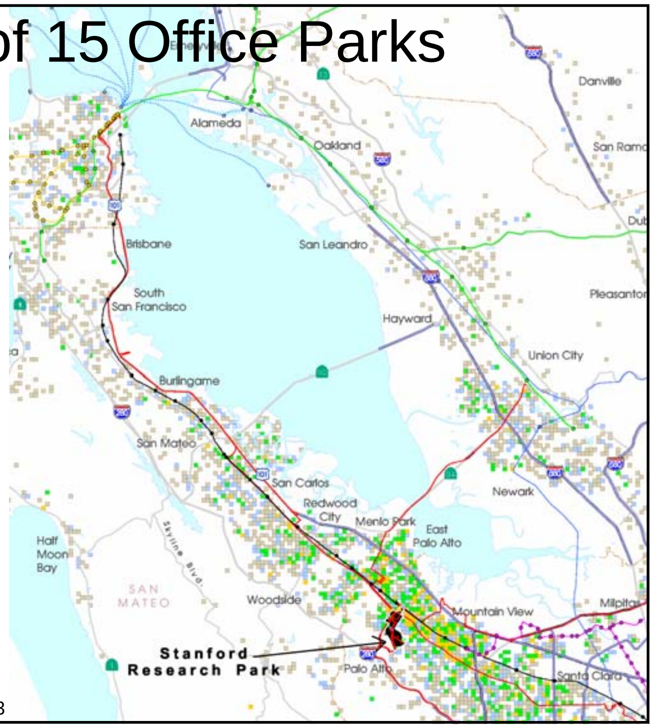
Door to Door



steve_raney@cities21.org, slide 12

GIS study of 15 Office Parks

- Census LEHD
- Commute Shed
- Aerial photography
- Demographics.



steve_raney@cities21.org, slide 13

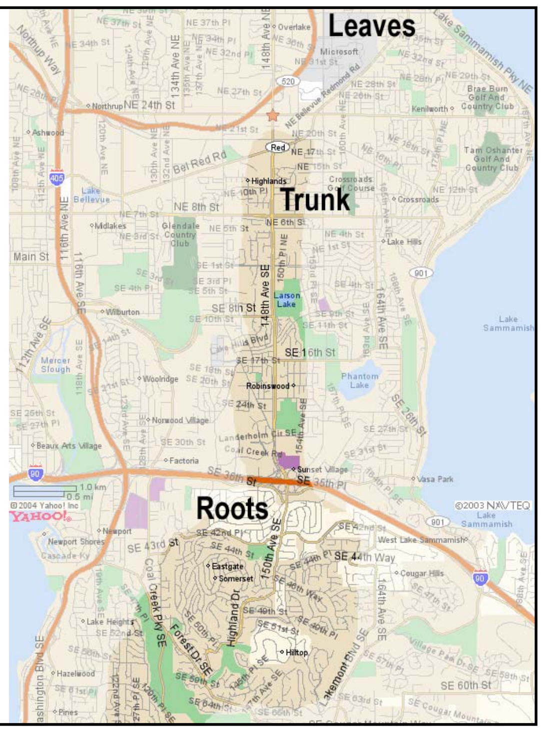
Company Town Housing

- Walk to work apts/condos for tech workers
- The most cost-effective suburban traffic reduction policy (ever). SF ←→ San Jose (swap)
- Priority access to housing for short commuters
- $100 monthly price incentives for good commutes
- Bad location decision creates "negative economic externality" for society. So, "internalize" the cost
- ? Improve tech worker quality of life and leave low income folks farther behind ?
- Low income upward mobility
  - {package deal: job, home, job training, better schools for kids, more family time.} Boost up the ladder.

steve_raney@cities21.org, slide 15

Digital Hitchhiking

- Exploit GIS patterns
- Bus + safe hitchhiking.



steve_raney@cities21.org, slide 16

Toolkit

- "Cool to be green" culture
  - All residents sign a green pledge to get housing
    - Force a tipping point
  - Supporting culture like EBay on-line community
- Grocery shopping without a trunk.

17

THE END

steve_raney@cities21.org, slide 18

Assessing the Effects of Technological & Economic Changes on the Location, Timing, and Ambient Air Quality Impacts of Power Sector Emissions

Investigators

Hugh Ellis (PI), Ben Hobbs

The Johns Hopkins University

Dallas Burtraw, Karen Palmer

Resources for the Future

This research is funded by
U.S. EPA - Science To Achieve Results (STAR) Program
Grant # R831836

PURPOSE

Develop methodology for:

- **creating geographically and temporally disaggregated emissions scenarios**
- **for the electric power sector**
- **on a multidecadal time-scale**

WHY POWER?

- **Source of a large share of SOx, NOx, mercury and CO2 emissions**
  - **Future shares are highly uncertain**
  - **Technology change, fuel mix, electric load growth, regulation**
- **Alternative scenarios affect total emissions and their spatial and temporal distribution**
- **Emissions & air quality impacts sensitive to the growth and distribution of electricity demands**
  - **Geographically and temporally**
  - **Linked to temperature and other climate variables that may change significantly**

Needed: Theoretically defensible, transparent and practical method for temporal and spatial emissions scenarios

- A sequence of models representing market-driven electricity supply and facility location constrained by land use and policy-based emissions limits
- HAIKU model (RFF) will:
  - Set regional boundary conditions for regional technology, demand, and emissions totals
  - Disaggregate national totals (e.g., IPCC scenarios) to regions
- Finer-scaled regional models then will:
  - Allocates specific generation facilities to a national grid (e.g., 132 columns x 90 rows of 36x36 km cells)
  - Estimate hourly emissions
  - Uses HAIKU totals as boundary conditions

- Must test the robustness of emissions disaggregations to assumptions concerning:
  - demand growth
  - technological change
  - policy (e.g., emissions caps, time of day electricity pricing)
- We will explore the sensitivity of both emissions *and* ambient air quality to these uncertain drivers
  - Tropospheric ozone and particulates for an example set of scenarios will be simulated using MM5/MCIP/SMOKE/CMAQ
- Goal: demonstrate the practicality of integrating the source disaggregation methodology with the SMOKE emissions processing system and subsequently CMAQ

Research Approach Summary

Regional-scale Technology and Emissions (Burtraw and Palmer, RFF)

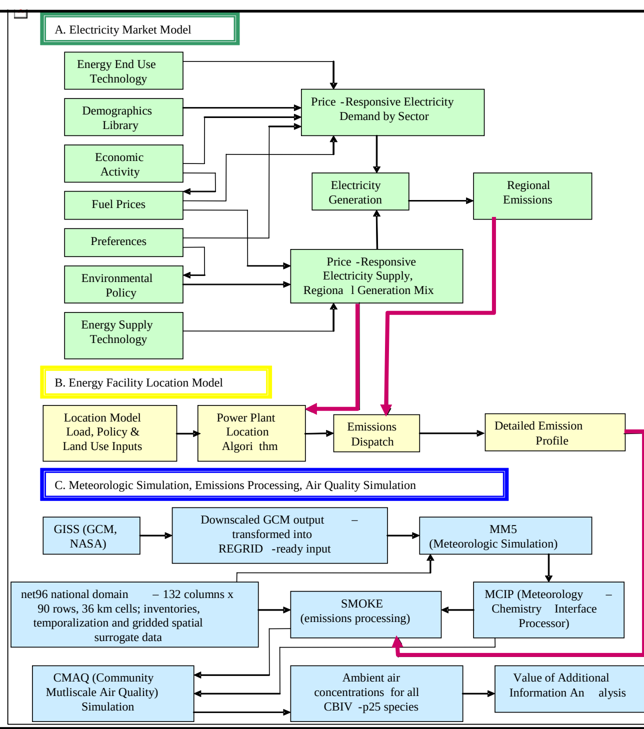
- Electricity supply
- Electricity demand
- Value of information in model development

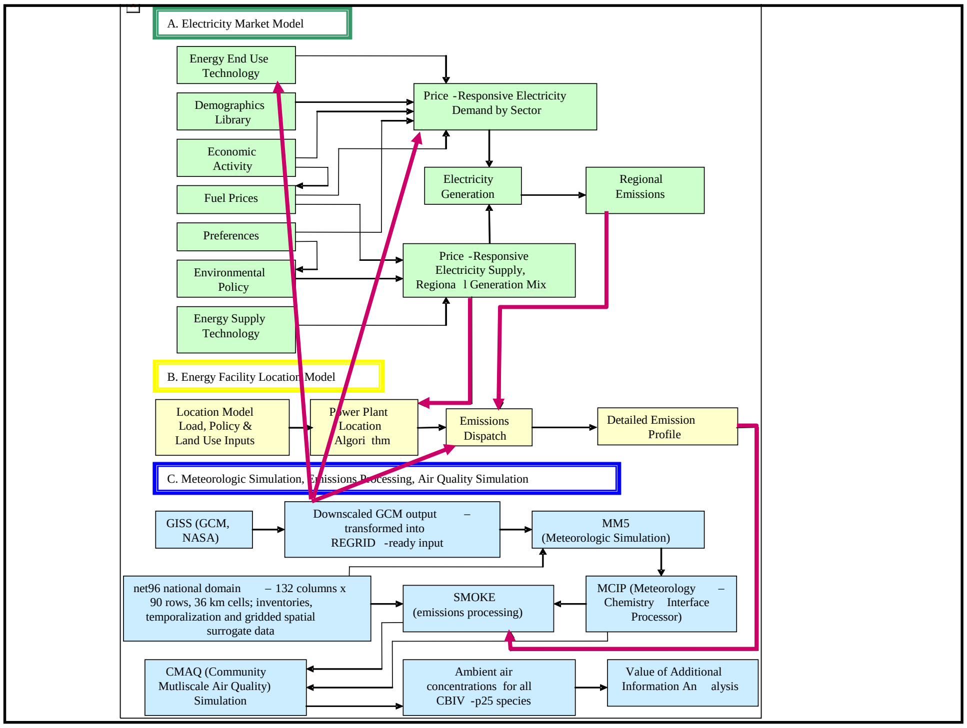
Emissions Downscaling: Load Disaggregation, Facility Siting and Generation Dispatch (Burtraw, Palmer – RFF; Hobbs, Ellis - JHU)

- Geographically disaggregate power use
- Geographically, temporally disaggregate emissions

Fine-Scale Emissions Processing and Ambient Air Quality Simulation (Ellis, JHU)

- Meteorologic simulation (MM5), transformation using MCIP, import downscaled emissions into SMOKE V2.2, air quality simulation using CMAQ
- In some cases, MM5 will be driven by the GISS GCM





Emission Processing in SMOKE

- Many inventory emissions are annual averages (e.g., tons/year)
- Hourly emissions created using temporal profiles
- Source-specific hourly emissions (e.g., generated through our downscaling) are integrated into the master inventory
- Other emissions can be left intact or modified through manually applied growth / reduction factors (by SCC)

Objective of the RFF Electricity Market Model (HAIKU)

To simulate outcomes of a electricity markets

- **Recognizing institutions for electricity and environmental regulation**
- **Using maximization of economic welfare (profits plus consumer surplus) subject to characterizations of demand, technology and institutions.**

➢ ***Choice variables:***

- **capacity investment**
- **retirement**
- **generation choices.**

Vintage Classico RFF Electricity Market Model

- ***Spatial disaggregation:***
  - **13 NERC subregions with inter-regional trade**
  - **~48 model plants in each region**
  - **Emission compliance (SO_2, NO_X, Hg, CO_2)**
- ***Temporal disaggregation:***
  - **3 seasons x 4 time blocks**
  - **Seasonal capacity and fuel costs**
- ***Price Responsive Demand*****:**
  - **3 customer classes**
  - **EIA demand forecast with elasticities**
- ***Technology & fuel characteristics and costs:***
  - **Data from EIA, EPA and industry sources**

Illustration of Demand, Supply Equilibrium and How Pricing Institutions Matter to Resource Use (Example: ERCOT Summer Baseload)

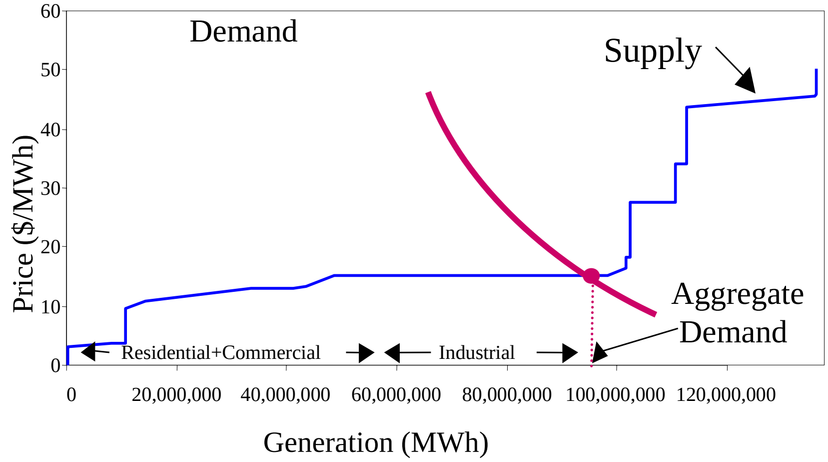


Illustration of Demand, Supply Equilibrium and How Pricing Institutions Matter to Resource Use (Example: ERCOT Summer Baseload)

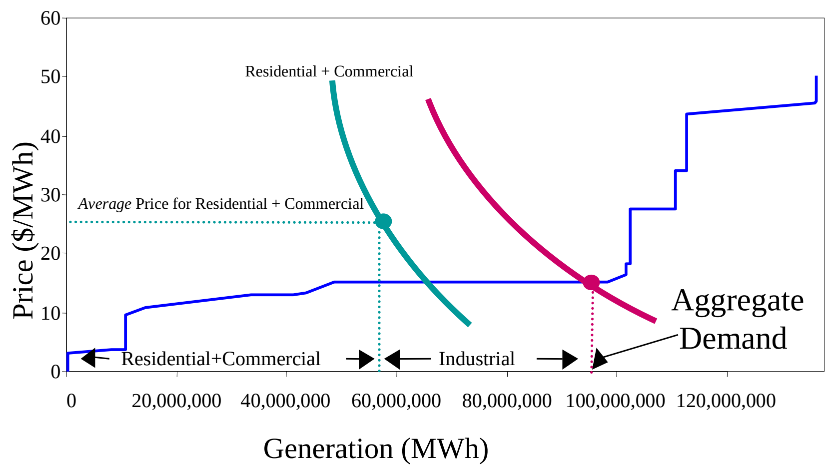


Illustration of Demand, Supply Equilibrium and How Pricing Institutions Matter to Resource Use (Example: ERCOT Summer Baseload)

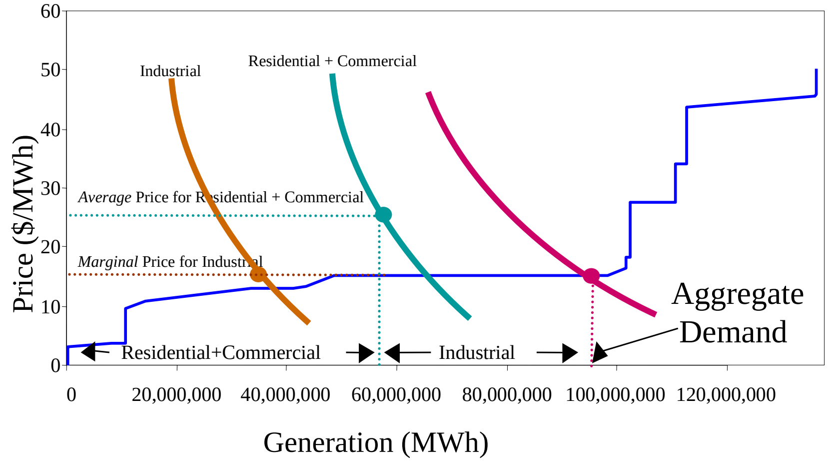
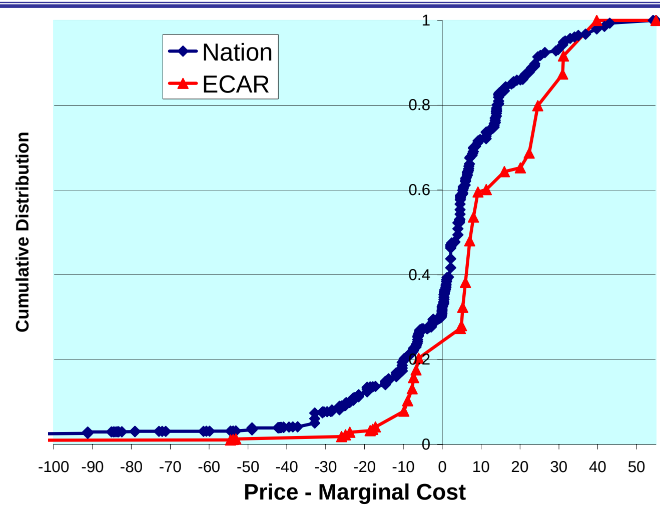


Illustration: How Institutions Set Prices Is Important



- A model based on marginal cost pricing would misestimate electricity demand and generation by specific technologies and times of day

Intermediate Projections: *Using the Model to 2025*

- ***Environmental policies, e.g.:***
  - Caps? Allowances allocation?
  - NSR: Announced settlements only?
  - Renewable incentives, state-level multi-pollutant and RPS?
- ***Industry restructuring, e.g.:***
  - 5 regions (NY, NE, MAAC, MAIN, ERCOT) with competitive prices?
  - Time of day pricing for industrial customers only?
  - Rate of transmission growth?

The Challenge: Long Term Projections *Using the Model to 2050*

- ***Environmental policy & institutions***
  - Aggregate caps for air pollutants / policy design
  - Regulation and institutions for setting electricity prices
- ***Demand modeling***
  - Demographic, technology forecasts for demand scaling
  - System of demand integrated over time blocks
- ***Technology paths for supply -- scenarios***
  - New nuclear, relicensing
  - Clean coal, carbon capture and storage
  - LNG, FACTS
  - Distributed generation
  - Advanced post combustion controls
  - Renewable penetration / efficiency improvements
  - Exogenous, endogenous technological change

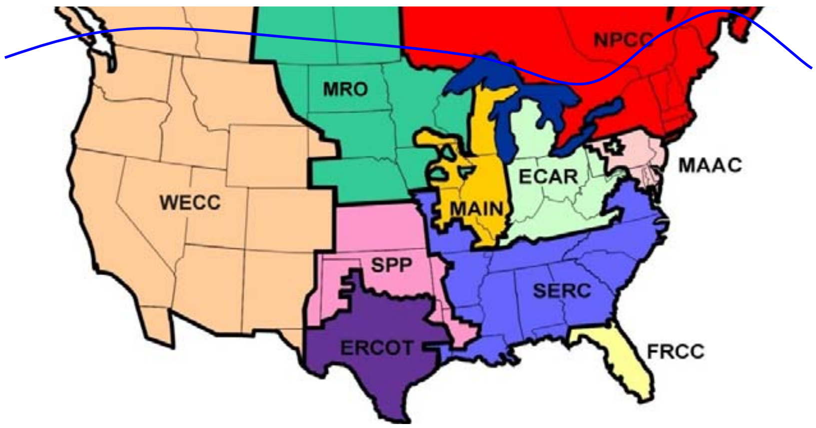
Recent Applications of the HAIKU Model

- "Cost-Effectiveness of Renewable Electricity Policies," (Palmer and Burtraw) 2006. *Energy Economics,* forthcoming.
- *Reducing Emissions from the Electricity Sector: The Costs and Benefits Nationwide and in the Empire State,* (Palmer, Burtraw and Shih) 2005. New York State Energy Research and Development Authority, Report 05-02.
- "Efficient Emission Fees in the U.S. Electricity Sector," (Banzhaf, Burtraw and Palmer) 2004. *Resource and Energy Economics* 26(3): 317-341.
- "Uncertainty and the Net Benefits of NOX Emissions Reductions from Electricity Generation," (Burtraw, Bharvirkar and McGuinness) 2003. *Land Economics*79(3): 382-401.
- "Ancillary Benefits of Reduced Air Pollution in the United States from Moderate Greenhouse Gas Mitigation Policies in the Electricity Sector," (Burtraw, Krupnick, Palmer, Paul, Toman and Bloyd) 2003. *Journal of Environmental Economics and Management* 45(3): 650-673.
- *Economic Efficiency and Distributional Consequences of Different Approaches to NOx and SO2 Allowance Allocation,* Burtraw and Palmer, Oct. 2003. Report to U.S. EPA.
- "The Effect on Asset Values of the Allocation of Carbon Dioxide Emission Allowances," (with Karen Palmer, Anthony Paul and Ranjit Bharvirkar) 2002. *The Electricity Journal* 15 (5): 51-62.

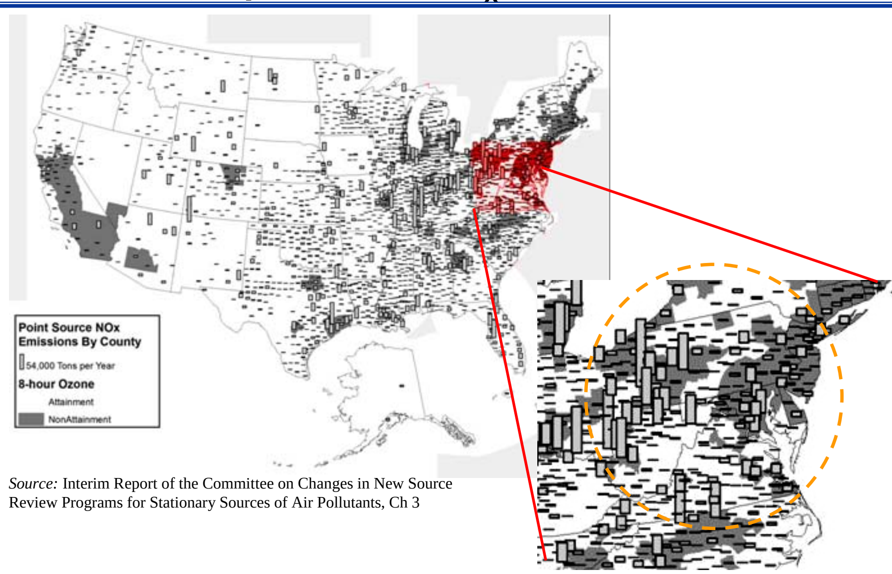
The Downscaling Problem

- **National electric sector models are aggregate in space and time. *RFF model:***
  - **13 NERC subregions**
  - **12 time blocks per year**
  - **Based on average seasonal climate conditions**
- ***The challenges:***
  - **CMAQ requires hourly emissions by point source**
  - **CMAQ results sensitive to interactions of location, meteorology and timing**
  - **There is significant interannual variation in climate and, thus, emissions and their impacts**

Spatial Aggregation
Model Output: By NERC Subregions

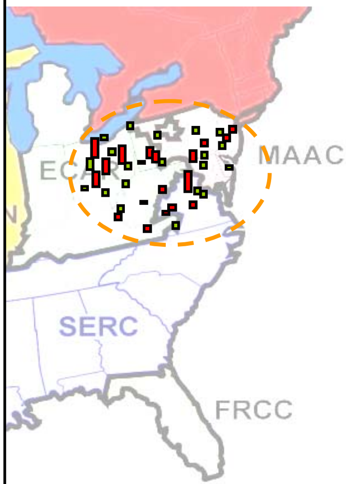


Required Spatial Resolution
CMAQ Input: Point NO_x Emission Sources



Source: Interim Report of the Committee on Changes in New Source Review Programs for Stationary Sources of Air Pollutants, Ch 3

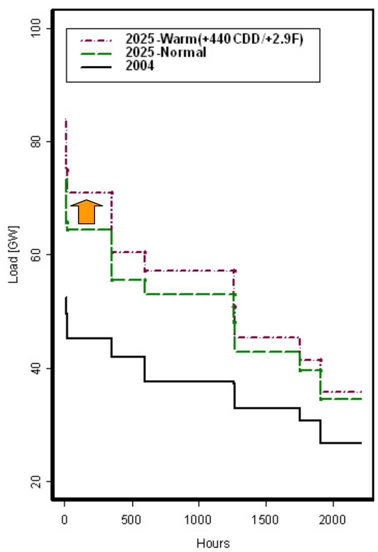
Spatial Disaggregation: Approach



- ***Competitive market simulation model (linear program)***
  - **Choose facility locations (e.g., by county), operation levels (by hour), and emissions**
  - **Subject to boundary conditions from RFF (regional generation mix, emissions by period)**
  - **Consider feasible siting locations, transmission grid**
- ***Similar method used by USDOE for emissions scenarios***
  - **E.g., 1978 National Coal Utilization Assessment**

Temporal Aggregation: Example from National Energy Modeling System

NEMS (National Energy Modeling System) Load



"Load Duration Curve" showing summer distribution of PJM electricity demands for three cases:

- NEMS 2004
- NEMS 2025 (normal climate)
- NEMS 2025 (warmer climate)

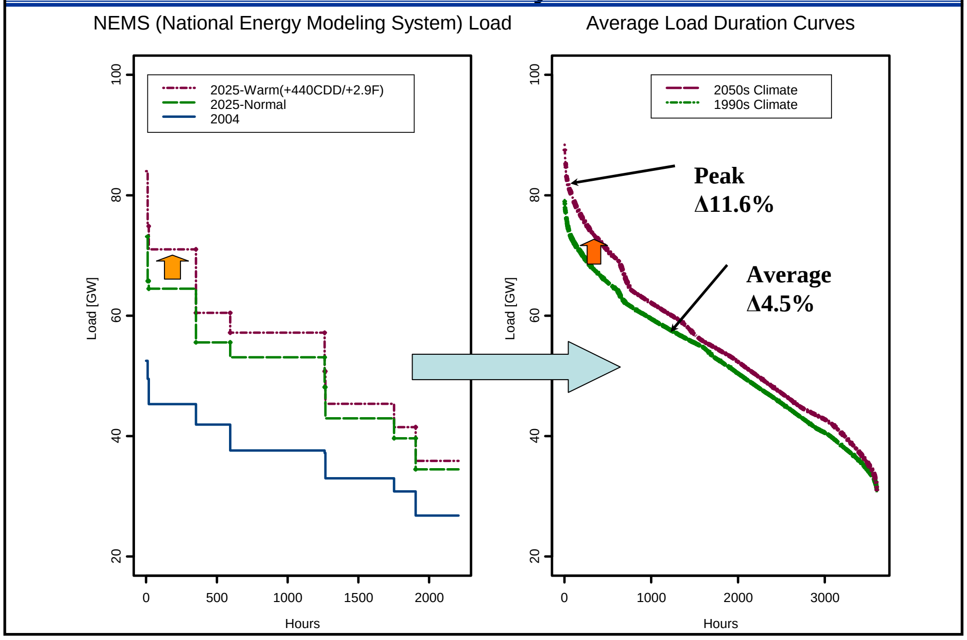
Warmer climate has largest effect during peak hours

- More likely to be coincident with ozone episodes

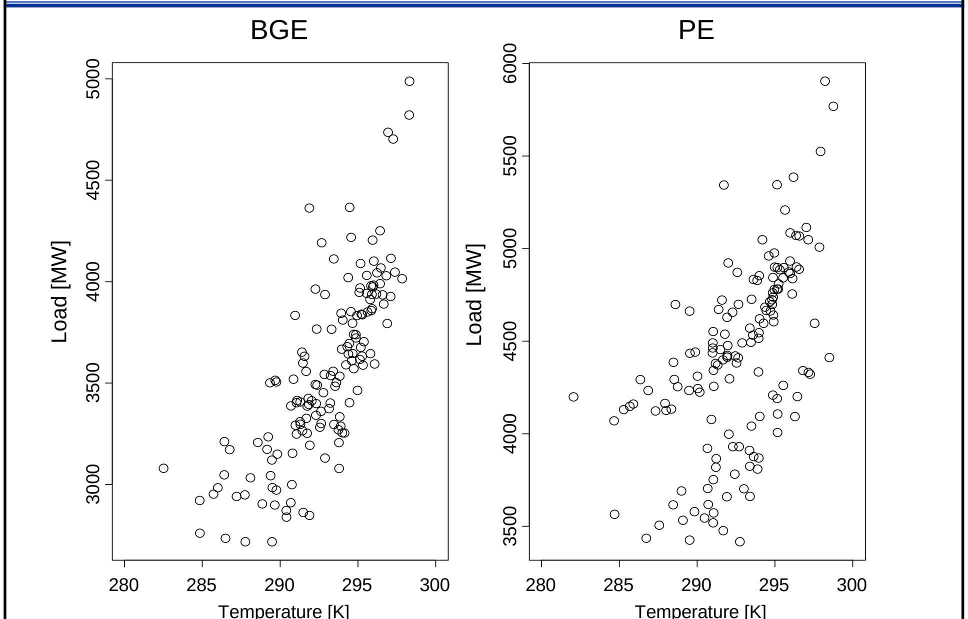
Represents average year

- But there is actually high year-to-year variability in peak demands due to weather
- PJM: σ = 5% of peak
- Ozone formation nonlinear $\Rightarrow$ *ozone during average year $\neq$ average ozone under annual variability*

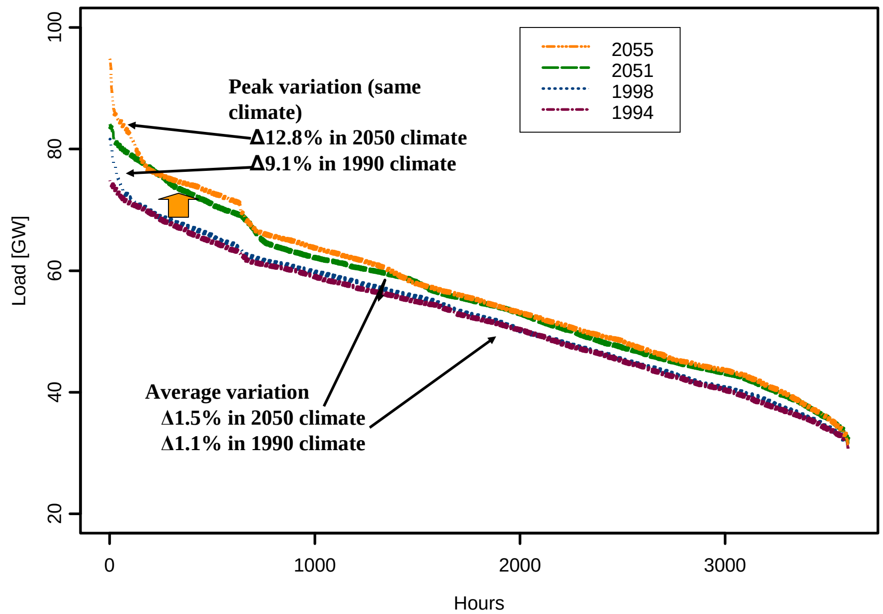
Required Temporal Disaggregation: Blocks to Hourly Demand



Required Temporal Disaggregation: Must Account for Weather-Load Relationships



Required Temporal Disaggregation: Interannual Variability

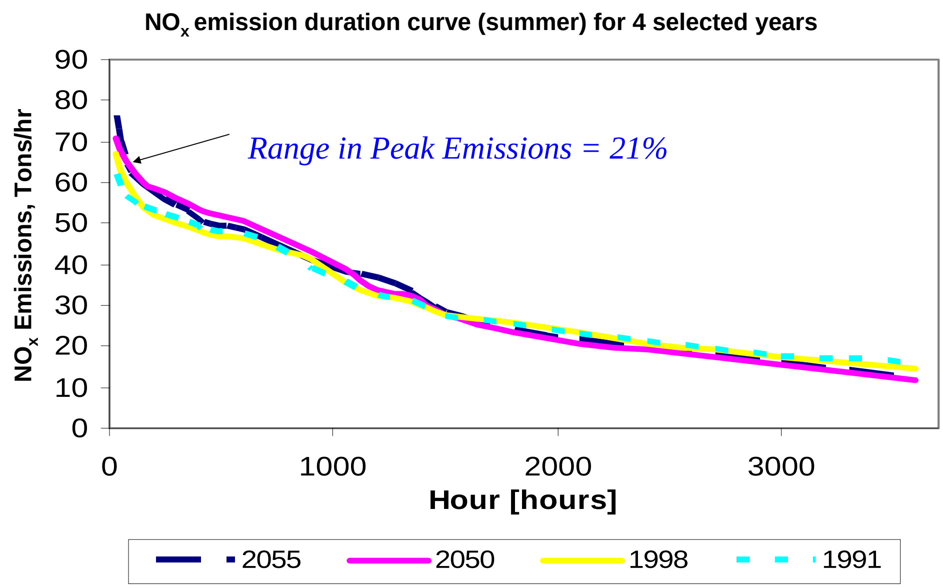


Temporal Disaggregation: Approach

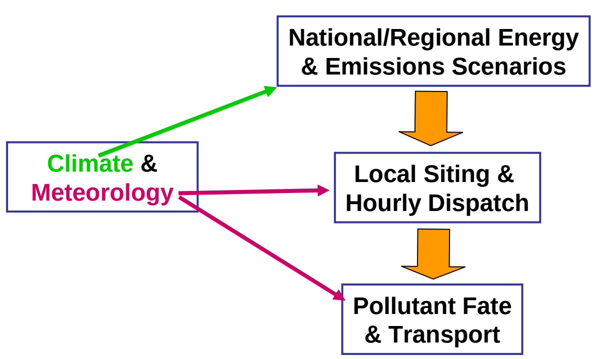
- ***Inputs:***
  - Average loads for 12 time periods under average climate (from RFF model)
  - Multiple years of simulated temperature data (from MM5)
  - Short-run (hourly) model that projects short run (given fixed appliance/housing stock) load response to temperature changes

- ***Procedure:***
  - Project hourly normalized load response to simulated temperature data
  - Transparent rescaling procedure converts normalized loads to hourly loads whose multiyear averages are consistent with RFF time-averaged loads
  - Resulting rescaled loads vary from year-to-year based on temperature

Temporal Disaggregation:
Higher interannual variation in NO_x during peak hours



Summary



Integrating Land Use, Transportation and
Air Quality Modeling

Socio-Economic Causes and Consequences of
Future Environmental Changes Workshop

November 16, 2005

Paul Waddell
206-221-4161
pwaddell@u.washington.edu

Center for Urban Simulation and Policy Analysis
Evans School of Public Affairs
University of Washington
http://www.urbansim.org

Agenda

- Research Agenda
- EPA STAR Project
- UrbanSim
- A Brief Example

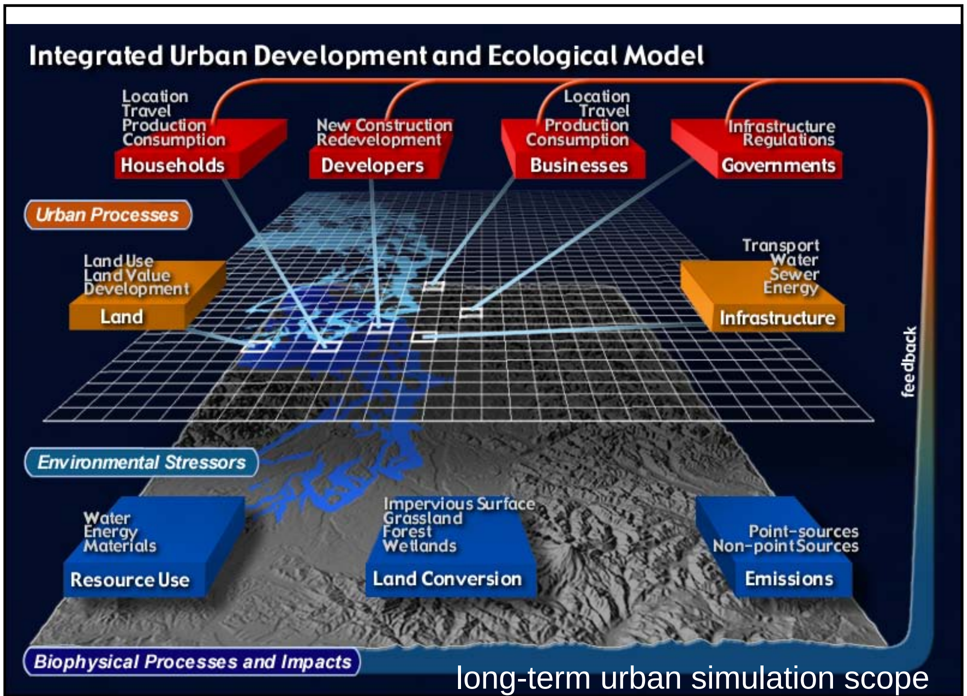
Center for Urban Simulation and Policy Analysis University of Washington

Core Faculty

- Paul Waddell, Director, Public Affairs, Planning
- Alan Borning, Co-Director, Computer Science and Eng.
- Marina Alberti, Urban Design and Planning
- Batya Friedman, Information School
- Mark Handcock, Statistics
- Scott Rutherford, Civil and Environmental Engineering

Current (Active) Research Projects

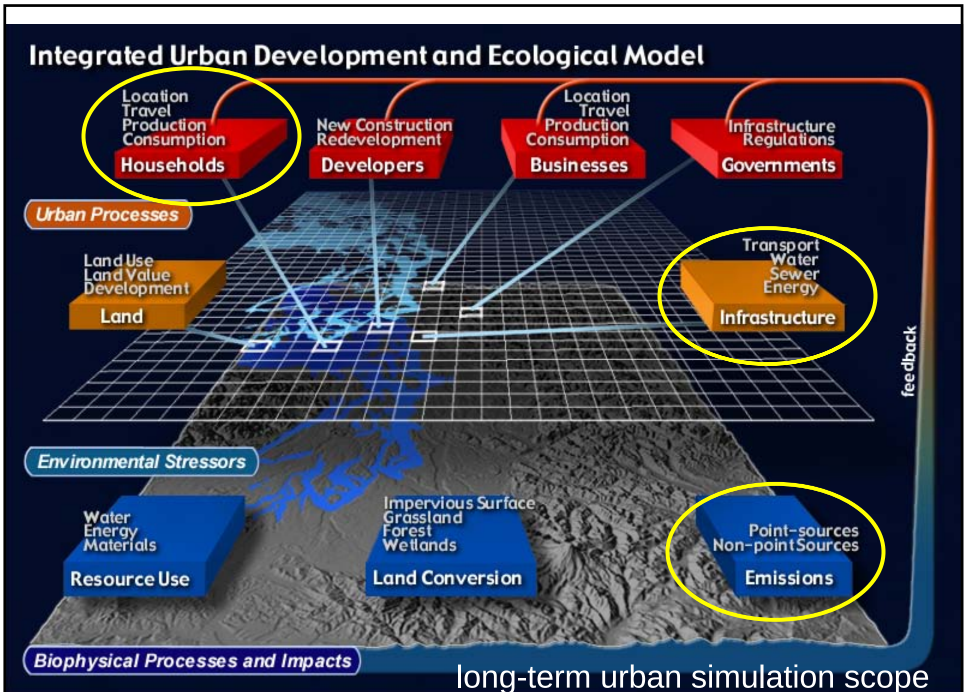
- Integrating Land Use, Activity-Based Travel and Air Quality Models (EPA)
- Integrating Urban Development, Land Cover Change, and Urban Ecology (NSF Biocomplexity)
- Measuring and Representing Uncertainty in Policy Modeling (NSF Digital Government)
- Analyzing Distributional Effects of Policies (FHWA Eisenhower Fellowship)
- Modeling and Measuring Walking and Transit Accessibility (FHWA Eisenhower Fellowship)
- A Stakeholder Interface for Urban Simulation Models (NSF ITR)
- Open Platform for Urban Simulation (NSF ITR)
- Application of UrbanSim to the Puget Sound Region (Puget Sound Regional Council)



EPA STAR Project Objectives

- From the RFA:

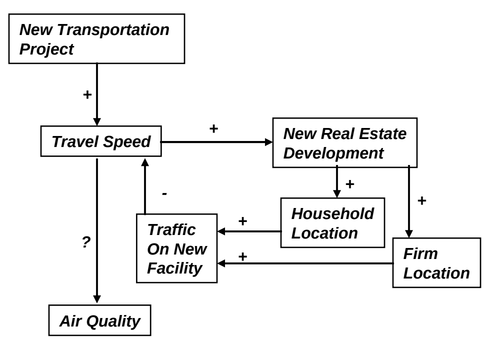
  "**How might models that project changes in land-use and activity locations be improved to better reflect and integrate lifestyle, economic production, and public policy factors that drive vehicle miles traveled?** How might spatial redistribution of activities and changes in land-use influence investments in transportation infrastructure and technology? Conversely, how might investment choices in transportation infrastructure and technology influence changes in spatial distribution of activities and land-use change?"



Long-term Induced Demand

Analysis of Project Effects on Air Quality

Considering Land Use Feedback



Behavioral and Operational Components

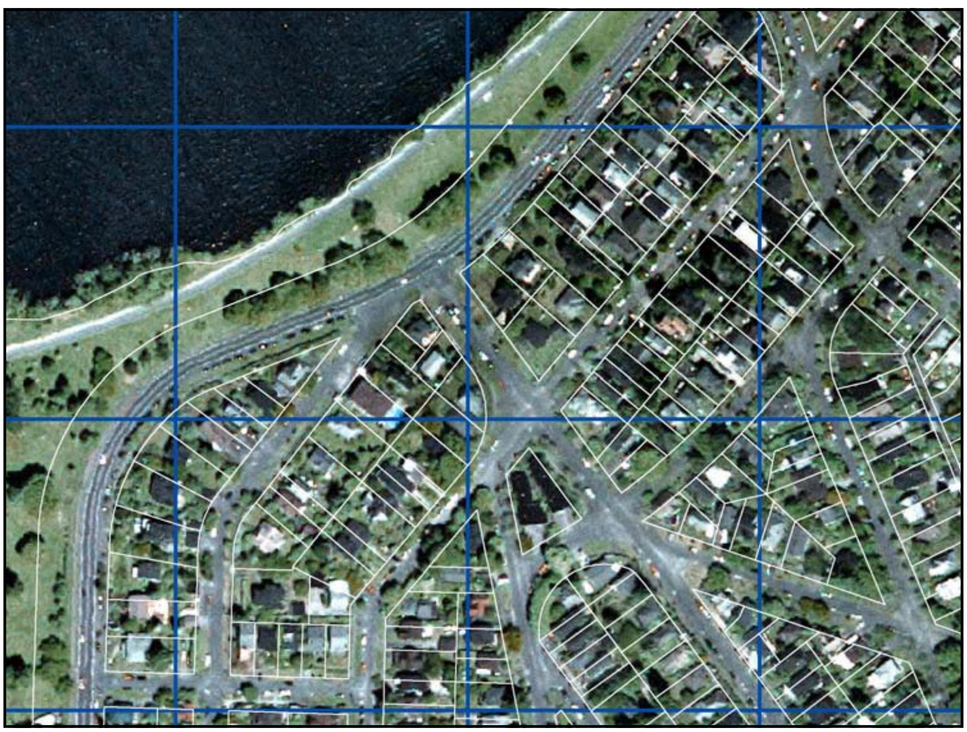
- Behavioral
  - Latent lifestyle choices
  - Substitution across long and short-term choices
  - Endogeneity and self-selection issues
  - Econometric estimation methods
- Operational
  - Integration of activity-based models with urban simulation models of land use
  - Integration with traffic assignment models
  - Integration with current and emerging emissions models
  - Testing of integrated platform on alternative scenarios

Key Operational Components

- UrbanSim/OPUS – urban simulation
- PCATS/DEBNetS – activity-based travel
- EPA Moves – emmissions

UrbanSim

- Microsimulation model of household location, job location, real estate development and prices
- Open Source software available on the web
- Individual households and jobs represented
- Simulates annual steps, with path dependence
- Land and real estate represented by small grid cells (150 m x 150 m), or potentially parcels
- Interfaces currently with 4-step travel models
  - Uses a range of zonal-based accessibility measures
  - Loose coupling
- Applied in multiple metropolitan areas in the US and abroad
- Funding: NSF Information Technology Research, Digital Government, Biocomplexity, Urban Research Initiative



Residential Location Variables

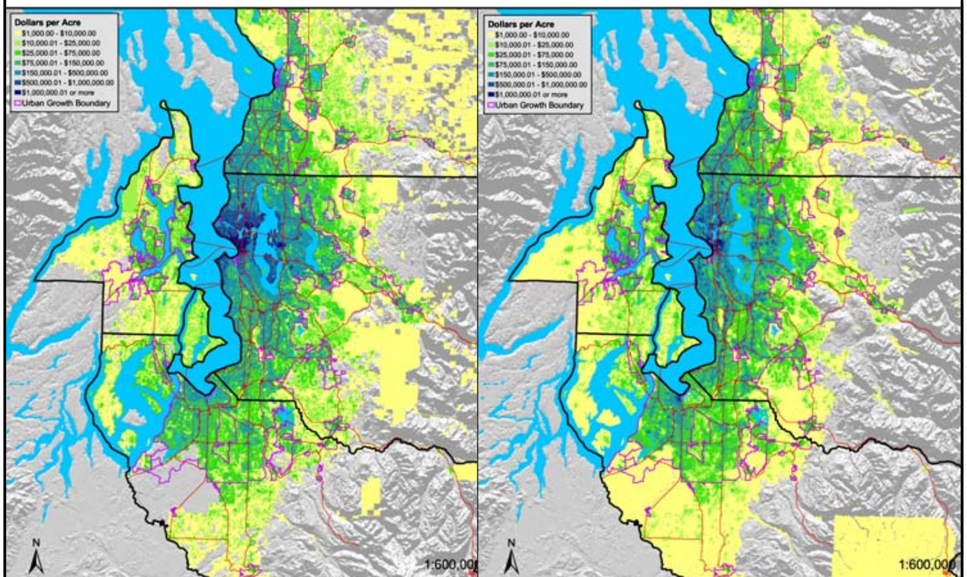
- Housing Characteristics
  - Prices (interacted with income)
  - Development types (density, land use mix)
  - Housing age
- Regional accessibility
  - Job accessibility by auto-ownership group
  - Travel time to CBD and airport
- Urban design-scale (local accessibility)
  - Neighborhood land use mix and density
  - Neighborhood employment
  - Compensates for large traffic zones in Travel Model

Land Price Variables

- Site characteristics
  - Development type
  - Land use plan
  - Environmental constraints
- Regional accessibility
  - Access to population and employment
- Urban design-scale
  - Land use mix and density
  - Proximity to highways and arterials

PSRC Region
2000 Total Land Value per Acre by Gridcell

PSRC Region
Predicted 2000 Total Land Value per Acre by Gridcell



Historical Validation from 1980 – 1994:

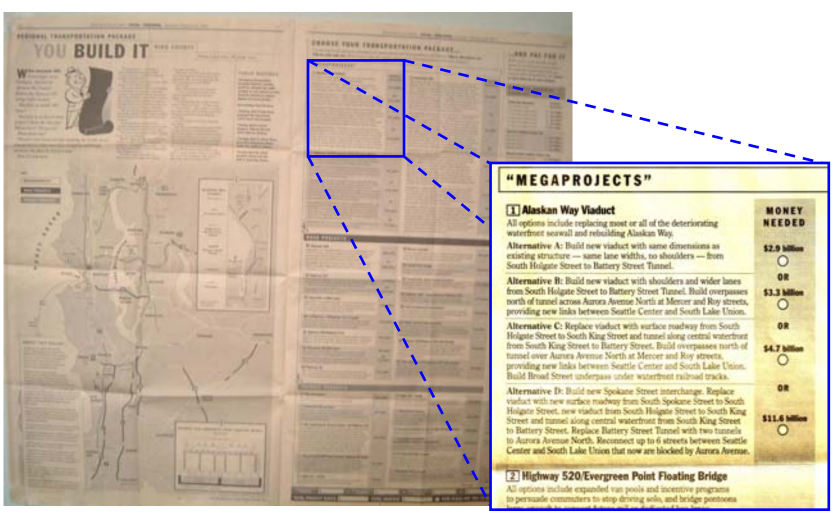
Correlation of Simulated vs Observed 1994
Eugene-Springfield, Oregon

	Cell	Zone	1-Cell Radius
Employment	0.805	0.865	0.917
Population	0.811	0.929	0.919
Nonresidential Sq ft	0.799	0.916	0.927
Housing Units	0.828	0.927	0.918
Land Value	0.830	0.925	0.908

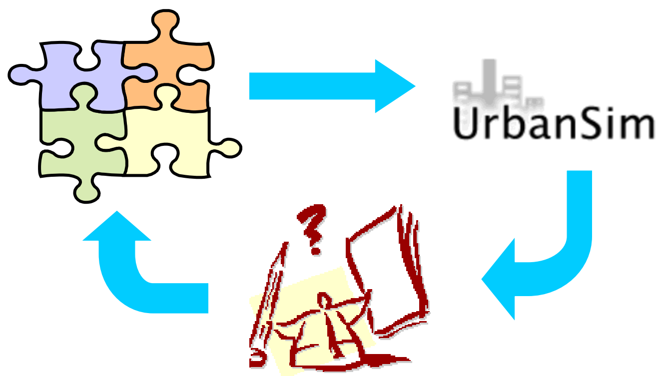
Creating Policy Scenarios

- Macroeconomic Assumptions
  - Household and employment control totals
- Development constraints
  - Can select any combination of
    - Political and planning overlays
    - Environmental overlays
    - Land use plan designation
  - Constraints determine which development types cannot be built
- Transportation infrastructure
- User-specified events

You Build It
(Seattle Times, March 20 2003)

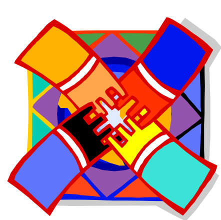


You Build It (UrbanSim)



Goals, Objectives, Indicators

- Help stakeholders to…
  - Evaluate scenarios in a way that relates to their values and concerns
  - Identify areas of consensus, conflict, and potential compromise



A Case Study:
Wasatch Front Region,
Utah

A Case Study:
Wasatch Front Region

- Existing Transportation System
  - Dominated by the automobile (~90% of all trips by auto)
  - 2 highly successful light rail lines
- Existing Land-usage
  - Low density
  - Subdivisions, retail centers and office parks
- Population:
  - 1.6 million in 2000
  - ~3.0 million by 2030
- Envision Utah
  - Highly successful visioning process
  - Intensive public outreach/involvement
  - However, the process mixed outcomes and regional goals

Current Modeling Practice at WFRC

- Federally mandated process
- Transportation Analyses:
  - Long-range plans (>20 years)
  - Short-range plans (3-5 years)
  - Corridor studies
- Accepted practice transportation models
- Land-use forecast is independent of planned transportation system

Environmental Concerns

- Inadequate modeling:
  - Treatment of land-use (secondary impacts)
  - Modeling of non-automobile travel
  - Over-exaggerating congestion in “no-build” or transit alternatives
- Inadequate planning:
  - Resource usage
  - Environmental quality
  - Sustainability
- General Skepticism

Lawsuits

- Legacy Highway
  - North of Salt Lake City
  - Wetlands (adjacent to The Salt Lake)
  - Construction halted by court (Clean Water Act violations)
- Long range plan analysis
  - Technical analysis challenged
  - Lawsuit settled: Test UrbanSim for suitability for use, with peer review by 12/31/03

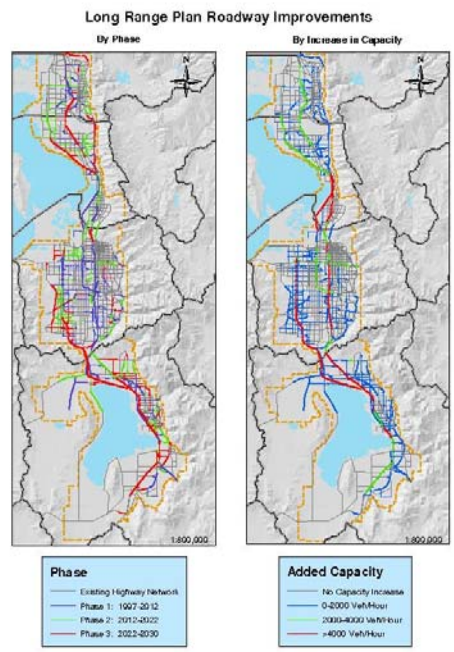
Legacy Highway

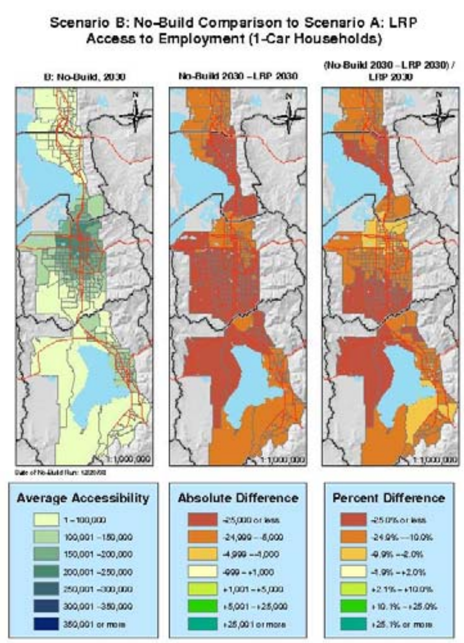
WFRC Goals (short to long-term)

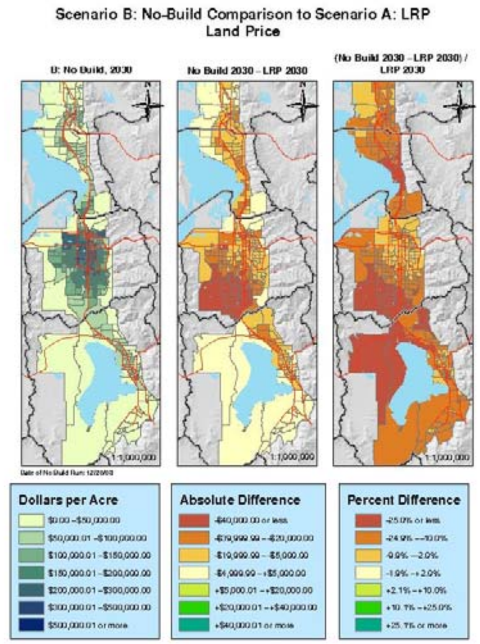
- Successful implementation & evaluation of land use model (UrbanSim)
- Incorporate into MPO modeling work
- Develop advanced-practice transportation models
- Use in a visioning process – evaluate scenarios in terms of regional goals

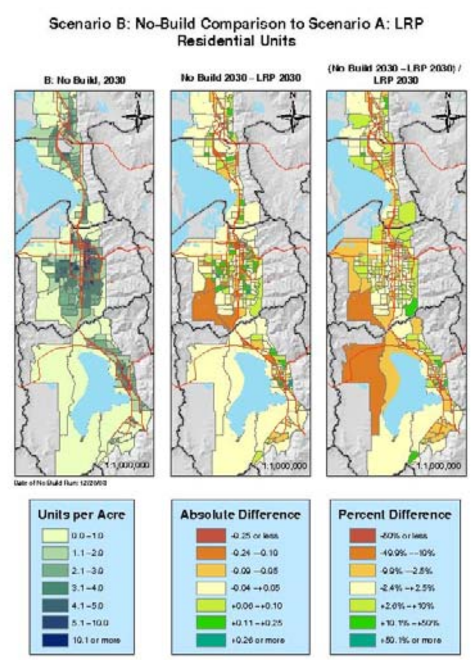
Sensitivity Testing of Integrated Land Use and Transportation Models

- Tested several scenarios:
  - Long Range Plan (Baseline)
  - No-build
  - Drop a highway project
  - Drop a light rail project
  - Add parking pricing
  - Impose Urban Growth Boundary


Long Range Plan Roadway Improvements
By Phase
By Increase in Capacity
1:800,000
1:800,000
Phase
Existing Highway Network
Phase 1: 1997-2012
Phase 2: 2012-2022
Phase 3: 2022-2030
Added Capacity
No Capacity Increase
0-2000 Veh/Hour
2000-4000 Veh/Hour
>4000 Veh/Hour


Scenario B: No-Build Comparison to Scenario A: LRP
Access to Employment (1-Car Households)
B: No-Build, 2030
No-Build 2030 – LRP 2030
(No-Build 2030 – LRP 2030) / LRP 2030
1:1,000,000
1:1,000,000
1:1,000,000
Average Accessibility
1 – 100,000
100,001 – 150,000
150,001 – 200,000
200,001 – 250,000
250,001 – 300,000
300,001 – 350,000
350,001 or more
Absolute Difference
-25,000 or less
-24,999 – -5,000
-4,999 – -1,000
-999 – +1,000
+1,001 – +5,000
+5,001 – +25,000
+25,001 or more
Percent Difference
-25.0% or less
-24.9% – -10.0%
-9.9% – -2.0%
-1.9% – +2.0%
+2.1% – +10.0%
+10.1% – +25.0%
+25.1% or more


Scenario B: No-Build Comparison to Scenario A: LRP
Land Price
B: No Build, 2030
No Build 2030 – LRP 2030
(No Build 2030 – LRP 2030) / LRP 2030
1:1,000,000
Dollars per Acre
$0.00 – $50,000.00
$50,000.01 – $100,000.00
$100,000.01 – $150,000.00
$150,000.01 – $200,000.00
$200,000.01 – $300,000.00
$300,000.01 – $500,000.00
$500,000.01 or more
Absolute Difference
-$40,000.00 or less
-$39,999.99 – -$20,000.00
-$19,999.99 – -$5,000.00
-$4,999.99 – +$5,000.00
+$5,000.01 – +$20,000.00
+$20,000.01 – +$40,000.00
+$40,000.01 or more
Percent Difference
-25.0% or less
-24.9% – -10.0%
-9.9% – -2.0%
-1.9% – +2.0%
+2.1% – +10.0%
+10.1% – +25.0%
+25.1% or more


Scenario B: No-Build Comparison to Scenario A: LRP
Residential Units
B: No Build, 2030
No Build 2030 – LRP 2030
(No Build 2030 – LRP 2030) / LRP 2030
1:1,000,000
Units per Acre
0.0 – 1.0
1.1 – 2.0
2.1 – 3.0
3.1 – 4.0
4.1 – 5.0
5.1 – 10.0
10.1 or more
Absolute Difference
-0.25 or less
-0.24 – -0.10
-0.09 – -0.05
-0.04 – +0.05
+0.06 – +0.10
+0.11 – +0.25
+0.26 or more
Percent Difference
-50% or less
-49.9% – -10%
-9.9% – -2.5%
-2.4% – +2.5%
+2.6% – +10%
+10.1% – +50%
+50.1% or more

Regional Development, Population Trend, and Technology Change Impacts on Future Air Pollution Emissions in the San Joaquin Valley

Michael Kleeman
Deb Niemeier
Susan Handy
Jay Lund
With Song Bai, Sangho Choo, Shengyi Gao, and Julie Ogilvie
University of California Davis

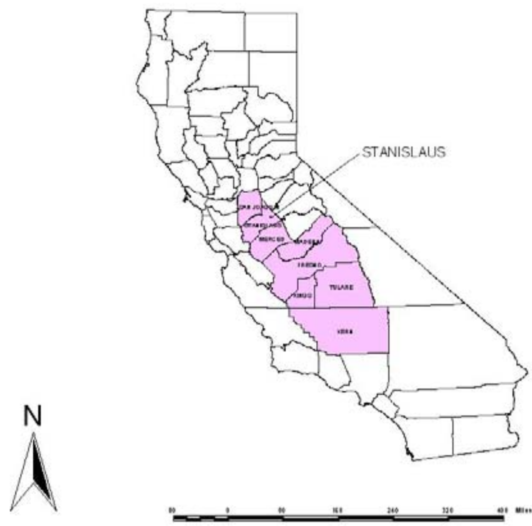
Dana Coe Sullivan
Sonoma Technology, Inc.

This research is funded by U.S. EPA - Science To Achieve Results (STAR) Program
Grant # RD-83184201

Project Objectives

- Develop a system of models for evaluating the impact of **local and regional** policies and trends on air quality
  - Global variables from sources like IPCC, California Department of Finance
- Apply this system to the San Joaquin Valley to evaluate the sensitivity of air quality to different policy scenarios.

San Joaquin Valley



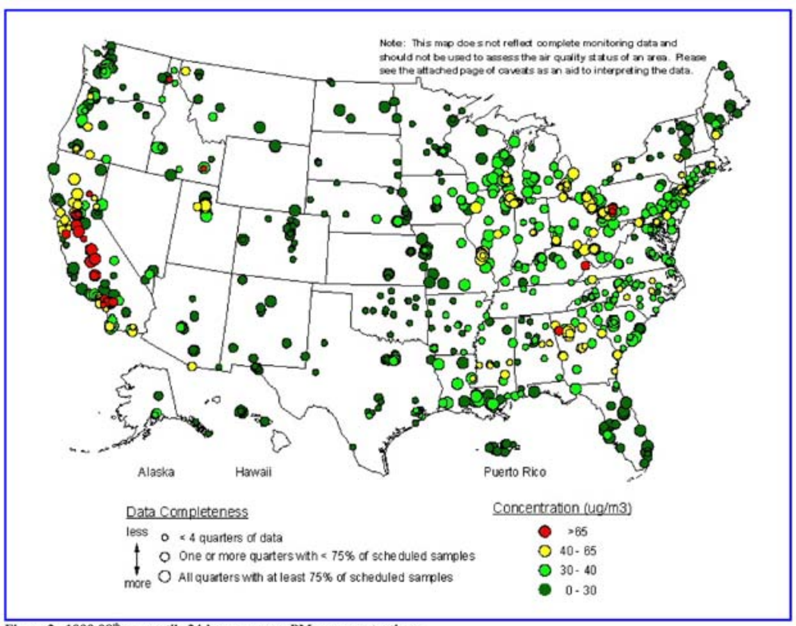
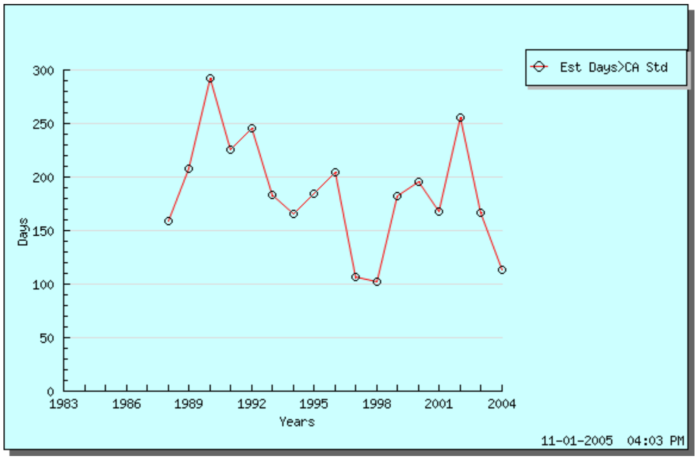


Figure 2. 1999 98th percentile 24-hour average $PM_{2.5}$ concentrations.
Source: U.S. EPA AIRS data base, July 12, 2000.

PM10 Trends Summary: San Joaquin Valley Air Basin



Source: CARB, http://www.arb.ca.gov/adam/php_files/aqdphp/graphtrendpm10bb.php

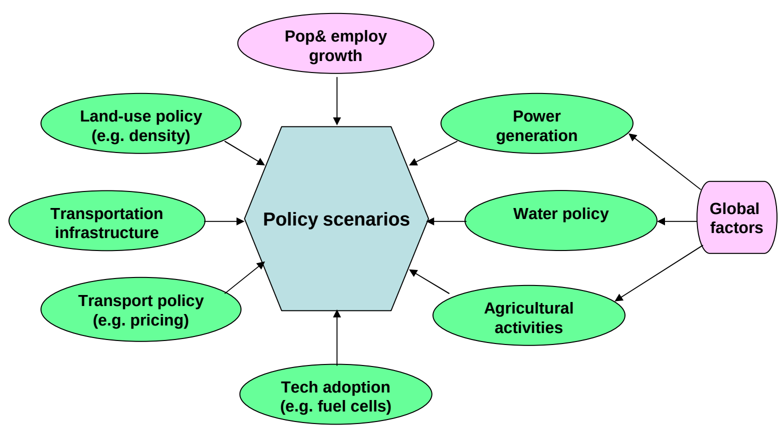
Ozone Trends Summary: San Joaquin Valley Air Basin

Source: CARB, http://www.arb.ca.gov/adam/php_files/aqdphp/graphtrendo3bb.php

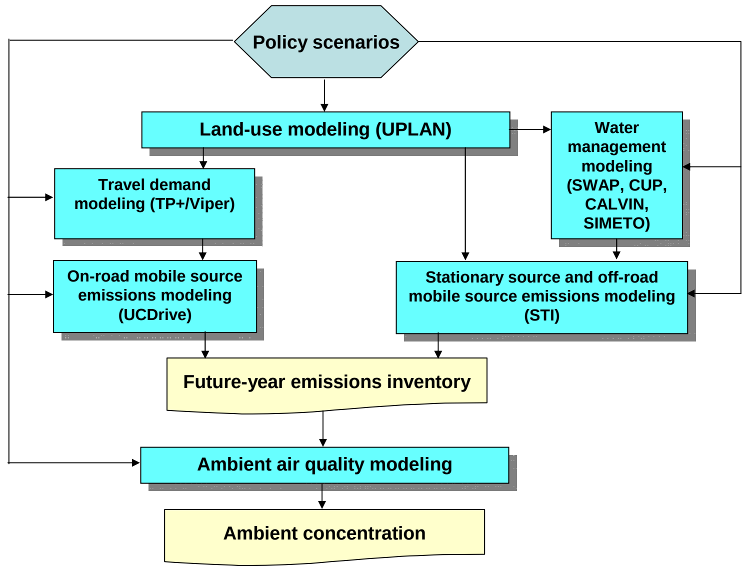
Project Schedule

	Tasks
Year 1	Develop policy scenarios for San Joaquin Valley Run land use models Run travel demand models Begin stationary source estimates
Year 2	Run emissions model Run water management models Complete stationary source estimates
Year 3	Estimate future year emissions inventory Run ambient air quality modeling Estimate future ambient air quality

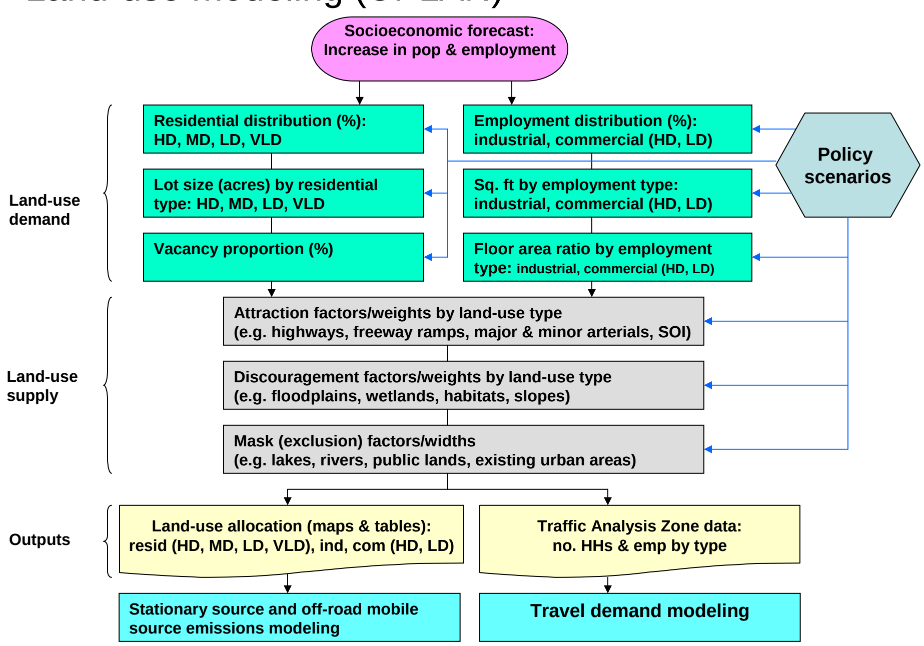
Policy Scenarios

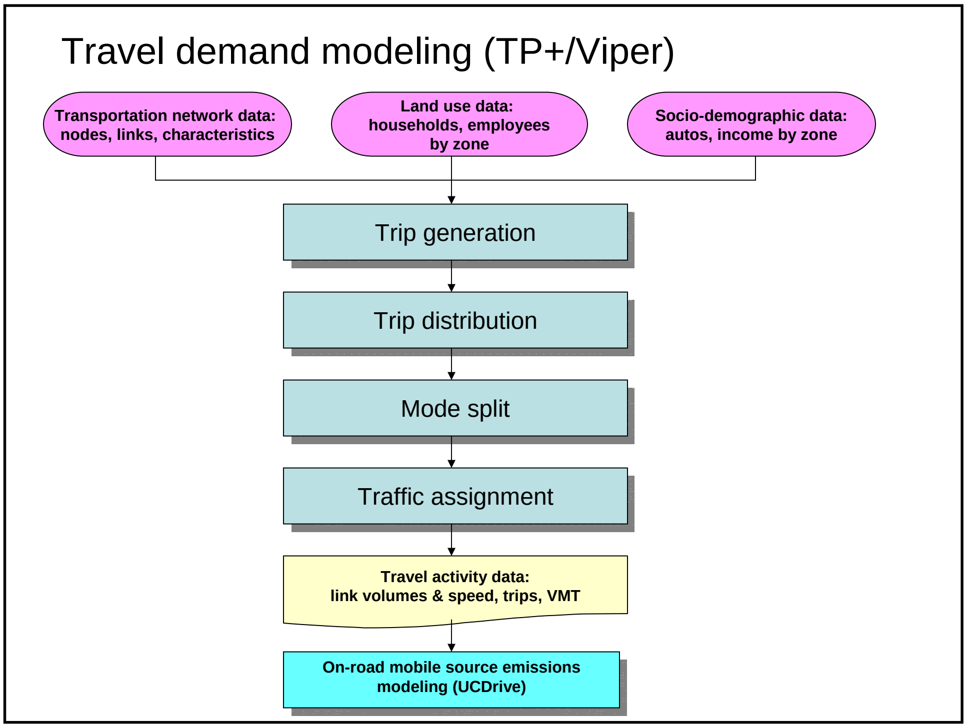


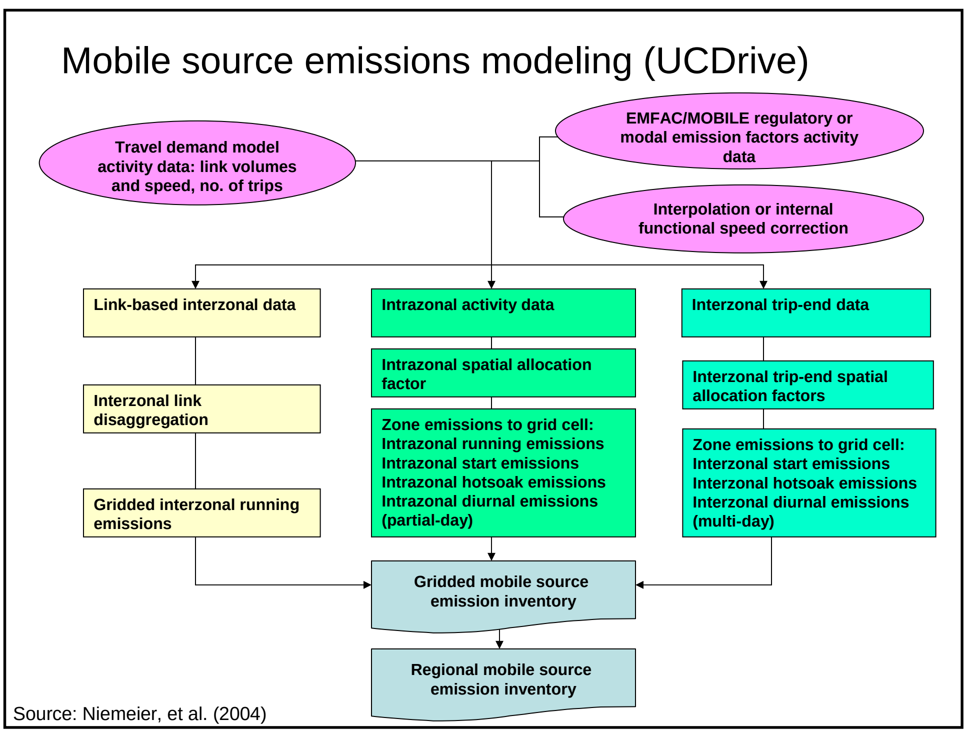
Overall Modeling Procedure



Land-use modeling (UPLAN)




Travel demand modeling (TP+/Viper)
Transportation network data: nodes, links, characteristics
Land use data: households, employees by zone
Socio-demographic data: autos, income by zone
Trip generation
Trip distribution
Mode split
Traffic assignment
Travel activity data: link volumes & speed, trips, VMT
On-road mobile source emissions modeling (UCDrive)


Mobile source emissions modeling (UCDrive)
Travel demand model activity data: link volumes and speed, no. of trips
EMFAC/MOBILE regulatory or modal emission factors activity data
Interpolation or internal functional speed correction
Link-based interzonal data
Interzonal link disaggregation
Gridded interzonal running emissions
Intrazonal activity data
Intrazonal spatial allocation factor
Zone emissions to grid cell: Intrazonal running emissions Intrazonal start emissions Intrazonal hotsoak emissions Intrazonal diurnal emissions (partial-day)
Interzonal trip-end data
Interzonal trip-end spatial allocation factors
Zone emissions to grid cell: Interzonal start emissions Interzonal hotsoak emissions Interzonal diurnal emissions (multi-day)
Gridded mobile source emission inventory
Regional mobile source emission inventory
Source: Niemeier, et al. (2004)

Scenario Development

- Initial list of variables
- Background research and preparation of white papers
- Initial levels and combinations of variables
- Expert panel review – April 2005
  - Caltrans, California High Speed Rail Authority
  - California Air Resources Board
  - Additional experts in economics and agriculture
- Finalization of variables, levels, combinations
- Translation of variables into model inputs

Scenarios

	Scenario 1: Baseline	**Scenario 2: Controlled**	**Scenario 3: Uncontrolled**	**Scenario 4: As Planned**
Transportation	No change	No new roads High Speed Rail	New roads No High Speed Rail	New roads High Speed Rail
Land use	No change	High-density residential Transit-oriented development Infill and redevelopment Increased ag preservation Increased habitat preservation	Low- and very-low density residential	Residential densities as planned Some increased preservation

Scenarios: continued

	Scenario 1: Baseline	**Scenario 2: Controlled**	**Scenario 3: Uncontrolled**	**Scenario 4: As Planned**
Other regional variables	No change	Decentralized power Complete burning ban Ag dust reduction	No change	Some decentralized power Statel rules on burning Some ag dust reduction
Technology variables	No change	Improved vehicle efficiency Fuel cell adoption Mandate alternative energies Complete diesel retrofit Dairy bio-energy	No change	No change

Stanislaus County Results to Date

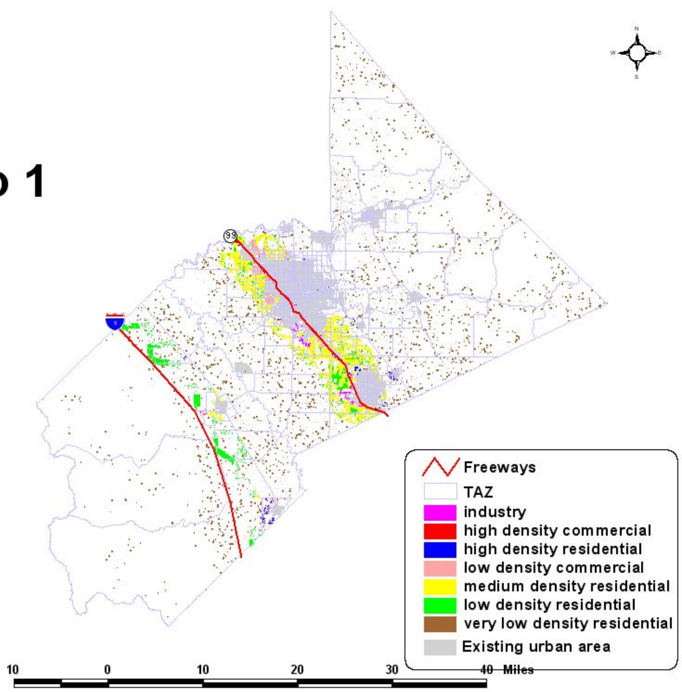
- Land use modeling
- Travel demand modeling

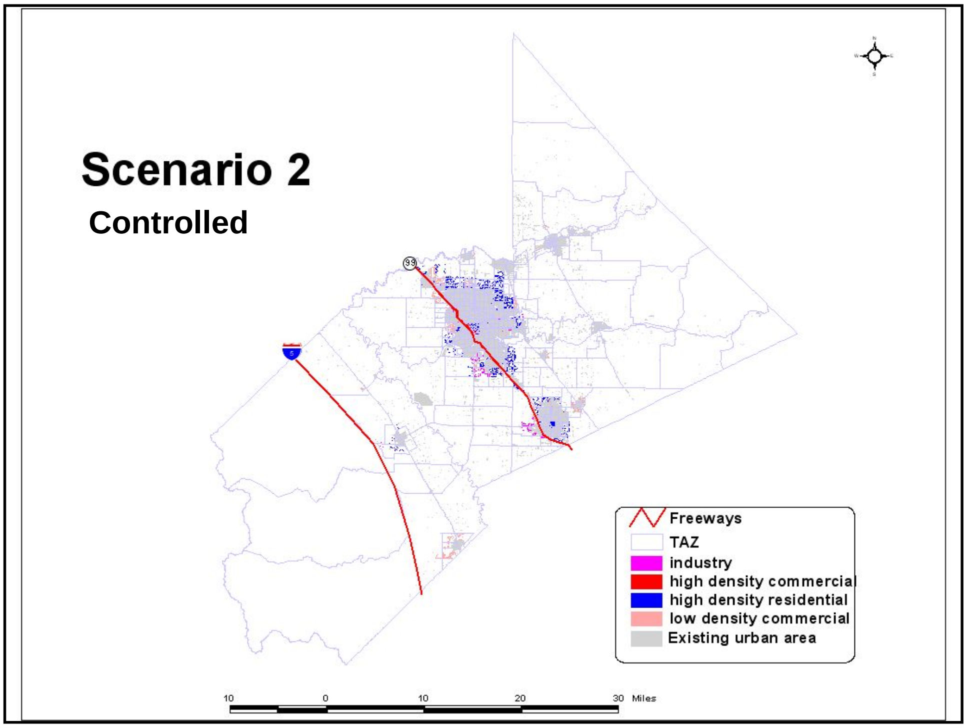
Stanislaus County Growth

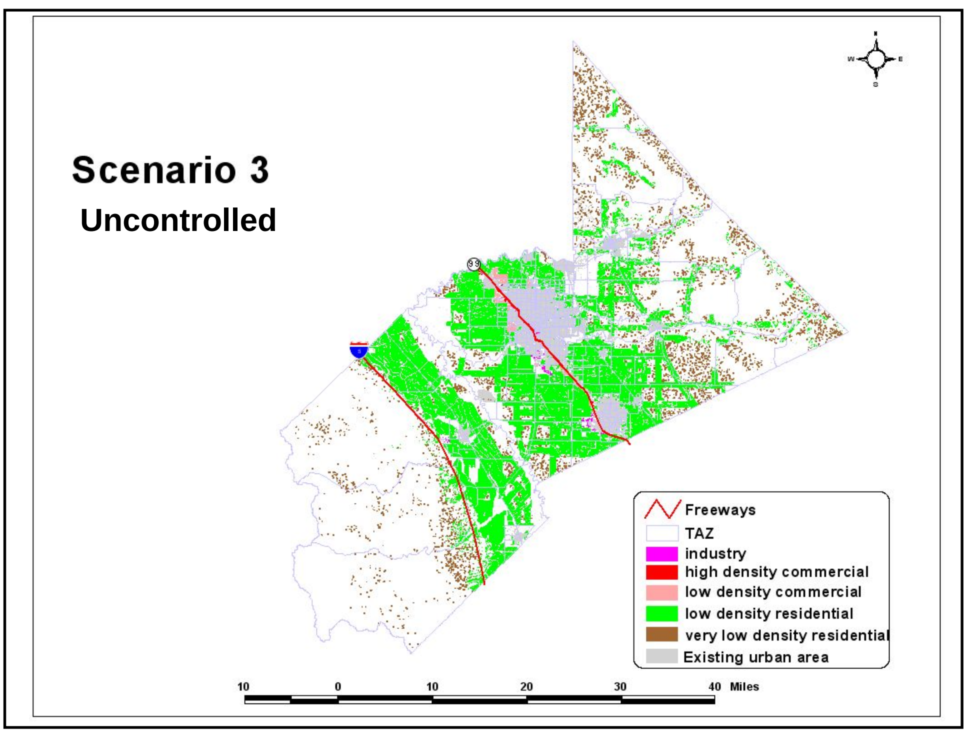
	2000	2030	Change
Population	446,997	744,599	+66.6%
Households	145,154	263,789	+81.7%
Employment	174,066	293,938	+68.9%

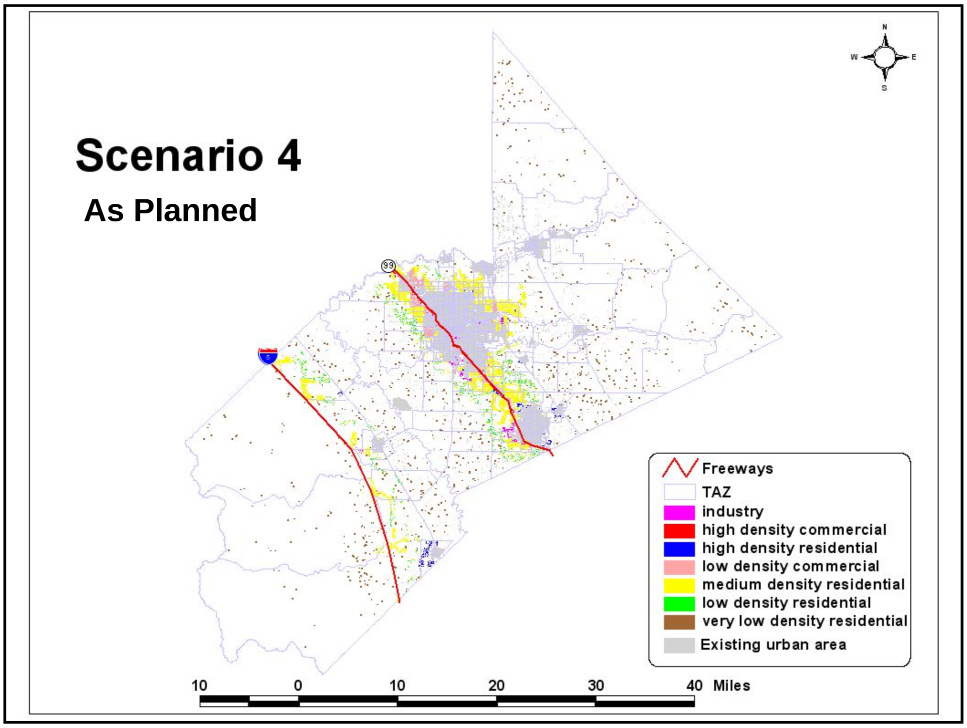
Scenario 1

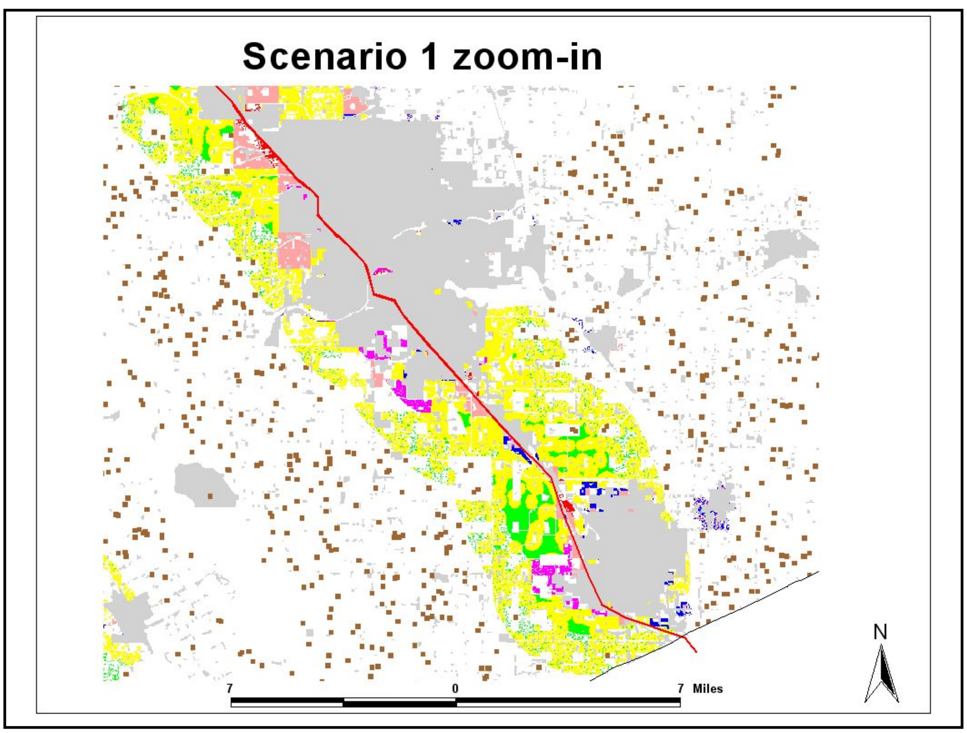
Baseline



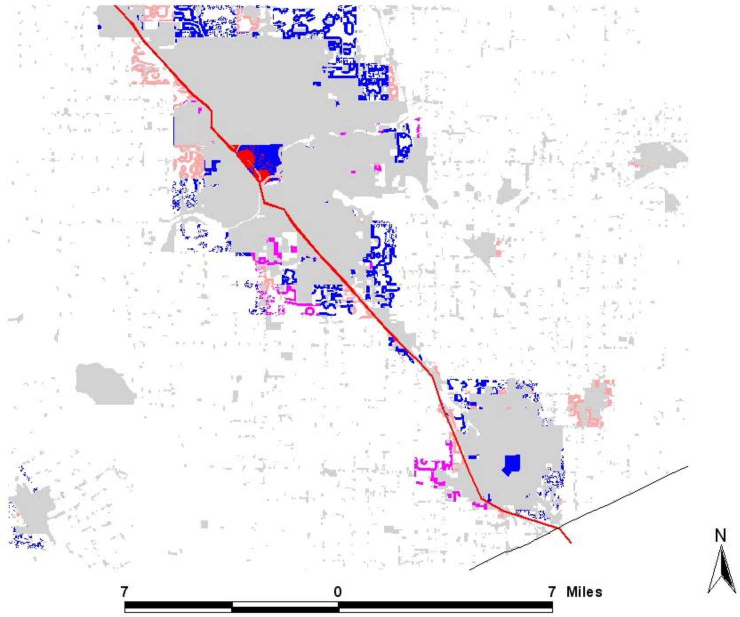

Scenario 2
Controlled
Freeways
TAZ
industry
high density commercial
high density residential
low density commercial
Existing urban area
10
0
10
20
30 Miles


Scenario 3
Uncontrolled
Freeways
TAZ
industry
high density commercial
low density commercial
low density residential
very low density residential
Existing urban area
10
0
10
20
30
40 Miles

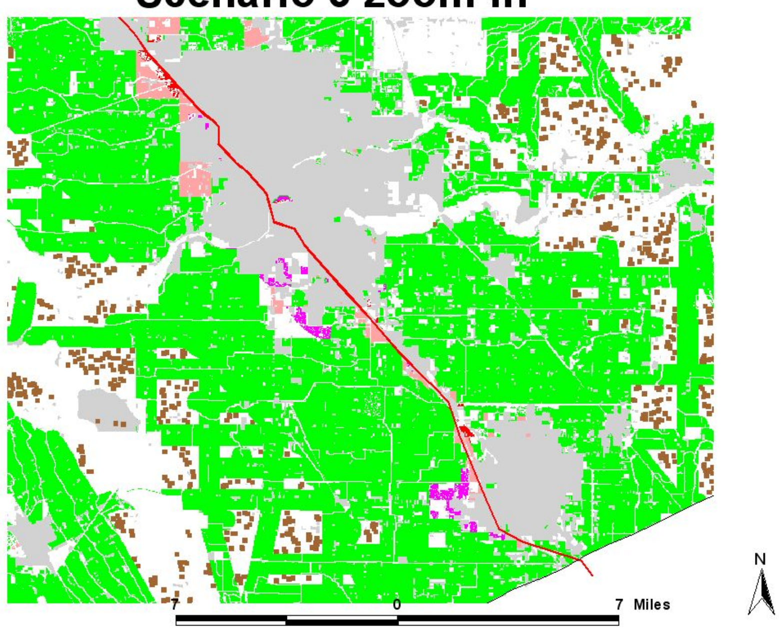

Scenario 4
As Planned
Freeways
TAZ
industry
high density commercial
high density residential
low density commercial
medium density residential
low density residential
very low density residential
Existing urban area
10 0 10 20 30 40 Miles


Scenario 1 zoom-in
7 0 7 Miles
N

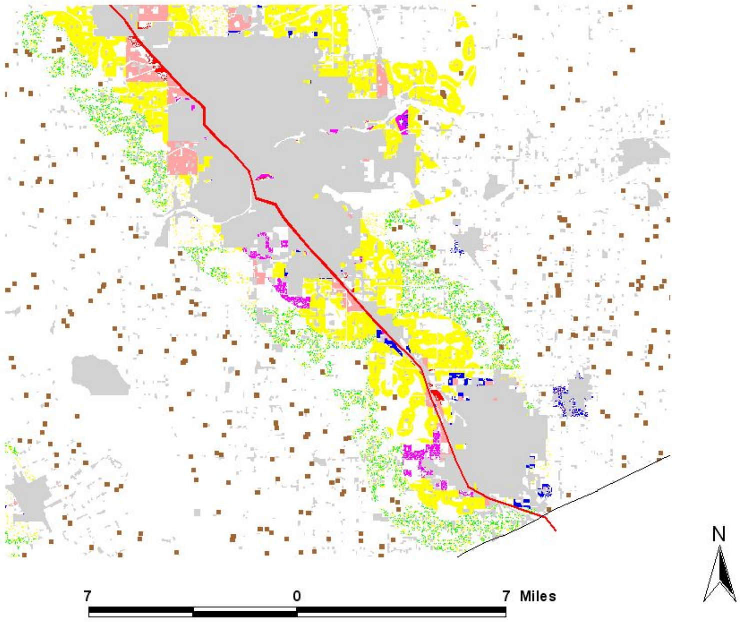
Scenairo 2 zoom-in



Scenario 3 zoom-in



Scenario 4 zoom-in



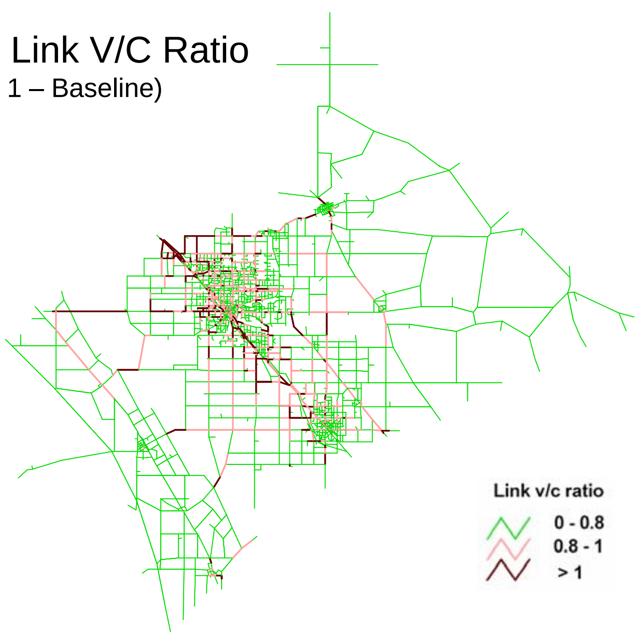
New Households by Residential Density
Stanislaus County

	Scenario 1 Baseline	Scenario 2 Controlled	Scenario 3 Uncontrolled	Scenario 4 As Planned
High density	21,280	118,760	0	23,620
Medium density	93,572	0	0	93,572
Low density residential	1,894	0	114,710	711
Very low density residential	1,894	0	3,983	711

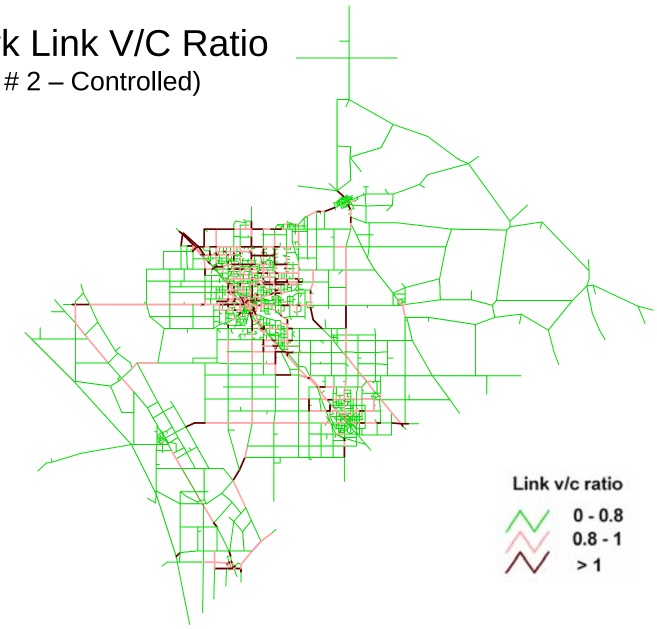
Travel Demand Modeling Results
Stanislaus County

	Unit	Scenario #1 (baseline)	Scenario #2 (controlled)	Scenario #3 (uncontrolled)	Scenario #4 (as planned)
Total VMT	mile	16,411,281	15,427,411 (-6%)	22,089,022 (+35%)	18,860,451 (+15%)
Total VHT	hour	712,671	617,969 (-13%)	1,022,107 (+43%)	744,941 (+5%)
Number of vehicle trips	one-trip	2,233,862	2,122,622 (-5%)	2,308,304 (+3%)	2,274,656 (+2%)
Average trip distance	mile	7.35	7.27	9.57	8.29
Average trip length	minute	19.14	17.47	26.57	19.65
Average trip delay	minute	8.18	6.66	12.72	7.62
Freeway congested speed	miles/hour	37.7	43.9	38.8	42.8
Freeway average vc ratio	v/c	0.898	0.829	0.915	0.865
Arterial congested speed	miles/hour	36.1	36.5	35.3	37.3
Arterial average vc ratio	v/c	0.691	0.654	0.746	0.666

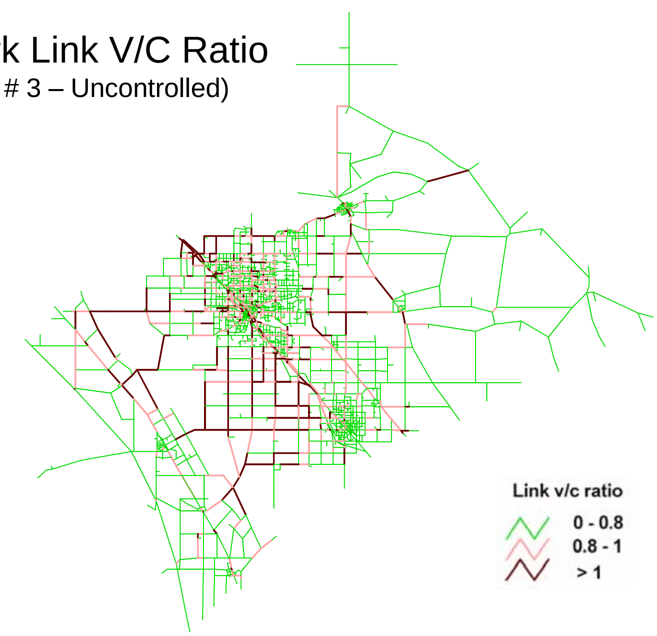
Network Link V/C Ratio
(Scenario # 1 – Baseline)



Network Link V/C Ratio
(Scenario # 2 – Controlled)

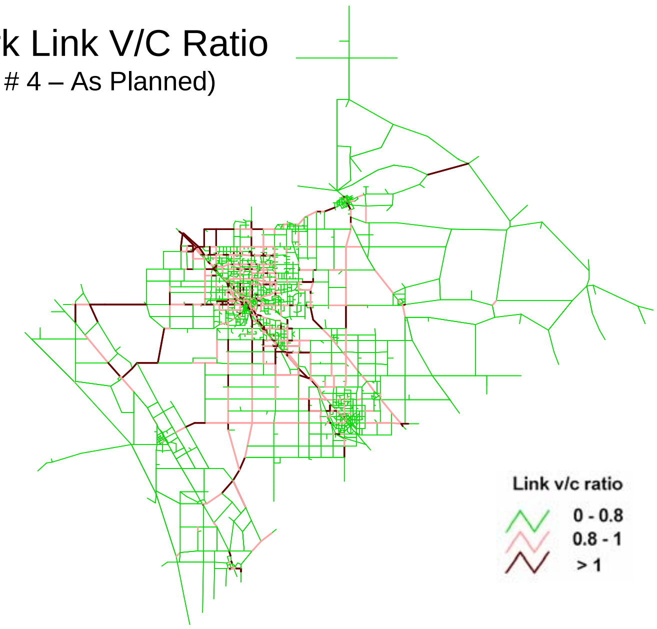


Network Link V/C Ratio
(Scenario # 3 – Uncontrolled)



Network Link V/C Ratio

(Scenario # 4 – As Planned)



Questions

- How will results differ by county?
- How will differences in travel demand translate into differences in vehicle emissions?
- How will differences in land use patterns translate into differences in stationary and off-road source emissions?

Acknowledgements

- United States Environmental Protection Agency Science to Achieve Results (STAR) Grant # RD-83184201

Summary of the Q&A Discussion Following Session III

Maurice Abrams, (a "concerned citizen")
Mr. Abrams asked about the status of the Hacienda Project—whether it has been completed.

Steve Raney, (Cities21)
Mr. Raney replied that the 24-month study was just getting underway. He added, "One of the key things in this study is that the General Manager of the office park, James Paxson, is just a great, progressive guy, and he participates in a lot of forward-thinking transportation studies. He also has a very high social IQ—he's really well liked—and that was really important as he helped in putting together the letters of support that created the winning grant proposal." Dr. Raney went on to say that the researchers are "tied in with MTC and BART and the Congestion Management Agency and lots of other good groups, so it's a pretty exciting team that came together mostly because of James's unique personality."

Steve Raney, (Cities21)
Directing his question to Dr. Paul Waddell, Mr. Raney asked, "What's the order of magnitude of effort to bring the Urban SIM model to the Bay Area or any big place?—Is it four person years of work or what?"

Dr. Paul Waddell, (University of Washington)
Saying, "You *would* end with a hard question," Dr. Waddell stated that as of a year ago the answer would have been "very high" due to the fact that the model is extremely "data hungry, requiring the use of parcel data and business establishment data as well as a lot of data cleaning and data synthesizing." He acknowledged that that's where most of the effort has gone. He added, however, that they've "been working quite hard over the course of this past year to develop capacity to create much simpler models, so that if one wanted to, you could start with a simpler version and then make it more sophisticated or more sensitive or more detailed, as time and data permit."

Dr. Waddell revealed that in about a month [approximately mid-December 2005] they're preparing to release a new version that will have the capacity to generate much more quickly "runnable models with local data, but with lighter data requirements and easier construction." He projected that a "light-weight version of the model could be up and running within 3 to 6 months." He added that a full-detailed model operating with parcel-level data "really depends on the quality of the data in hand and how long it takes to get it into usable shape."

Nancy Levin, (U.S. EPA Region 9)
Saying that she works on the environmental review of transportation projects, Ms. Levin stated that one of the questions they deal with is: To what extent does transportation

affect land use? She asked the panelists what the current thinking is on that and "whether there is an increasing willingness to use land-use models in looking at impacts of transportation projects."

Dr. Paul Waddell, (University of Washington)
Stating that there seemed to be "a couple of questions in there," Dr. Waddell identified one of them as "How much does transportation influence land use?" Another, he said, pertains to connecting land-use models and the interest in using them.

Addressing the first question, Dr. Waddell said, "California has some of the few critics of the argument that transportation influences land use. He specifically named Genevieve Giuliano (USC School of Planning, Policy, and Development), Harry Richardson, and Peter Gordon (both also at USC) as people who have made "pretty strong claims that there are reasons to think that transportation just isn't what it used to be in influencing land use." One of the reasons for this belief, he stated, is that in larger metropolitan areas we now have very mature systems, so adding a particular highway or transit project is a fairly incremental change. He said an additional argument used to bolster this case is that multi-worker households make it much harder to minimize commuting time.

On the other hand, Dr. Waddell feels that "there is still a large body of evidence to the contrary, that even in a large metropolitan area with a mature transport system building a particular project will have at least *localized* effects and [a number of projects] will add cumulative effects across the metropolitan region. He stated that he has found that "even in a place as utterly dominated as Salt Lake City, both regional accessibility and local, walking-scale accessibility measures turn out to be significant in predicting people's location choices in the housing market."

Acknowledging that Susan Handy "has done a lot of work on this topic," Dr. Waddell yielded the floor to her input.

Dr. Susan Handy, (University of California at Davis)
Dr. Handy commented, "I don't think I could answer it any better, Paul."

Dr. Paul Waddell
Dr. Waddell asked whether the second question posed by Ms. Levin was whether there is a greater willingness now to use land-use models.

Nancy Levin
Ms. Levin clarified that in speaking with others from transportation agencies she has found a general reluctance to use land-use models due to great costs, great time involvement, and/or great data needs—basically just the huge investment required. She rephrased her question in this fashion: "Can you only use these models really in a big academic setting for a huge project or is there some move to make them a little bit more accessible to policy makers?"

Dr. Paul Waddell
Saying, "This is perhaps not totally unrelated to the earlier question," Dr. Waddell said that "there were several discussions along this line at the Transportation Research Board conference at the beginning of the year." He added that "there was a sense that academics promoting very complex models—activity-based travel models and integrated land-use and transportation models—may tend to oversell them a little bit, and the practitioners out there who need to implement the models are cautious or skeptical. Essentially, they're being asked to make huge commitments of time and resources to implement models without a whole lot of evidence to date they'll make significant differences in what the benefit/cost ratio really is." Dr. Waddell feels that the skepticism among practitioners is well founded and that academics need to do two things: First, make models easier to implement. Second, "provide more of an incremental development path so that one could start with a simple model, get it running quickly, identify what the weaknesses are in that, and then work on making improvements gradually and with lower levels of investment." He concluded by saying that it's important to be able, at each stage, to document what's been gained and what it cost so that it's easier to make a case for further development of the project. "Otherwise, it will be rather irrelevant if we can't make it [i.e., a model] accessible to practitioners."

Dr. Susan Handy
Dr. Handy added, "The Transportation Research Board is organizing a conference that will be held in May or June in Austin, Texas that will deal with this very issue: How do you bring all these innovations that are coming out of academia into practice?—sort of helping to build that bridge."

Unidentified Questioner
Addressing Dr. Paul Waddell, the questioner said, "Given the effort that is involved in assembling the data for these types of models, is it really the case that what you really need is to assemble the data for the major metropolitan areas and then you can use whatever model is appropriate to use with that? What fraction of the effort involved in setting up a more realistic picture of how transportation interacts with land use is data assembly and data cleaning versus the model itself, and should we perhaps just put that effort into getting the data because we'll need it for whatever we decide to do?"

Dr. Paul Waddell
Dr. Waddell commented that "this is an excellent point," and he said he "would wager that something on the order of 75 percent or so of the effort is in the data" and he added that "there are some important lessons in all that." One lesson is for agencies/institutions to view the data as "infrastructure that has lots of other uses besides the modeling applications—it enables them to answer lots of questions that they couldn't answer otherwise." Consequently, many agencies/institutions are deciding "to go ahead and make commitments and invest in creating databases and maintaining them because they'll have lots of secondary applications."

Continuing, Dr. Waddell added, "Secondly, I'd say we probably need to be a lot smarter about how we deal with the data development process." He noted that in the past he and his colleagues simply assumed that they could "get good quality data and integrate it and resolve errors in it to the point that it was completely internally consistent—and then use it in modeling." As an example, he cited the accounting of where jobs are and where commercial space is—"there's an implied square-footage-per-employee ratio that tells you how many jobs you can fit into the quantity of space that is available." He went on to explain that errors in the data can create some really unreasonable or impossible square-footage per employee values that really distort the modeling. Dr. Waddell feels that a lesson from this is that "we should make the modeling much more robust to data artifacts, data errors." He also thinks "we should probably be synthesizing data a little bit more than we are now, using statistical data mining tools to explore data patterns and being less concerned about getting every single data point exactly right, so we can cut the cost down on getting usable data at a high level of detail."

Michael Gill, (U.S. EPA Region 9)
Mr. Gill commented that "we are fairly blessed in the West with a lot of land and fairly blessed in this country with low gas prices," particularly in comparison to Europe. He asked, "Are we learning any lessons from Europe or other places in this realm of transportation and land use?"

Steve Raney
Mr. Raney responded that "the grocery bag cart that you showed was the one that I used in the Netherlands to walk from my home to my grocery store." He added, "It's a cultural thing there—there it's *good* to be cheap, which, incidentally, makes you green."

Dr. Benjamin Hobbs
Dr. Hobbs said he believes that we're making some progress and beginning to "get in the right mindset," although these changes are coming slowly. In his view, the environmental challenges we're facing dictate that the changes "need to accelerate significantly."

Dr. Susan Handy
Dr. Handy added this comment: "Those of us who care about these things look a lot to Europe and say, "Why can't we do that here?" She believes that, more and more, we are seeing American versions of European ideas. At the same time, "Europe is also seeing a lot more of what we have happening too," with Wal-mart and suburbanization. She concluded, "Maybe they need to learn from the mistakes we've made, as much as we need to learn from the right things they've done."

Dr. Paul Waddell
Referring to the post-Katrina spike in gas prices, Dr. Waddell said this might provide "one little bit of evidence we have about how people might react to substantially higher gas prices. The sort of spike we've seen in transit ridership, for example, provides a little bit of optimism" that sustained higher gasoline prices might bring on meaningful shifts in

people's behavior. He added, "Before this, we didn't really know what threshold of fuel prices would start to trigger that," but this episode has provided "at least some glimmer of evidence that there is some elasticity of demand with respect to fuel prices there."

Dr. Waddell went on to say that he wanted to echo what Susan Handy had said about Europe. He explained that he spent last year on sabbatical in the totally pedestrian environment of central Paris—he had no car and walked everywhere. Shortly afterward he went to a seminar on transportation trends, where he heard about "reports on travel surveys that have been done since 1970 or so in the Isle de France region," and he said he was horrified by what these reports revealed. The trends in central Paris were fairly stable, with very low auto ownership and very high transit ridership being maintained. However, the story in the suburbs is different, with inter-suburban traffic climbing drastically over the years of the studies, and "there's nothing that gives any indication that the pattern of development and the pattern of transport in the suburbs is anything like the old core of the city." Dr. Waddell said he believes this is true not just in Paris but in a lot of European cities. This causes him to wonder whether "they have it all figured out and they're doing things so much better, or whether they have an accident of history on their side—that their cities were built on a more pedestrian transportation economy, and now the outlying areas are developing more on an auto-oriented basis." He ended by classifying this possibility as "quite scary."

END OF SESSION III Q & A