THREE APPROACHES TO UNDERSTANDING THE ROLE OF GEOGRAPHY ON NATURAL RESOURCE DEVELOPMENT

A Dissertation
Presented to the Faculty of the Graduate School
of Cornell University
In Partial Fulfillment of the Requirements for the Degree of
Doctor of Philosophy

by
Javier Ignacio Perez Burgos
January 2014

THREE APPROACHES TO UNDERSTANDING THE ROLE OF GEOGRAPHY ON NATURAL RESOURCE DEVELOPMENT

Javier Ignacio Perez Burgos, Ph. D.
Cornell University 2014

This dissertation proposes three different modeling approaches for studying the role of geography in the regional development of natural resources. We explicitly introduce the notion of space into market-based economic concepts in order to capture a more realistic picture of recent trends in the development of greener energy technologies through a more responsible utilization of natural resources.

First, we use a regional extension of a Computable General Equilibrium model in order to understand the short term impacts of the extraction of natural gas using hydrofracking, numerical experiments are used to analyze potential impacts of this industry in the New York State and Pennsylvanian economy. There is clear evidence that hydrofracking in Pennsylvania has had spillover effects on bordering New York State counties were hydrofracking is not yet permitted. Policies on natural resource development should adopt a regional approach since jurisdictional boundaries are not relevant when dealing with whole-wide economic impacts.

Second, we adopt recent advances in the analysis of spatial panel data in order to study agglomeration economies in the greenhouse and nursery industries in the

Northeast of the United States. These industries have become essential to the urban consolidation of this region.

Finally, we employ the bottom-up top-down paradigm through the combination of a static Computable General Equilibrium model and a production and distribution framework for the analysis of the potential effects of the hydrogen industry for vehicle transportation. We use the case of Hawaii since it has the highest energy prices within the US and has a clear necessity for adopting cheaper and more sustainable sources of energy in the near future. The numerical results show that a public-private subsidy scheme represents the most viable policy for the adoption of hydrogen as a source of energy in the island.

BIOGRAPHICAL SKETCH

Javier Perez-Burgos was born in Bogota, Colombia in 1981. He earned a Bachelor degree in Economics and History from Universidad de los Andes in 2004 and 2005 respectively. Later on in 2006 he received a Masters degree in Economics from the same University. During that time he taught classes related to economic geography and geopolitics. Before starting his PhD at Cornell University in 2008 he did some consulting work on local economic development and agricultural policy. Since August 2013 he has been an Assistant Professor in Alberto Lleras Camargo School of Public Policy at Universidad de los Andes in Bogota, Colombia.

To Carmen

ACKNOWLEDGMENTS

I would like to express my deepest gratitude to my advisor, Dr. Kieran Donaghy, for his guidance, support, and encouragement throughout my graduate studies at Cornell University. His exemplary work ethic and his commitment to quality and excellence have always been the sources of inspiration for me to accomplish this work at my best effort. There is no doubt that his impacts will continue to benefit me in my future career and life.

I am indebted to my committee members, Dr. Susan Christopherson and Dr. Miguel Gomez for their participation and help along this process. Their insightful comments and constructive criticisms have been valuable inputs to my research and dissertation. My appreciation is also extended to professors Dr. Nelson Bills, Dr. Mark Turnquist, and Dr. Ian Sue Wing for providing valuable collaboration and assistance in the development of this research. I'm also grateful for the useful comments and support of fellow colleague Arash Beheshtian. Last but not least I would like to extend my gratitude to the Heinz Foundation, the Park Foundation, General Motors, and the Atkinson Center for a Sustainable Future, which provided funding for parts of this research.

My heartfelt gratitude goes to my parents and my siblings for their generous love. Finally, I want to thank my wife, Carmen, for her love and understanding throughout the past few years. Her encouragement has always been the key source of motivation for me to finish this work. I dedicate this dissertation to her *mi divina*.

Table of Contents

LIST OF TABLES

Table Page

LIST OF FIGURES

1 CHAPTER ONE: INTRODUCTION

1.1 Motivation

To date, more than ever policy-makers have been encouraged by the prospects of job creation and economic development to expedite natural resource development across the United States. Up to the present time, however, there has been little regional examination of the economic impacts of different alternatives for natural resource development. The proposed research will employ various methodologies in order to examine the current development patterns and potential effects of increased activity in three different natural resource industries such as natural gas drilling, greenhouses, and hydrogen fuel for vehicles. The principal objective of this research is to identify and measure the full range of costs and benefits associated with these industries and develop capabilities to support better informed natural resource policy decisions.

This research will develop and implement a tools such as Computable General Equilibrium (CGE) Models and Spatial Panel Econometric analysis to assess the short-term and long-term socioeconomic impacts of these natural resource industries. The proposed framework will account for the behavior of players in the natural resource development process and explore their responses to different policy interventions. The analysis for all three cases will be based on county-level data in order to identify different economic interactions.

A profound study of the transformation in the local economic bases will allow the proposed research to give citizens, community organizations, environmental advocates, and state and local policy makers a more complete understanding of the social and economic impacts of natural development in different regions across the Unites States.

Modeling the behavior of markets and their interdependence with space will provide an alternative framework for understanding the potential of economic impacts associated with natural resource development, with particular attention to the effects in the different region's economic geography.

Finally, a study of this sort can develop impact analytic and planning support capabilities that different stakeholders and state or local policy makers can use to assess future natural resource development projects, including those favoring a transition from high carbon demanding to "greener" sources of energy.

1.2 Objectives of the Study

Experts agree that a shift from fossil fuels to sustainable low-carbon sources of energy will take decades. For this reason, the availability of alternative fuels, such as natural gas or hydrogen and more local sources of production such as greenhouses, has become central to the debate over energy transitions. One of the most interesting characteristics of these industries is their potential as a transition for low CO2 and pollutant emission technologies. These industries offer a realistic opportunity to mitigate the environmental impact of fossil fuels in the near future.

Natural resource development has frequently been described as transformative to regions that experience it. So far, policy makers have paid attention primarily to the environmental and health impacts of the new natural resource development approaches in North America, ignoring the broader economic and social transformations associated with them.

The primary goal of this research is to develop and implement appropriate tools for understanding the economic and social impacts of these new industries. More specifically, the research will focus on three critical questions:

1. What are the short and long term impacts of natural resource development in places where natural gas extraction by fracking, hydrogen fuel cell vehicles or greenhouse production are becoming key industries?

2. What are the likely critical transformations in the economic geography of a region facing a natural resource development of this sort?

3. How can planning support be improved by incorporating in our models features that better reflect our economies?

My hypothesis is that as long as natural resource development is viewed as an isolated regional economic transformation agent apart from other systems with which it is engaged, economic development plans based on resource exploration and recovery will fail to generate sustainable growth.

1.3 Organization of the Dissertation

In order to achieve the above objectives this dissertation is organized as follows:

Chapter 2 examines multiple approaches to conducting regional economic impact analyses of unconventional gas exploration and extraction in the Marcellus Shale. It revisits the findings of earlier studies of economic impacts obtained with input-output (or I-O) and social accounting matrix (or SAM) models at the state level for New York and Pennsylvania. We then attempt to replicate the findings of these studies, using similar models based on assumptions and data employed in the earlier studies, and compare our impact projections with those previously obtained. We find considerable variance in the model results. We also proceed with regional/county-level I-O analyses that focus on multiple counties on both sides of the New York and Pennsylvania border. A comparison of our projections with historical data suggests that I-O and SAM analyses may be overly optimistic about the benefits of increased activity in the gas industry. We then go on to develop and deploy a more comprehensive framework, a regional Computable General Equilibrium (CGE) model, for studying and understanding the potential economic and social impacts of unconventional exploration and extraction activity in New York State and Pennsylvania at the county level. In considering several scenarios pertinent to increased activity in the natural gas industry, it becomes evident that cross-border spillovers have significant impacts. The model presented provides benchmark performance measures to answer questions concerned with short-term impacts of natural gas development in the region and the spillover effects ensuing from natural gas exploration and extraction.

Chapter 3 uses a spatial panel data approach to examine the relationship between urban agglomeration and greenhouse/nursery production in the Northeast. We use data from the last five (1982-2007) U.S. Agricultural Census to examine the effect of urbanization, spatial concentrations of firms, and firm-internal factors on greenhouse/nursery production levels. Results suggest that there is strong presence of spatial dependence in the greenhouse/nursery industry in the region. This sector clearly benefits from clustering among firms within the same sector. Also, greenhouse/nursery production levels are positively associated with higher income levels, and labor force as well as more extensive built environments. The economic vibrancy of greenhouse/nursery businesses in urban areas requires balancing increased land competition with opportunities offered by proximity to consumers.

Chapter 4 assess long-term economic benefits from converting to the use of hydrogen as a vehicle fuel. We adopted a “top-down, bottom-up” approach to regional economic modeling to capture the effects of changing energy sources as they work through the economy. At the upper level, we construct a macroeconomic model that includes interactions among various industrial sectors, influences of changing energy prices and availability, and policies of government on household income and consumption, total economic output, employment, etc. At the lower level, we construct a more detailed model of hydrogen production and distribution (as an energy sub-sector) that reflects the influence of relative fuel prices and vehicle costs on the use of hydrogen as a vehicle fuel. We solve these two models iteratively to conduct an assessment of economic benefits under different scenarios.

We use Hawaii as a case study in the research. Because Hawaii is geographically isolated from the remainder of the U.S., it forms an economic region of its own and is of a suitable scope for a study of this nature. Hawaii currently has the highest energy costs in the U.S. because it is almost entirely dependent on imported petroleum. There is a significant effort underway in Hawaii to diversify from petroleum and hydrogen has the potential to play a significant role as an alternative fuel in the long term (i.e., over the next several decades). The potential hydrogen infrastructure in Hawaii is likely to include hydrogen production from several sources, some centralized and others more decentralized. This state of affairs is reflected in our “bottom-up” model. Our findings show how with the current state of affairs a public-private subsidy scheme for the adoption of hydrogen as viable source for vehicle fuel represents the most promising option in the short term.

Finally, chapter 5 discusses the overall conclusions of the research and highlights some key contributions of the study. We also identify potential topics a further directions for future research.

2 CHAPTER TWO: REGIONAL ECONOMIC IMPACT ANALYSES OF NATURAL GAS EXPLORATION AND EXTRACTION IN THE MARCELLUS SHALE

2.1 Introduction

Currently, there is widespread agreement that a shift from fossil fuels to sustainable low-carbon sources of energy, although necessary to slow and mitigate the effects of climate change, will take decades to achieve. For this reason, the possibility of substituting coal with alternative, less-polluting fuels, such as natural gas, in the near term has attracted much attention. Factors contributing to interest in wider use of natural gas include its increased availability and its potential to serve as a transition fuel while lower-emission technologies are being developed. Notably, in the last several years, the United States has reduced its greenhouse gas emissions more than any other industrialized country by substituting natural gas for coal in electrical power generation (Chazen, 2012). Thus, natural gas would appear to offer a realistic opportunity to mitigate the impact of fossil fuels in the near future.

Increased use of natural gas has been enabled by the development of new technologies of extraction—hydrofracturing, or ‘hydrofracking’—that have made it possible to gain access to natural gas reserves that once were inaccessible with conventional drilling technologies. The natural gas supply paradigm has shifted with this development and recent discoveries around the world of shale gas (or ‘tight gas’) deposits, which are accessible by new unconventional drilling technologies. North America, Europe, and China all perceive an historic opportunity to gain access to cheaper and cleaner energy resources (Kuuskraa and Stevens, 2009). These recent changes in the world’s proven and recoverable natural gas reserves raise many questions about the changes that regions with natural gas formations will face.

Economic history is replete with examples of natural resource extraction leading to the transformation—both good and bad—of the regions that have experienced it. And, due to its size and potential impact on the economy of the northeastern United States, the deep low-permeability gas formation in the Marcellus Shale has received special attention. While increased activity of industries that explore and extract natural resources indisputably creates jobs and increases tax revenues, the experience of many economies based on such industries has been that short-term gains frequently fail to translate into lasting, community-wide economic development. Increasingly, credible research findings have shown that communities dependent on extractive industries can—and often do—end up economically worse-off than if their economic bases had been more diversified, as a result of the crowding out of productive investments in other sectors (James and Aaland, 2010). Regional economies in the Marcellus Shale provide an interesting case study due to the controversy surrounding the potential economic impacts of the drilling (Food and Water Watch, 2011).

To date, policymakers have focused primarily on the environmental and health impacts of gas drilling and to a lesser extent on the broader economic and social transformations associated with this type of natural resource development (Christopherson and Rightor, 2011). Analyses of potential economic impacts of unconventional drilling in Pennsylvania's Marcellus Shale have emphasized the beneficial effects, expected to be experienced statewide, of increased activity of resource extraction industries in economically deprived areas where the gas deposits are to be found. The methodologies that the authors of these analyses have employed—namely, input-output analysis (or I-O) and social accounting matrix (or SAM) analysis—are based on a set of relationships depicting how industrial production must adjust to meet changes in final demand (i.e., demand by final users of goods and services). As will be discussed below, we believe that there are several troubling features of these studies which call into question the perhaps overly optimistic conclusions that their authors have reached. One such feature is the lack of clarity in how estimates of impacts of increased extraction activity were reached, given assumed patterns of industrial expenditures. Another is the demand-side-only approach taken to the study of economic impacts (ignoring supply-side considerations and price effects). A third feature is the level of spatial aggregation at which the analyses in question proceed.

In this article, we examine multiple approaches to conducting regional economic impact analyses of unconventional gas exploration and extraction in the Marcellus Shale. We first revisit the findings of earlier studies of economic impacts obtained with I-O and SAM models at the state level. We then attempt to replicate the findings of these studies, using similar models based on assumptions and data employed in the earlier studies, and compare our impact projections with those previously obtained. We find considerable variance in the model results. Because the impacts of natural gas exploration and extraction are experienced locally, we also proceed with regional/county-level I-O analyses that focus on multiple counties on both sides of the New York and Pennsylvania border. A comparison of our projections with historical data suggests that I-O and SAM analyses may be overly optimistic about the benefits of increased activity in the gas industry. We then proceed to develop and deploy a more comprehensive framework—a regional computable general equilibrium (CGE) model—for studying and understanding the potential economic and social impacts of unconventional exploration and extraction activity in New York State and Pennsylvania at the county level.

2.2 Methodologies of Regional Economic Impact Analysis

Impact analyses of prospective developments in a regional (sub-state) or more aggregate (state or national) economy are usually performed by conducting thought experiments (or simulations) with a computer model representing important relationships—between firms, households, and government entities—within the economy in question. These experiments enable analysts to gain a sense of how an economy or constituent groups within the economy will be affected by 'shocks', which may take the form of increased activity of a particular industry (or interdependent set of industries) in response to external developments, changes in government expenditures or taxes, and/or changes in production techniques or trade relationships. All impact analyses conducted prior to anticipated developments are conjectural; they are more or less informative depending on the extent to which the assumptions upon which they are based are 'true' in large.

Models used to conduct relevant thought experiments tend to be of several types. *I-O models* are based on systems of accounting identities describing patterns of sales between industries and sales by industries to sources of final demand in the forms of consumer goods and services, exports, fixed investment, and government purchases. I-O models can be used to estimate how industrial production must adjust in order to meet changes in final demand and what the economy-wide sales and employment effects will be. *SAM models* are constructed in a fashion similar to I-O models but articulate more finely effects on incomes and expenditures of different demographic groups. SAM models can be used to estimate who will be effected by a prospective development and how. *General-equilibrium models*, whether they are *econometric* (i.e., calibrated by statistical methods from empirical data) or *computable general equilibrium* (CGE) in nature (i.e., calibrated from benchmark data in a SAM by imposing theoretical assumptions), can convey a sense of adjustments on both sides of the market (i.e., supply and demand) and the nature of price and substitution effects that will ensue from a prospective development.

Regional impact analyses conducted with any of these three types of models are usually of a so-called ‘comparative static’ nature; that is, an economy in equilibrium—in the sense that supply and demand in all markets are offsetting—is ‘shocked’ and then reexamined after it has reestablished equilibrium.

Most of the economic impact studies of natural gas development in the Marcellus Shale conducted to date have employed I-O and SAM modeling approaches. These studies (Considine et al., 2009; Considine et al. 2010; Considine et al. 2011; Weinstein and Clower, 2010) have generally predicted positive effects on sales, employment, and fiscal revenue. While the modeling approaches employed in these studies can provide reasonable indications of potential demand-side effects of new economic activity in an area of study in terms of ‘real’ quantities, they can be also be misleading as they fail to account for supply-side constraints or adjustments and price effects.

In order to understand economy-wide impacts of natural gas development, a framework is needed that can capture a range of anticipated and unobserved outcomes, while reproducing certain stylized facts that have been observed in studies of natural gas drilling. We believe that I-O and SAM models are limited in meeting this requirement.

We also believe that a CGE framework, which accurately captures the market structure of the regional economies, can better assist us in assessing the social and economic effects of the drilling while taking into account the interdependence of different agents (e.g., firms, households, government, gas companies) in different regions. By employing such a framework, one can investigate scenarios in which the effects on local economies of increased drilling activity can be gauged through socioeconomic indicators such as sectoral outputs, spending patterns, and employment of various demographic groups.

Ideally, one would like to consider impacts of natural gas drilling in a general-equilibrium framework with a dynamic cast that enables one to investigate both short-term phenomena of a ‘boom and bust’ nature and longer-term developments redolent of the ‘resource curse’ of slower-growing, less-advanced economies that result from the crowding out of more productive investments in other industries (Barth, 2010; Conners et al., 2010; Donaghy, Friesz, and Perez-Burgos, 2010). These phenomena lie beyond the scope of this study, however. In the next subsection, we review evidence from existing studies and compare our findings with analogous analyses.

2.3 Evidence from Multiplier/Demand-driven Models

Most estimates of the economic impacts of unconventional gas drilling in the Marcellus Shale have come from studies in which static I-O models have been employed. The models have been calibrated with data on industrial purchase patterns that existed prior to the increased activity in the extractive sector and data from surveys conducted in places where hydrofracking drilling has already begun. In particular, the study by Considine et al. (2009) was the first attempt to estimate the economic impact of the Marcellus Shale in the Northeast economy. In their study, the authors focused on the impacts on the economy of the State of Pennsylvania through the use of I-O tables obtained from the Minnesota IMPLAN Group, Inc., which were derived from data produced by the Bureau of Economic Analysis in the US Department of Commerce. Use of the

IMPLAN tables allowed Considine et al. to estimate the employment and sales multipliers for natural gas exploration, development, and production as well as the effects of increased extraction activity on other sectors of the economy.

Since increased activity in the natural gas industry is relatively recent in the State of Pennsylvania, I-O tables preceding the increased activity cannot accurately capture the effects of the industry's activity on the economy. To obtain estimates of expenditure patterns for relevant industries that better characterize the current state of affairs, the authors used surveys to estimate purchases by the gas industry from other businesses as well as data on payroll expenditures, payments to landowners, and royalties and taxes paid to governments.

Table 2.1 presents a summary of all economic impact estimates based on the industry spending patterns estimated by Considine et al. (2011). For the benchmark year 2008, the authors found that gas drilling companies spent over $3.2 B, most of which was within the state (95 %). Of expenditures made within the state, 69% were payments to landowners, 29 percent were payments to suppliers, and the remaining 2 percent were spent between payroll and taxes. The preliminary projections of Considine et al. show that, while leases and bonuses comprised the majority of expenses of gas drilling companies in 2008 and 2009, the costs of drilling and completion activities soon surpassed them and grew to an estimated $9.3 billion in 2012. Interestingly, projections for New York State are not as promising as in Pennsylvania. With this analysis, the authors show that the gas drilling activity would not reach $2.2 billion in spending until 2020.

On the basis of their estimates of gas industry expenditure patterns, Considine et al. proceeded to calculate the economic impact of increased Marcellus Shale gas industry activity in

Pennsylvania. Their calculations indicate a direct economic stimulus of $2.18 billion as well as $868 million and $1.17 billion of indirect and induced spending, respectively, for a total of $4.2 billion. These impact projections imply an estimated output multiplier of 1.94 for the industry as well as impacts on Pennsylvania's employment of nearly 30,000 new jobs, which imply a multiplier of 6.9 jobs per $1 million of new industrial activity. According to the estimates of Considine et al., total tax revenues should increase by over $600 million. Finally, using a linear econometric model, the authors estimated that over the next ten years (i.e., 2010 to 2020), this growth trend would continue in the state of Pennsylvania, generating a total of 175,000 jobs, over $13 billion in value added, and $12B in tax revenues. These are extraordinary magnitudes, indeed.

On the basis of gas industry expenditure patterns, Considine et al. have also extrapolated potential impacts of increased gas industry activity in New York State. Employing the same methodology as in their 2009 study, the authors' estimates show that if drilling were to occur in New York State's Marcellus Shale, it could result in an increase of $1.7 billion in value added, over 15,000 jobs and $214 million in local and state tax revenues (Considine, 2011). These projections have been cited in policy briefings advocating for the development of the industry in New York (Public Policy Institute of New York State, 2011); however, they are not without controversy since they imply significant positive transformations for the regional economy in the short term. Other studies have challenged these results by arguing that payments to landowners will not stay in the state's economy and that some of the high-paying gas industry jobs would be outsourced elsewhere (Food Water Watch Report, 2011). In the next section, we present the findings of our efforts to replicate the projections discussed above.

2.4 Replicated Impact Analyses

As discussed above, it has been estimated that the economic impact of natural gas drilling on the Marcellus Shale is such that each well in Pennsylvania generates on average $6.2 million of economic impact (Considine, 2010). On the basis of the figures employed in this study, for the State of Pennsylvania alone, the drilling of 364 wells in 2008 generated over $2.2 billion in value added, over 29,000 jobs, and $591 million in state ($238 million) and federal ($354 million) taxes. Indeed, the natural gas industry grew significantly in Pennsylvania between 2008 and 2009; over 763 wells were drilled. This expansion represented over $3.8 billion in value added, over 44,000 jobs, and $1.4 billion in state ($389 million) and federal ($1,056 million) taxes.

Table 2.1 Natural Gas Spending Estimates for Pennsylvania and New York State (millions)

	Pennsylvania					New York State		
	2008	2009	2010*	2011*	2012*	2011**	2015**	2020**
Lease & Bonus	1,837.70	2,172.40	2,068.50	759	481.6	66.6	502.2	502.2
Exploration	121.9	117.1	208.4	143.3	167.1	5.9	68.9	73.8
Drilling & Completion	857.8	2,151.00	7,377.00	8,295.10	9,294.60	78.2	918.5	984
Pipeline & Processing	329.4	698.6	1,303.90	2,633.80	2,768.40	19.1	224.5	240.5
Royalties	22.2	53.4	346	734.7	1,863.00	0	152.3	373.5
Other	55.5	91.4	173.3	166.7	73	2.9	33.5	35.9
Total Spending	3,224.60	5,283.90	11,477.10	12,732.60	14,647.80	172.6	1,899.90	2,209.90
Wells Drilled	364	763	1,454	2,300	2,415	14	304	330

Source: Considine 2010, 2011

* Preliminary

** Projected

Table 2.2 Economic Impact of Gas Drilling in Pennsylvania 2008-2012

	2008	2009	2010	2011*	2012*
Wells drilled	364	763	1,454	2,300	2,415
Value-added (billion)	2.20	3.80	11.16	12.84	14.53
Jobs	29,284	44,098	139,889	159,695	181,335
Federal taxes (million)	354	1,057	1,439		
State/local taxes (million)	239	389	1,085	2,285	2,485

Source: Considine 2011

Over 1,454 wells were drilled in Pennsylvania in 2010, which means that, if the per-well figures are accurate, there was an economic impact of over $11 billion, using the $6.2 million per well assumption from before. If we look at specific regions, the northeastern tier of the state was one of the regions where most of the drilling took place, particularly in Tioga and Bradford counties. Between 2009 and 2010, the number of wells drilled in these two counties grew by 192 percent from 227 to 662 wells.

Based on the results of Considine et al.'s 2009 survey of gas industry spending patterns,[1] we have estimated the effect of new industry activity on Pennsylvania's state economy using a multiplier approach for the year 2008. Tables 2.3, 2.4, and 2.5 present the results of this analysis. Table 2.3 presents the results obtained by Considine et al., Table 2.4 presents the results of our efforts to replicate their study, and Table 2.5 presents a comparison between (ratios of)

---

[1] For a detailed analysis, please see appendix 1

their previous estimates and ours. These results illustrate the main effects on the gross output, value added, and employment of our calculations against Considine et al.'s estimated effects. The figures in these tables show that most of Considine et al.'s estimated direct, indirect, and induced economic impacts are higher than the impacts we have calculated with the same gas industry spending pattern, sectoral aggregation, and IMPLAN data. In terms of total effects in gross output, value added, and number of jobs, Considine et al.'s numbers are at least 1.5 times higher than ours.

Table 2.3 Summary of Economic Impacts 2008 (millions)

	Gross Output				Value Added				Employment			
Sector.	Direct	Indirect	Induced	Total	Direct	Indirect	Induced	Total	Direct	Indirect	Induced	Total
Ag, Forestry, Fish & Hunting.	8	9.6	8.8	26.4	3.2	3.9	3.4	10.5	65	97	98	259
Mining (oil, gas, and minerals).	614.5	12.4	5.5	632.5	270.3	6.9	3.3	280.5	2,101	34	13	2,148
Utilities.	24.1	26.3	30.9	81.3	15.6	15.7	19.9	51.2	47	28	36	111
Construction.	458.1	12.7	9.5	480.3	207	6.6	5	218.6	3,611	109	75	3,795
Manufacturing.	80	162.4	134	376.4	20	43.9	32.9	96.8	162	418	280	860
Wholesale Trade.	293.4	56.9	61.3	411.6	191	37.1	39.9	268	1,568	304	327	2,200
Transportation & Warehousing.	130.2	7.7	124.5	262.4	90.5	5.3	85.9	181.8	1,900	120	1,979	3,998
Retail Trade.	50.3	53.6	31.9	135.9	25.2	29	16	70.1	366	421	239	1,027
Information.	14.5	36.4	35.5	86.4	7.2	17	16.8	40.9	49	120	120	290
Finance & Insurance.	37.9	92	105	235	18.8	48.7	52.8	120.3	148	412	435	995
Real Estate & Rental.	99.6	77.4	192.8	369.8	68.6	55.3	134.8	258.7	174	377	405	957
Professional Services -Scientific & Technical.	98.3	161	54.8	314.1	69.8	101.1	34.9	205.8	528	1,231	395	2,154
Management of Companies.	0	47.9	13.6	61.5	0	28.3	8.1	36.4	-	201	57	258
Administrative & Waste Services.	14.8	49	25.2	89	7.8	29.2	14.7	51.7	200	773	382	1,355
Educational Services.	18.2	1	23.5	42.6	10.4	0.6	13.5	24.5	266	15	362	643
Health & Social Services.	132.7	1.4	177.6	311.6	82.9	0.8	110.2	193.9	1,569	11	1,997	3,577
Arts -Entertainment & Recreation.	10.8	3.4	15.3	29.5	6.5	1.9	9.1	17.5	209	75	297	580
Accommodation & Food Services.	38.8	17.7	59.1	115.7	19	8.9	28.8	56.7	694	305	1,068	2,066
Other Services.	32.2	22.7	48.3	103.1	16.2	12	24.7	52.9	550	269	828	1,647
Government & Other.	11.6	16.4	20.3	48.4	5.8	10.4	9.9	26.1	97	128	139	364
Institutions.	12.1			12.1								
Total.	2,180	868	1,177	4,226	1,136	462.8	664	2,263	14,307	5,446	9,531	29,284

Source: Considine et. al. 2009

A closer look at the effects reveals that most of the over-estimation is concentrated in the direct effects where differences of over 166 times are evident in the Real Estate and Rental sector for the gross output measure. On the other hand, it is interesting to see that our estimated total induced effects are 15 percent lower on average than the estimates obtained by Considine et al.

(2011). Overall, on the basis of IMPLAN's 2009 data, our analysis of the gas industry's impact on the economies of two Pennsylvania counties indicates that every $1 spent by the industry in the state generated $1.36 of total economic output. This estimate differs significantly from the $1.94 calculated by Considine et al., but it is closer to evidence found in other studies where the obtained multiplier has ranged between $1.34 and $1.55.[2]

Table 2.4 Replicated Summary of Economic Impacts 2008

	Gross Output				Value Added				Employment			
Sector.	Direct	Indirect	Induced	Total	Direct	Indirect	Induced	Total	Direct	Indirect	Induced	Total
Ag, Forestry, Fish & Hunting.	3.4	1.0	2.6	7.0	1.1	0.3	0.8	2.3	49	15	37	101
Mining (oil, gas, and minerals).	334.1	12.4	3.9	350.4	161.0	6.0	1.9	168.8	1,170	43	14	1,227
Utilities.	4.0	9.1	25.9	39.0	2.3	5.3	15.1	22.8	5	11	32	48
Construction.	259.0	6.4	89.9	355.3	129.0	3.2	44.8	177.0	2,132	53	740	2,924
Manufacturing.	6.4	43.4	94.4	144.2	1.8	12.2	26.4	40.4	14	97	211	323
Wholesale Trade.	141.1	25.1	61.5	227.7	90.6	16.1	39.4	146.1	695	124	303	1,121
Transportation & Warehousing.	26.1	9.9	86.8	122.8	22.0	8.3	73.1	103.5	466	177	1,549	2,191
Retail Trade.	21.5	20.1	32.6	74.1	11.7	11.0	17.8	40.5	171	160	259	590
Information.	0.3	14.9	47.5	62.7	0.2	7.9	25.4	33.5	1	51	164	216
Finance & Insurance.	0.4	23.7	124.8	148.9	0.2	13.9	73.0	87.1	2	102	537	641
Real Estate & Rental.	0.6	39.5	172.4	212.5	0.4	27.5	119.9	147.8	2	123	537	662
Professional Services -Scientific & Technical.	48.5	53.0	80.1	181.6	34.4	37.6	56.8	128.9	380	416	628	1,423
Management of Companies.		16.8	12.4	29.3		11.4	8.4	19.8		79	58	137
Administrative & Waste Services.	6.8	14.0	31.3	52.0	4.4	9.0	20.2	33.6	106	218	488	811
Educational Services.	0.9	0.2	24.1	25.2	0.6	0.1	15.0	15.7	13	3	346	362
Health & Social Services.	0.9		167.1	168.1	0.5		99.4	99.9	10		1,798	1,808
Arts -Entertainment & Recreation.	0.4	1.1	14.4	16.0	0.2	0.7	8.9	9.9	7	20	255	282
Accommodation & Food Services.	0.5	3.9	45.7	50.0	0.3	2.0	23.7	26.0	9	67	795	871
Other Services.	0.9	7.0	47.9	55.8	0.5	4.0	27.7	32.2	13	104	712	829
Government & Other. Institutions.		7.8	113.8	121.6		6.6	96.8	103.4		105	1,534	1,638
Total.	855.8	309.3	1,279.0	2,444.1	461.3	183.2	794.5	1,438.9	5,244.0	1,967.9	10,994.2	18,206.1

Finally, another important difference from previous work on economic impacts of the gas industry is the effects of these impacts on taxes. Table 2.6 provides a summary of these results. According to Considine et al. (date), the new industry could generate a total of $593 million between state and local ($239 million) and federal ($354 million) taxes for Pennsylvania. Our estimates are more conservative and show that this activity potentially could generate a total of

---

[2] Baumann et. al (2002) found a 1.34 multiplier in their study of the impacts of oil and gas activities on the Louisiana economy. Walker and Sonora (2005) assume an output multiplier of 1.43 in a study of the economic impacts of the natural gas industry in New Mexico. The study by Snead (2002) finds an output multiplier of 1.55 for Oklahoma.

$326 million in taxes—more specifically, $142 million in state and local tax revenues and $184 million in federal.

Table 2.5 Comparison of Economic Impacts 2008 (millions)

	Considine	D&PB	Ratio
Gross Output			
Direct	2,180	855.8	2.55
Indirect	868	309.3	2.81
Induced	1,177	1,279.0	0.92
Total	4,226	2,444.1	1.73
Value Added			
Direct	1,136	461.3	2.46
Indirect	462.8	183.2	2.53
Induced	664	794.5	0.84
Total	2,263	1,438.9	1.57
Employment			
Direct	14,307	5,244.0	2.73
Indirect	5,446	1,967.9	2.77
Induced	9,531	10,994.2	0.87
Total	29,284	18,206.1	1.61

Source: Considine 2011, authors calculations

Table 2.6 Tax Impacts in millions of 2008 dollars

	Considine	Revisted
Total State and Local Tax	239	142
Total Federal Tax	354	184
Total	593	326

Source: Considine 2009, authors' calculations

2.5 Economic Impact of the Gas Industry at the County Level

Even though previous economic impact studies of the gas industry in the Marcellus Shale region have used state-wide data for their analysis, it is important to recognize that the drilling and exploration activities have been concentrated within a smaller, sub-state geographical area. In the case of Pennsylvania, most of the drilling has taken place in the southwestern and northeastern tiers of the state. In the following section, we use IMPLAN's county-level data to calculate the impacts of the gas industry development in Bradford and Tioga counties, where most of the drilling in Pennsylvania has taken place.

For this exercise, we use Considine et al.'s gas industry spending pattern on a per-well-drilled basis for the year 2008, which can be found in Appendix 2. In 2008, according to these estimates, 364 wells were drilled in Pennsylvania, each of which generated $6.2 million in total value added. Table 2.7 delineates the number of wells drilled in Bradford and Tioga counties between 2008 and 2011.

Table 2.7 Wells Drilled in Pennsylvania 2008-2011

	2008	2009	2010	2011	TOTAL
Bradford	28	113	386	408	935
Tioga	11	114	266	268	659

Source: Pennsylvania's Department of Environmental Protection 2012

As is clear from this evidence, the industry has grown at a very high rate in this area of the state. According to Pennsylvania's Department of Environmental Protection, this trend will continue; in fact, just in the month of January 2012, a total of 75 and 50 well permits were issued in Bradford and Tioga counties, respectively.

An urgent question then is "what have been the economic impacts of this new activity on these local economies?" Using the per-well spending patterns given in Appendix 2, we have calculated the effects on gross output, value added, employment, and taxes of the gas industry for these counties between 2008 and 2011. Table 2.8 presents the projected economic impacts for these counties.

Table 2.8 Summary of Total Economic Impacts (millions)

	2008	2009	2010	2011
Bradford				
Output	103.87	425.34	1,475.25	1,584.28
Value-added	56.89	231.71	807.60	870.98
Employment	966	3,896	13,310	14,068
State and Local Ta	5	22	77	83
Federal Tax	7	28	96	104
Tioga				
Output	388	4,018	9,376	9,447
Value-added	23.14	242.04	576.23	592.36
Employment	42	445	1,065	1,101
State and Local Ta	2.4	24.7	58.9	60.5
Federal Tax	2.8	29.4	69.9	71.9

Source: IMPLAN and authors calculations

The changes portrayed in Table 2.8 are especially dramatic for Bradford County, where the gas industry's value added is estimated to have increased from a modest $57 million in 2008 to $870 million in 2011, creating a total of 32,240 new jobs over that three-year period. Tioga's economy shows some potential changes but none nearly as big as in Bradford's case.

It is important to ask here how feasible these projections are. Table 2.9 shows the data for personal income and employment for the two counties estimated by the Bureau of Economic Analysis. As can be seen, actual changes are far smaller than the economic impact projections. In the case of employment, the numbers of jobs actually decreased between 2008 and 2009 and then recovered slightly for 2010. These findings contrast markedly with the 13,310 and 1,065 new jobs projected to result from the gas activity in Bradford and Tioga in 2010, respectively.

Table 2.9 Regional Economic Profile

	2008	2009	2010
Bradford			
Personal Income	1,834	1,819	1,954
Employment	31,151	30,955	32,797
Tioga			
Personal Income	1,090	1,092	1,154
Employment	18,730	18,265	18,647

Source: BEA 2012

This evidence reported in Table 2.9 supports the conclusion that the cited estimated economic impacts of the industry, obtained by using an I-O multiplier approach, may overestimate the effects of the new economic activity and fail to capture the reality that this type of rapid economic transformation brings changes not only to the places where it occurs but also in surrounding areas. In the case of Bradford and Tioga counties, it is not absurd to think that the economic impacts might cross state borders, even though drilling is not permitted in New York State. A regional CGE framework would allow us to investigate this kind of phenomena; hence, we present such a framework in the following section.

2.6 A Regional Computable General Equilibrium Framework

While analysis at the county level will be important to improving our understanding of the potential economic impacts of unconventional gas drilling in the Marcellus Shale, concerns about realism suggest a clear need to move beyond I-O analysis. To provide such an analysis, we shall develop and employ a CGE model for three counties in New York State (Broome, Chemung, and Tioga) as well as two in Pennsylvania (Bradford and Tioga) in order to capture some of the cross-border effects of the drilling. Before doing so, however, we provide a description of these local economies using IMPLAN data for the year 2009, our benchmark year.

Table 2.10 Regional Economic Indicators

	NY			PA		
	Broome	Chemung	Tioga	Bradford	Tioga	TOTAL
GRP	$7,228,937,544	$2,853,511,666	$1,194,067,360	$1,662,127,980	$903,731,868	$13,842,376,418
Total Personal Income	$6,650,734,000	$2,822,779,000	$1,683,720,000	$1,865,207,000	$1,065,093,000	$14,087,533,000
Total Employment	103,321	42,724	16,495	27,523	16,360	206,423
Number of Industries	13	14	11	14	14	
Land Area (Sq. Miles)	707	408	519	1,151	1,134	3,919
Population	194,630	88,331	50,064	61,131	40,875	435,031
Total Households	79,562	34,466	19,372	25,057	16,587	175,044
Average Household Income	$83,592	$81,899	$86,914	$74,438	$64,211	$78,211

Source: IMPLAN 2009

Table 2.10 provides a summary of the regional economic indicators for the five border counties chosen for our analysis. From the data provided, it is clear that Broome County in New York State represents over 50 percent of the region's output and population. Notably, this regional economy is mostly driven by manufacturing activities, which represent over 50 percent of the GRP. The region's main urban areas are located in the cities of Elmira and Binghamton, which are in Chemung and Broome Counties, respectively.

Our CGE model incorporates activities of the producer, the consumer and the institutions in a certain region. The flow of goods shows how producers pay wages to consumers to spend on the final goods (Fig. 2.1). When the economy depicted by such a model is in equilibrium, all of the goods produced and demanded are equal. Finally, the capital flow allows us to capture the investment impact arising from the changes in the final demand (Fig. 2.2).

Although normally employed to address issues from a macroeconomic perspective, CGE models can also process detailed information at a regional or sub-regional level (Partridge and Rickman, 2007). For example, such models can support analyses of the impact of expenditures by the natural gas industry on different regional industries, households, and institutions.

We have constructed our prototype static regional CGE model for five counties in the Marcellus Shale by adopting some assumptions made about small open economies. Included among these is the assumption that export and import prices are not affected by the behavior of the regional economy. In developing the modeling framework, we have also exploited the set of GAMS (General Algebraic Modeling System) routines developed by Rausch and Rutherford (2008) for building national economic models using state-level IMPLAN social accounts.

Figure 2.1 Circular Flow of Goods

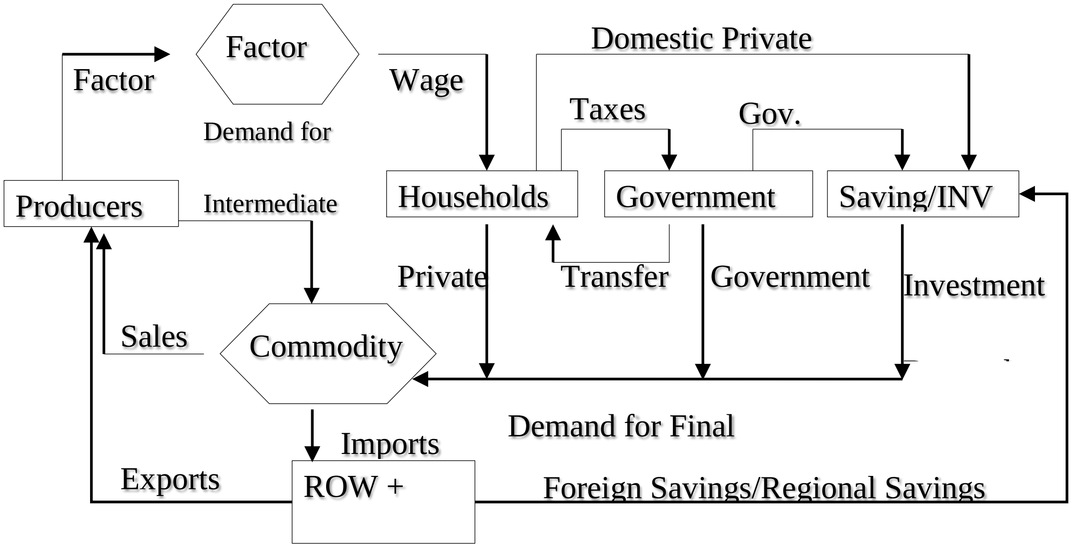
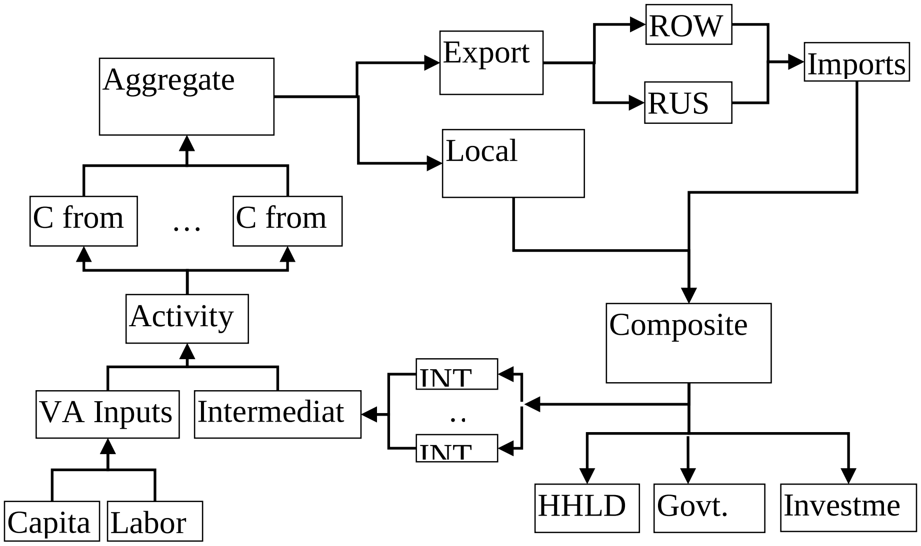


Figure 2.2 Circular Flow of Income



2.6.1 The Regional CGE Model

The following are the activity levels and relative price variables for goods and factors to be determined by the model:

ACTIVITY LEVELS

Variable	Description
$Y_{s,r}$	Sectoral production
$A_{s,r}$	Armington aggregation
$C_{h,r}$	Consumption by household
$GOV_{pub,r}$	Public output
INV_r	Investment
$RH_{h,r}$	Income of representative households
$GOVT_{pub,r}$	Income of government agents
TAXREV	Income of tax revenue agent

PRICES

Variable	Description
$py_{s,r}$	Sectoral output prices
$p_{s,r}$	Price for domestic output
$pa_{s,r}$	Armington aggregate prices
$pc_{h,r}$	Consumption by household
pn_s	Intra-national trade price
$pinv_r$	New investment
$pgov_{pub,r}$	Public output
$pf_{fa,r}$	Factor prices
pfx	Foreign exchange
$ptax_r$	Business taxes

In perfect competitive equilibrium, we assume both producers and consumers to be optimizing. Given this fact, we can assume that profit maximization in the constant-returns-to-scale setting is equivalent to cost minimization subject to technical constraints.

For sector $Y_{s,r}$, we characterize input choices as though they arose from minimization of unit costs:

$$min_{ddifm_{g,s,r},dfm_{f,s,r}} \ c^A_{s,r} + c^F_{s,r} + c^{BT} \quad (0.1)$$

s.t.

$$c^A_{s,r} = \sum_g pa_{g,r} \, ddifm_{g,s,r}$$

$$c^F_{s,r} = \sum_{fa} pf_{fa,r}\, dfm_{fa,s,r}$$

$$c^{BT} = ptax\, dfm_{btax,s,r}$$

$$F_{s,r}(ddifm_{g,s,r}, dfm_{f,s,r}) = Y_{s,r}$$

where $ddifm_{g,s,r}$ represents the intermediate demand for imported good *g* in the production of good *s* in region *r*; and $dfm_{fa,s,r}$ represents the factor demand in the production of good *s* in region *r*. The transformation function $F(\cdot)$ is described by a nested constant-elasticity-of-substitution (CES) with *s:0 va:1*.

The supply of output $Y_{s,r}$ to domestic and trade (domestic and foreign) markets is portrayed as arising from the following profit-maximization problem:

$$max_{sdmi_{s,r}, sxm_{s,trd,r}}\ p_{s,r}\, sdmi_{s,r} + pfx\, sxm_{s,ftrd,r} + pn_s\, sxm_{s,dtrd,r}$$

s.t.

$$Y_{s,r} = \Gamma_{s,r}(sdmi_{s,r}, sxm_{s,trd,r})$$

The production function $\Gamma(\cdot)$ is described by a constant-elasticity-of-transformation (CET) with *t:2*.

The choice among imports from different trading partners (e.g., domestic, domestic and foreign trade) is based on Armington's idea of regionally differentiated products. This is reflected by the following cost minimization problem:

$$min_{ddmi_{s,r},dim_{s,trd,r}}\ p_{s,r}\ ddmi_{s,r} + pfx\, dim_{s,ftrd,r} + pn_s\ dim_{s,dtrd,r}$$

s.t.

$$F^{A}_{s,r}(ddmi_{s,r}, dim_{s,trd,r}) \ = A_{s,r}$$

The import aggregation function portrayed by $F^{A}(\cdot)$ in {eq:armington_aggregation} is described by the nested CES function with *s:4 and m:8*.

The investment demand is represented by a fixed coefficient (Leontief) aggregation of Armington goods. Its production can be portrayed by the following cost minimization problem:

$$min_{dinvd_{s,r}} \sum_{s} pa_{s,r}\ dinvd_{s,r}$$

s.t.

$$F^{INV}_{r}(dinvd_{s,r}) \ = INV_r$$

where the respective production function portrayed by $F^{INV}(\cdot)$ is described by a Leontief function.

Similarly, public consumption in the model is a Leontief (linear) composite of Armington goods. Its production can be portrayed by the following cost minimization problem:

$$min_{ddgm_{s,pub,r},digm_{s,trd}} \sum_{s} pa_{s,r}\left(ddgm_{s,pub,r} + \sum_{trd} digm_{s,trd,pub,r} \right)$$

s.t.

$$F_{pub,r}^{GOV}(ddgm_{s,pub,r}, digm_{s,trd}) \ = GOV_{pub,r}$$

Private consumption consistent with utility maximization is portrayed by minimization of the cost of a given level of aggregate consumption:

$$min_{ddpm_{s,h,r}, dipm_{s,h}} \sum_{s} pa_{s,r} \left(ddpm_{s,h,r} + \sum_{trd} dipm_{s,trd,h,r} \right)$$

s.t.

$$F_{h,r}^{C}(ddpm_{s,h,r}, dipm_{s,h}) \ = C_{h,r}$$

Final demand in the model is characterized by a Cobb-Douglas tradeoff across composite goods which include both domestic and imported inputs. The nested CD-CES function includes *s:1.*

We now define the general equilibrium of the model in a complementarity format. Rutherford (1995) and Mathiesen (1985) have shown that a complementary-based approach is convenient, robust, and efficient. A characteristic of economic models is that they naturally involve a complementary problem, i.e., given a function $F: \mathbb{R}^n \to \mathbb{R}^n$, find $z \in \mathbb{R}^n$ such that $F(z) \geq 0$, $z \geq 0$, and $z^T F(z) = 0$.

Equilibrium in a complementarity format is represented by a vector of activity levels, a non-negative vector of prices, and a non-negative vector of incomes such that:

a) No production activity makes a positive profit (zero profit conditions);

b) Excess supply (supply minus demand) is non-negative for all goods and factors (market clearance conditions); and

c) Expenditure does not exceed income (budget constraints).

Zero-profit conditions exhibit complementary slackness with respect to associated activity levels; market clearing conditions exhibit complementary slackness with respect to market prices; and budget constraints define income variables. To clarify exposition, we denote benchmark data parameters with a bar “–"' to distinguish them from model variables.

Zero-profit conditions

All production activities in the model are represented by constant-returns-to-scale technologies, and markets are assumed to operate competitively with free entry and exit.

Consequently, equilibrium profits are driven to zero and the price of output reflects the cost of inputs. The following sets of equations relating marginal cost (LHS) to output prices (RHS) are part of the definition of an equilibrium (NB: we indicate the complementarity aspects by writing associated variables in parentheses):

Sectoral production ($Y_{s,r}$):

$$\theta^{i}_{s,r}\, ca_{s,r} + \theta^{fa}_{s,r}\, cf_{s,r} + \theta^{t}_{s,r}\, ptax_{r} = py_{s,r} \quad itcf_{s,r} = \prod_{fa} \left(pf_{fa,r} \right)^{\theta_{fr,r}}$$

$$ca_{s,r} = \sum_{g} \theta^{a}_{g,r}\, pa_{g,s}$$

$$py_{s,s} = \left(\theta^{d}_{s,r}\, p^{1+\eta}_{s,r} + \theta^{fx}_{s,r}\, pfx^{1+\eta} + \theta^{nt}_{s,r}\, pn^{1+\eta}_{s} \right)^{1/(1+\eta)}$$

Armington aggregation ($A_{s,r}$):

$$(\theta_{s,r}\, p_{s,r}^{1-\sigma_a} + \sum_{trd} \theta^{ar}_{trd,s,r}\, cfn_{s,r}^{1-\sigma_a})^{1/(1-\sigma_a)} = pa_{s,s}$$

where

$$itcfn_{s,r} = \left(\theta^{ftrd}_{s,r}\, pfx^{1-\sigma_t} + (1-\theta^{ftrd}_{s,r})\, pn_s^{1-\sigma_t}\right)^{1/(1-\sigma_t)}$$

Investment (INV_r):

$$sum_s\, pa_{s,r}\, \overline{vinvd}_{s,r} = pinv_r\, \overline{vinv}_r$$

Public consumption ($GOV_{r,pub}$):

$$\sum_s pa_{s,r} \left(\overline{vdgm}_{s,pub,r} + \sum_{trd} \overline{vigm}_{s,trd,pub,r} \right) = pgov_{pub,r}\, \overline{vgm}_{pub,r}$$

Private consumption ($C_{r,h}$):

$$\prod_s (pa_{s,r})^{\theta^c_{s,h,r}} = pc_{h,r} \, .$$

The values of shares from the benchmark data used in the zero profit conditions above are given by:

$$\theta^i_{s,r} = \frac{\sum_g \overline{vdifm}_{g,s,r}}{\overline{vdmi}_{s,r} + \sum_{trd} \overline{vxm}_{s,trd}} \, ,$$

$$\theta_{s,r}^{fa} = \frac{\sum_{fa} \overline{vfm}_{fa,s,r}}{\overline{vdmi}_{s,r} + \sum_{trd} \overline{vxm}_{s,trd}},$$

$$\theta_{s,r}^{t} = \frac{\overline{vfm}_{btax,s,r}}{\overline{vdmi}_{s,r} + \sum_{trd} \overline{vxm}_{s,trd}},$$

$$\theta_{fr,r} = \frac{\overline{vfm}_{fa,s,r}}{\sum_{fa'} \overline{vfm}_{fa',s,r}},$$

$$\theta_{g,r}^{a} = \frac{\overline{vdifm}_{g,s,r}}{\sum_{g'} \overline{vdifm}_{g',s,r}},$$

$$\theta_{s,r}^{d} = \frac{\overline{vdmi}_{s,r}}{\overline{vdmi}_{s,r} + \sum_{trd} \overline{vxm}_{s,trd,r}},$$

$$\theta_{s,r}^{fx} = \frac{\overline{vxm}_{s,ftrd,r}}{\overline{vdmi}_{s,r} + \sum_{trd} \overline{vxm}_{s,trd,r}},$$

$$\theta_{s,r}^{nt} = \frac{\overline{vxm}_{s,dtrd,r}}{\overline{vdmi}_{s,r} + \sum_{trd} \overline{vxm}_{s,trd,r}},$$

$$\theta_{trd,s,r}^{ar} = \frac{\overline{vdmi}_{s,r}}{\overline{va}_{s,r}},$$

$$\theta_{s,r}^{ftrd} = \frac{\overline{vim}_{s,ftrd,r}}{\sum_{trd} \overline{vim}_{s,trd,r}}, \text{ and}$$

$$\theta_{s,h,r}^{c} = \frac{\overline{vdpm}_{s,h,r} + \sum_{trd} \overline{vipm}_{s,trd,h}}{\sum_{s'} \overline{vdpm}_{s',h,r}}$$

Market clearance conditions

Market clearance conditions exhibit complementary slackness with respect to prices. We make use of Shepard's Lemma to derive conditional demand from unit cost functions. Demand components are related to the notation used in the primal formulation of the model by using braces below the respective terms on the RHS of market clearance conditions. The following sets of equations relating supply (LHS) to demands (RHS) are part of the definition of an equilibrium (NB: the variables in parentheses denote the associated price variable for each condition).

Market for domestic output ($p_{r,s}$):

$$Y_{s,r}\left(\frac{p_{s,r}}{py_{s,r}}\right)^{\eta} = \underbrace{A_{s,r}\left(\frac{pa_{s,r}}{p_{s,r}}\right)^{\sigma_a}}_{=dmi_{s,r}} .$$

Market for Armington aggregation ($pa_{r,s}$):

$$\overline{va}_{s,r}\, A_{s,r} = \sum_{g} \underbrace{\overline{vdifm}_{g,s,r}\, Y_{s,r}}_{ddifm_{g,s,r}}$$

$$+ \sum_{h} \underbrace{\left(\overline{vdpm}_{s,h,r} + \sum_{trd} \overline{vipm}_{s,trd,h,r} \frac{pc_{h,r}}{pa_{s,r}}\right) C_{h,r}}_{=ddpm_{s,h,r}+dipm_{s,trd,h,r}}$$

$$+ \underbrace{\overline{vinvd}_{s,r}\, INV_{r}}_{=dinvd_{s,r}}$$

$$+ sum_{pub} \underbrace{\left(\overline{vdgm}_{s,r,pub} + \sum_{trd} \overline{vigm}_{s,trd,pub}\right) GOV_{pub,r}}_{=ddgm_{s,pub,r}+digm_{s,trd,pub,r}}$$

Market for intra-national trade (pn_s):

$$\sum_r \overline{vxm}_{s,dtrd,r} Y_{s,r} \left(\frac{pn_s}{py_{s,r}}\right)^{\eta} = \sum_r \underbrace{A_{s,r}\overline{vim}_{s,dtrd,r}\left(\frac{pa_{s,r}}{cfn_{s,r}}\right)^{\sigma_a}\left(\frac{cfn_{s,r}}{pn_s}\right)^{\sigma_t}}_{=dim_{s,dtrd,r}}.$$

Market for investment ($pinv_r$):

$$\overline{vinv}_r\, INV_r = \sum_h \overline{vinvh}_{h,r}.$$

Market for public consumption ($pgov_{pub,r}$):

$$\overline{vgm}_{pub,r}\, GOV_{pub,r}\, pgov_{pub,r} = GOVT_{pub,r}.$$

Market for primary factors ($pf_{fa,r}$):

$$\sum_h evo_{h,fa,r} = \sum_s \underbrace{\overline{vfm}_{fa,s,r}\, Y_{s,r}\frac{cf_{s,r}}{pf_{fa,r}}}_{=dfm_{s,fa,r}}.$$

Market for foreign exchange (pfx):

$$\sum_r \sum_h \overline{incadj}_{h,r} + \sum_{pub,r} \overline{vgm}_{pub,r} + \sum_r \sum_s \overline{vxm}_{s,ftrd,r} Y_{s,r}\left(\frac{pfx}{py_{s,r}}\right)^{\eta} = \sum_r \sum_s dfx_{s,r} + \sum_r \frac{TAXREV_r}{pfx}$$

where

$$dfx_{s,r} = \underbrace{A_{s,r}\,\overline{vim}_{s,,ftrd,r}\left(\frac{pa_{s,r}}{cfn_{s,r}}\right)^{\sigma_a}\left(\frac{cfn_{s,r}}{pfx}\right)^{\sigma_t}}_{=dim_{s,ftrd,r}}.$$

Market for private consumption ($pc_{r,h}$):

$$vpm_{h,r}\,C_{h,r}\,pc_{h,r} = rh_{h,r}.$$

Market for business taxes ($ptax$):

$$\sum_s \overline{vfm}_{btax,s,r} = \sum_s \overline{vfm}_{btax,s,r}\,Y_{s,r}.$$

Income definitions

Private income ($RH_{h,r}$):

$$RH_{h,r} = \sum_{fa} pf_{fa,r}\,\overline{evo}_{h,fa,r} + pfx\,\overline{incadj}_{h,r} + pinv_r\,(-\overline{vinvh}_{h,r}).$$

Public income ($GOVT_{pub,r}$):

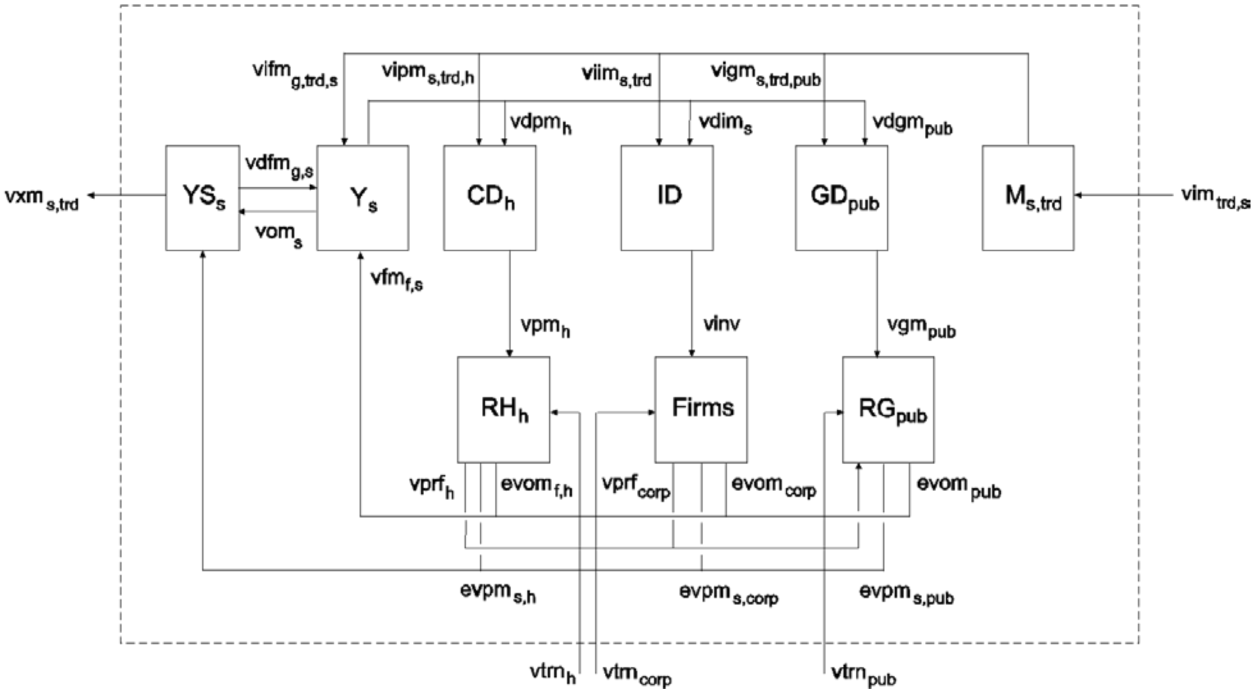
$$GOVT_{pub,r} = pfx\,\overline{vgm}_{pub,r}.$$

Income of tax revenue agent ($TAXREV_r$):

$$TAXREV_r = ptax_r \sum_s \overline{vfm}_{btax,s,r} .$$

This completes the sets of equations that describe the equilibrium conditions. The general equilibrium is defined by equations (x) - (y). Figure 2.3 shows a graphical representation of the regional Computable General Equilibrium Model.

Figure 2.3 Regional Economic Structure



The implementation of the model begins with the calibration of the previous equations with IMPLAN county data to obtain a benchmark equilibrium solution that satisfies the standard theoretical assumptions or conditions, including zero-profit, market-clearance, and income-balance conditions.[3] To obtain this solution, we had to extract the SAMs for each county and

---

[3] While these assumptions are blatantly false, they are considered to impose less violence to reality than the previous analytical frameworks we have considered.

check whether the accounting identities were satisfied. Trade adjustments were performed in the SAMs where equilibrium conditions were not satisfied,. Adjustments were made via a non-linear programming approach provided by one of the GAMS routines mentioned earlier. Finally, with the re-calibrated equations and adjusted data in hand, we solved the model and achieved the benchmark equilibrium for variables of interest, such as gross output or employment. The benchmark equilibrium solution provides the basis for analyzing different scenarios in which the initial conditions of the model are modified, so that one can track the sources of changes as well as potential impacts of the expansion of the gas industry in the five-county region. The following section presents the results of these hypothetical scenarios.

2.6.2 Simulation Results

This section report findings obtained by conducting thought experiments with our static regional CGE model to analyze the impact of increased economic activity in the gas industry on the five-county economy under three scenarios. Our model uses the same industrial sectorial classification scheme as in Section 2.2 (18 economic sectors), in order to permit direct comparison of results with the static I-O multiplier analysis; however, we aggregate the 18 economic sectors into 5 groups for the sake of simplicity in the analysis of the results. The 5 sectors of analysis chosen were Mining, Agriculture, Non-Tradables (e.g., Construction, Manufacturing, Transportation), Basic Services – SERV1 (e.g., Education, Health, Accommodation & Food, Entertainment, Real State, Government, and Other), and High Value-added Services – SERV2 (e.g., Finance, Wholesale & Retail Trade, Information, and Management & Administration services).

We present our findings for three different scenarios consistent with stylized facts for regions going through an economic boom that is associated with natural resource development. In these experiments, we assume that drilling occurs only in the two Pennsylvania counties where hydrofracking is legally permitted. We concentrate our analysis on the effects of drilling on economic activity's output and employment, on household welfare,[4] and on fiscal performance. In the first scenario, we assume a large inflow of capital resources. In the second, we simulate changes in population associated with the economic expansion. Finally, in the third scenario, we combine the previous assumptions with supply constraints in the form of installed capacity and the provision of locally non-tradable goods and services.

2.6.2.1 Scenario 1: Increase in Pennsylvania's Capital Endowments

One of the first effects of natural resource development is the rapid inflow of capital, especially in the case of natural gas development, which is a capital-intensive activity. For this first scenario, we simulate a shock in the capital endowments of Pennsylvania counties. Given the size of their economy, we assume an increase of 20 percent in the capital endowments for the 2009 economy, a year that experienced a significant growth in drilling activity.

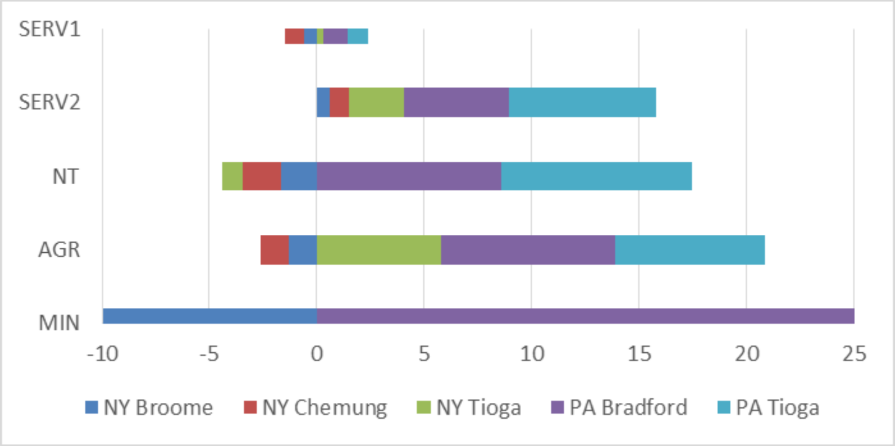
Figures 2.4, 2.5, 2.6 show the effects of this shock in gross domestic output (GDO), employment, and our welfare measure. In general, a 20 percent increase in the capital endowments for Pennsylvania counties generates a gross output growth of 13.9 and 2 percent for Bradford and Tioga counties in Pennsylvania, respectively, while it represents a -4, -1.5, and -4

---

[4] We calculate welfare in terms of levels of consumption by household type

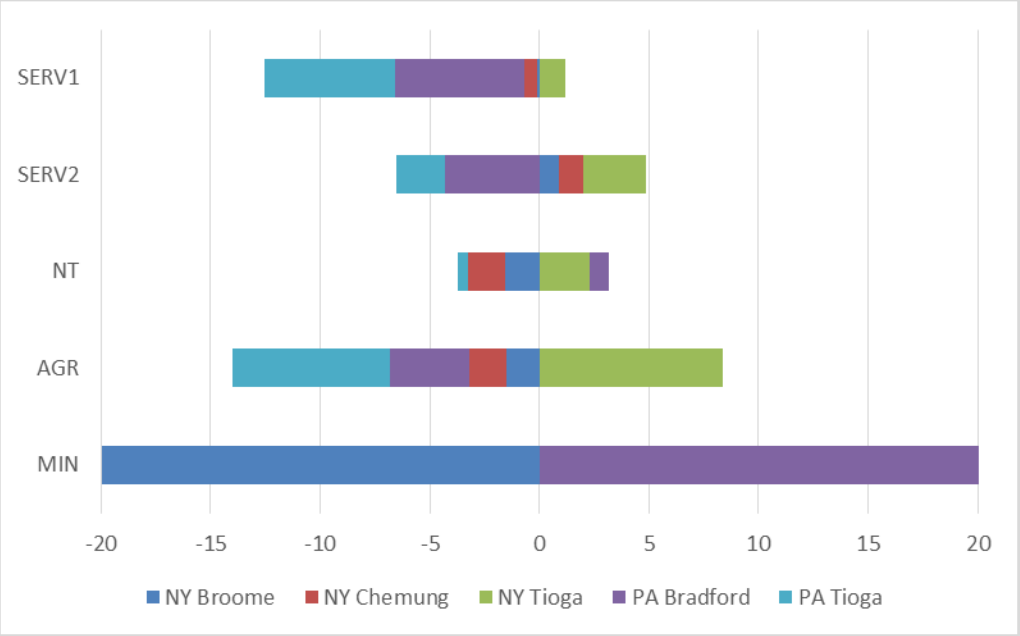
percent decrease in Broome, Chemung, and Tioga counties in New York, respectively. From this, one might infer that a substitution effect is taking place between more expensive resources in New York State and cheaper resources in Pennsylvania. These effects are clearly seen in New York counties where we can see a decrease in their respective GDOs. If we take a close look at the results from an industrial sector perspective, one economic sector that benefits from this inflow of resources is mining activity, which grows significantly in Bradford (187.7 percent)—the county where most of the drilling is concentrated. As before, one might infer that a substitution effect is taking place in NY counties, where the output of mining activity decreases by 60.6 percent on average.

Figure 2.4 Gross Domestic Output after 20% increase in PA capital



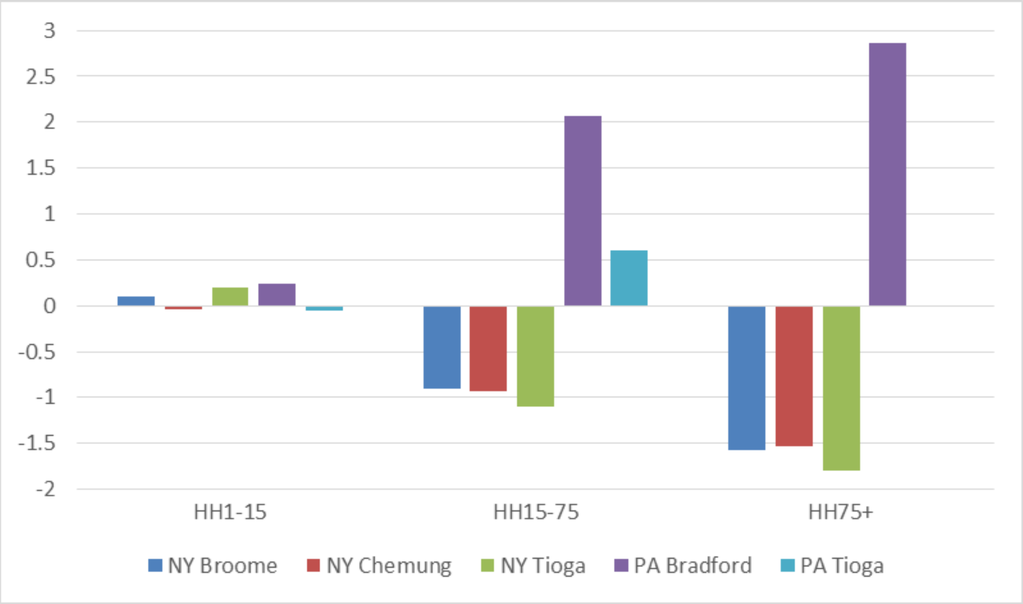
It is interesting to observe from the gross output perspective that neither in Pennsylvania nor in New York is growth experienced uniformly by all sectors. For example, higher value-added sectors shown in the vertical axis of Figure 2.4 in the SERV2 group have positive effects in every country, whereas basic services and non-tradable sectors only do well in Pennsylvania counties. Agriculture seems to benefit significantly from the capital shock in Pennsylvania and in Tioga, New York. One could argue that cheaper capital allows these activities to thrive under the new gas industry boom. As a matter of contrast with the multiplier analysis, in those results, the construction sector is one of the sectors that benefits most according to the multiplier analysis (output multiplier value of 1.1); however, in our model, it grows modestly in Pennsylvania, 0.6 percent on average, while it decreases 0.8 percent on average in New York State.

Figure 2.5 Employment after 20% increase in PA capital



One of the benefits of our regional CGE analysis is that it enables us to track the effect of this shock on variables such as employment. Figure 2.5 shows the effects on employment by our aggregation of different economic sectors. Employment follows a trend similar to what we described earlier in the GDO; however, certain things are worth highlighting—in terms of aggregate employment, the changes are interesting since employment only increases by a slight percentage in all counties. On the other hand, when we analyze what happens to the different sectors of the economy, it is clear that high value-added services are the ones that have positive results under this scenario but only for New York State. With the exception of mining in Bradford, Pennsylvania, and agriculture in Tioga, New York, all other sectors see decreases in their levels of employment. This is clear from the fact that capital becomes cheaper than labor in the regional economy.

Figure 2.6 Household Income after 20% increase in PA capital

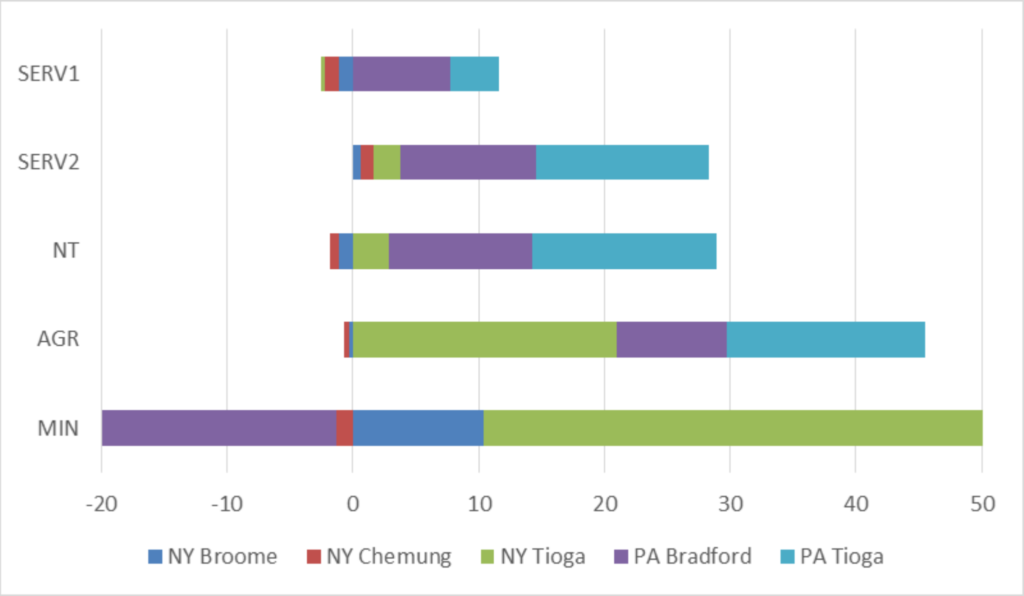


As briefly mentioned earlier, general equilibrium models approach the well-being of households through variations in their utility measures by changes in their income level. For example, in terms of household consumption, Figure 2.6 shows that the capital shock only has a positive effect on the lowest-income group (less than $15,000 annually) in Broome, Tioga (NY), and Bradford (PA); and for higher-income groups, the effect is positive only in Pennsylvania. As before, since capital is now more abundant (in PA, at first, it becomes cheaper) rates of return are less, which means that high-income households (which are the capital owners) would be mostly affected by this phenomenon; however, households in Pennsylvania are able to compensate for this shock by means of positive increases in income resulting from the capital influx.

2.6.2.2 Scenario 2: Rapid Population Growth across Counties

The development of a new industry such as the gas industry requires a large portion of labor, and often specialized labor, which normally cannot be found in the areas where the resources are located. The association between mining booms and rapid changes in the population is well documented in the literature. For this reason, our second scenario considers the effect of changes in population on the order of a one-time 20 percent increase in Pennsylvania counties, where drilling has already begun. The results are summarized in Figures 2.7, 2.8, and 2.9.

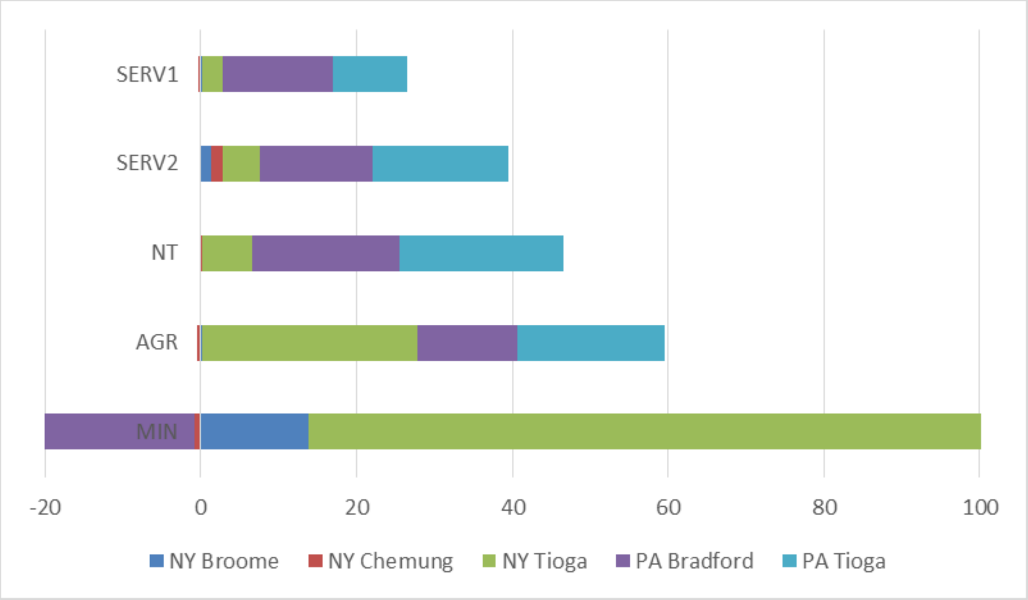
Figure 2.7 Gross Domestic Output with 20% increase in PA labor



Population growth is reflected in increases in productivity. In the case of Pennsylvania, these changes elicit growth in gross output (15.5 percent on average). As we can see in Figure 2.7 growth is mostly driven by the strong performance of the mining and agriculture sectors in

Pennsylvania and in Tioga County in New York.[5] Perhaps, it is only basic services in New York State that are unable to reap the benefits of cheaper labor in the regional economy.

Figure 2.8 Employment after 20% increase in PA labor



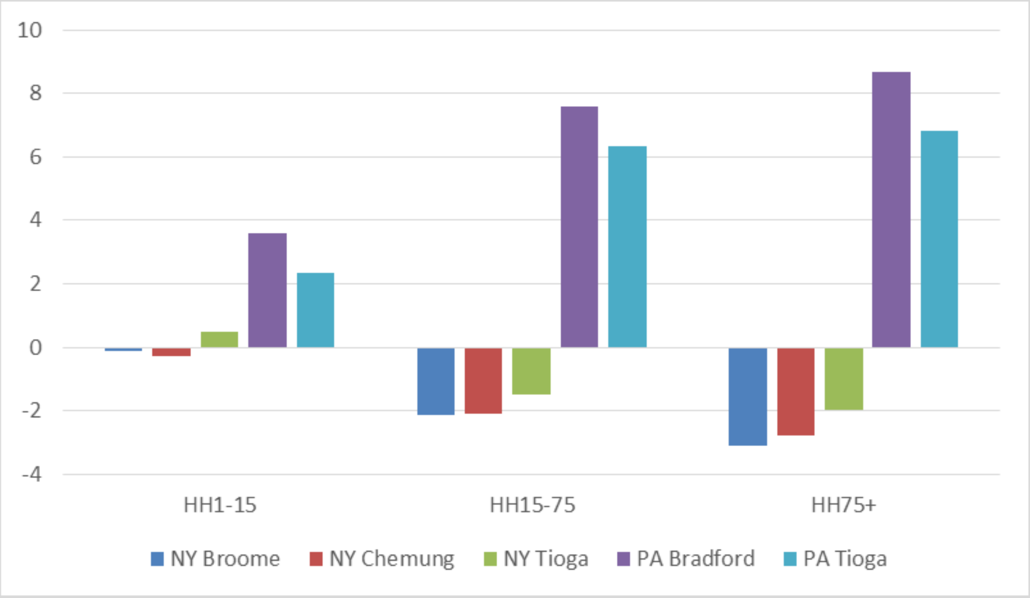
Employment results are interesting since they are at the center of the discussion. Figure 2.8 shows that, as expected in regard to overall employment in Pennsylvania counties, the 20 percent increase in population is distributed across different economic sectors. On the one hand, agriculture, non-tradable, and high value-added services are the leading sectors in this growth. From this, one may conclude that a substitution effect is taking place in Pennsylvania, as can be clearly seen in the mining sector, which shows a decrease of 100 and 97 percent in its employment levels in Bradford and Tioga Counties, respectively.

---

[5] It is important to notice, that Tioga County in New York is the smallest economy out of the five county regional economy. Any changes in the initial values of the variables of interest generates higher percent changes (in absolute value) compared to the other counties.

Figure 2.9 shows how again there is an overall increase in the level of welfare (in terms of consumption) for Pennsylvania counties, particularly for the high-income brackets in Bradford County (i.e., more than $75,000) for which its consumption levels increase by 9 percent on average, just as in the case of the previous scenario.

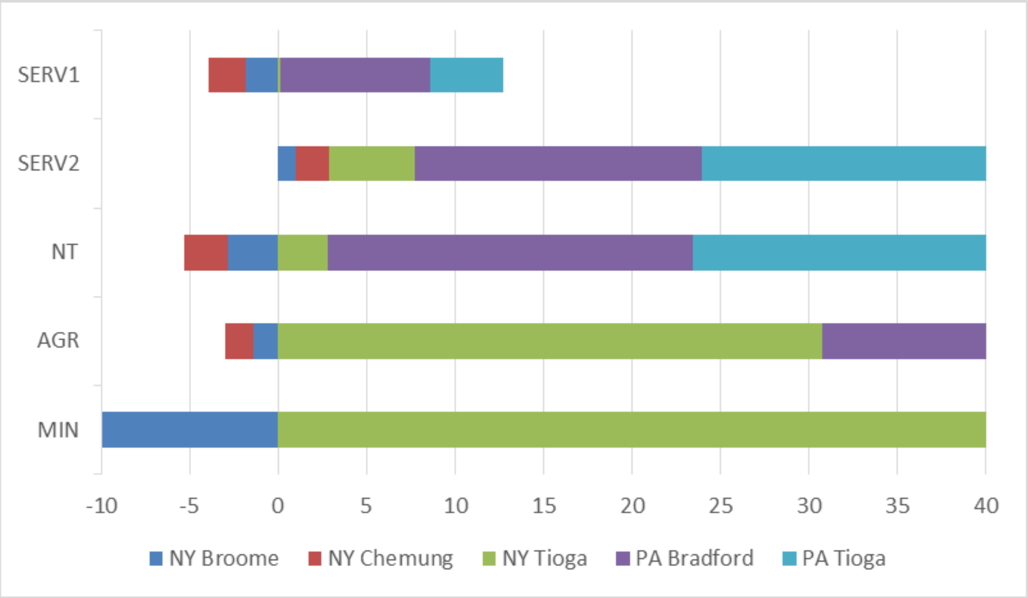
Figure 2.9 Household Income after 20% increase in PA labor



2.6.2.3 Scenario 3: Capital and Labor Increases under Fixed Supply of Non-tradable Goods

In the real world, shocks do not come one at a time; they tend to happen simultaneously, and their combined occurrences affect markets in different ways. Even though scenarios 1 and 2 might be illustrative for analytical reasons, they do not illustrate what one can expect in a booming economy that has resulted from natural resource development. In the following scenario, we will simulate what we believe to be a closer estimation of the stylized facts associated with booming mineral economies. This time, we combine both capital and population increases on the magnitude of 20%. Also, in this scenario, we assume that supplies of certain non-tradable goods, such as housing accommodations, food services, construction, transportation and utilities, are fixed in the short term. We are interested in seeing the responses of these markets when we assume that the supplies of certain goods and services cannot change as rapidly as the demand for them. In other words, the supply for certain non-tradable goods and services in the Pennsylvania counties can be assumed to be fixed in the short run. This assumption is consistent with the evidence on small economies' installed capacity before the introduction of an expanding sector.

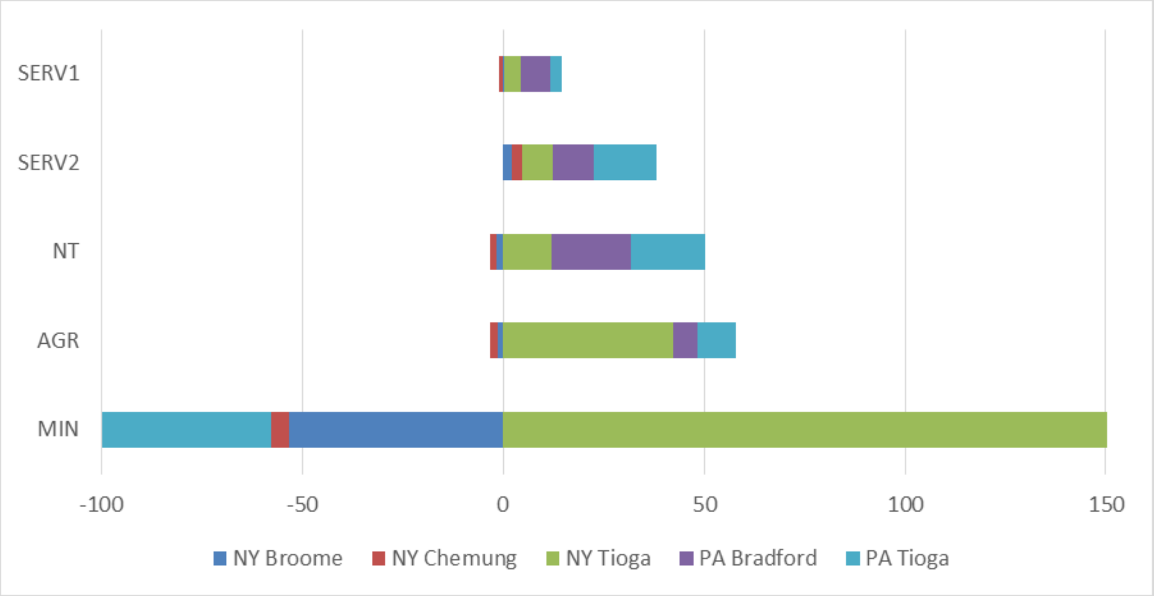
Figure 2.10 GDO with 20% increase in PA capital and labor with fixed supply of non-tradables



As shown by Figures 2.10, 2.11, and 2.12, some of the results from scenario 1 and 2 hold, but certain differences must be highlighted. Initially, we can see an overall growth in aggregate output for all counties, except for the biggest regional economy—namely, Broome County—which continues to experience a decrease in its output after all of the combined shocks. Looking at different economic sectors, this growth continues to be driven by mining, agriculture, and high value-added services.

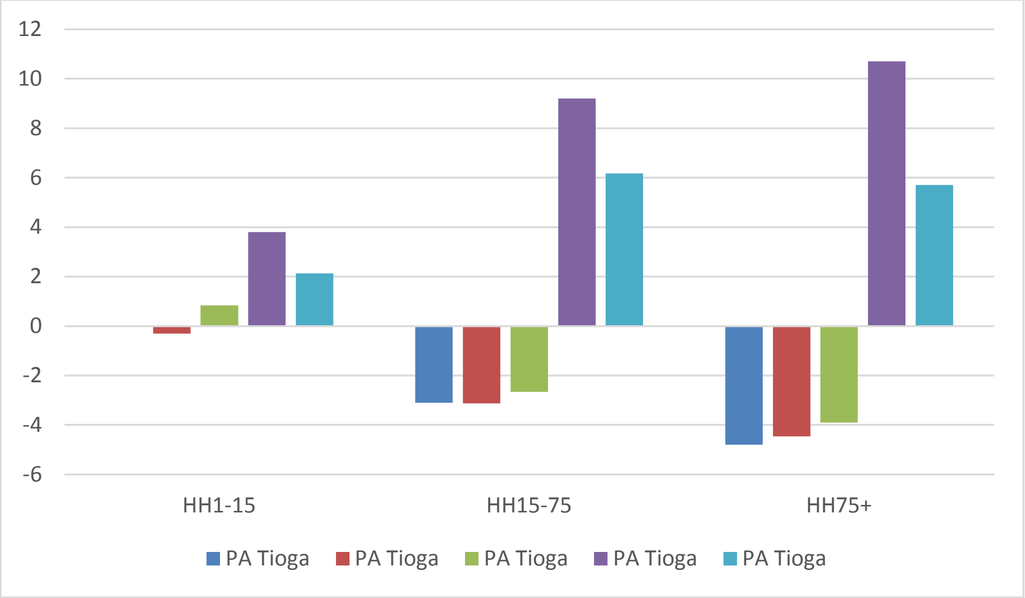
The welfare analysis shows that all Pennsylvania households experience a general growth in their well-being, measured in terms of levels of consumption of goods and services, while this effect can only be seen in low-income households in Tioga County in New York. As before, mid- and high-income households in New York are significantly and negatively affected by changes in the neighboring state.

Figure 2.11 Employment with 20% increase in PA capital and labor with fixed supply of non-tradables



In the same fashion, employment continues to affect mostly agriculture and high value-added services in Pennsylvania counties; however, mining employment in New York's Tioga county continues to experience dramatic growth; while this sector experiences significant decay in Tioga County, Pennsylvania.

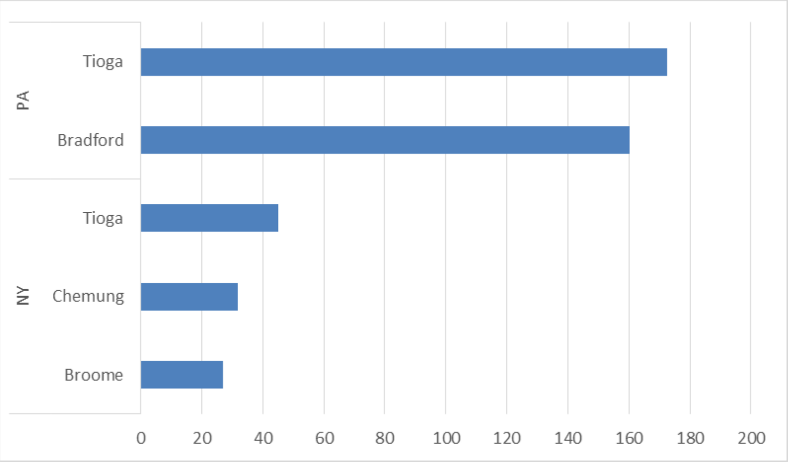
Figure 2.12 Income with 20% increase in PA capital and labor with fixed supply of non-tradables



2.6.2.4 Government Revenue

One important aspect of our model is that it explicitly considers the role of government and its fiscal behavior as benchmark conditions of the economy are being affected. Under all three scenarios, government revenue experienced a significant growth in both Pennsylvania and New York State, but the impact was more pronounced in Pennsylvania where government revenue increased by 166 percent, as shown in Figure 2.12. The average government revenue in New York State increased by 35 percent.

Figure 2.13 Government Revenue with 20% increase in PA capital and labor with fixed supply of non-tradables



2.7 Conclusions and policy recommendations

The Marcellus Shale's natural gas development will bring significant changes to the regions that embrace the drilling industry. One area that has attracted special attention is the Northeastern tier of Pennsylvania, where drilling has already begun and grown since 2008, and the southern tier of New York State, where hydrofracking has not yet been permitted. One of the biggest questions and challenges surrounding the effects of this new industry concerns the potential impacts on the region's economic and social conditions.

In this document, we used the results of previous economic impact analyses as a benchmark for a model that fully considers the interdependence of markets across borders and the fact that economic impacts have spatial spillover effects. Based on multiplier economic impact reports for the State of Pennsylvania, we built a regional CGE model to describe the effect of the new gas drilling industry in the area where most of the drilling has taken place. For this purpose, we recreated a hypothetical regional CGE model that included the counties of

Broome, Chemung, and Tioga in New York State as well as Bradford, and Tioga in Pennsylvania.

Our results indicate that there is sufficient information to believe that static multiplier analysis based on I-O models overestimate the impact of new industry. Since demand-driven analyses fail to capture the leakage of the multipliers, they fail to account for supply-side adjustments and substitution and price effects; thus, they are incapable of considering interactions with the economies of surrounding areas. Even at the county level with the same industry spending pattern that was used in the multiplier analysis, we found that the projections are infeasible since they are completely beyond the bounds of the evidence captured by actual data of regional economic accounts.

From the results of our regional CGE mode, several details should be highlighted. Based on the analyses of our hypothetical scenarios, which describe the short-term effects of the development of the natural gas industry in Pennsylvania’s counties, one can generally expect growth in GDO for most of the region, with the exception of the biggest local economy—Broome County in New York State. This finding is consistent with the direction of the multiplier analysis presented in Section 2.3; however, the changes are not as large as those predicted by the other methodologies. Even with such strong assumptions as large increases of the labor and capital endowments, this regional economy does not perform in the manner that one would be led to expect by previous studies. For example, the multiplier analysis showed that the gross output of this economy would more than double with the introduction of the gas industry, whereas under the CGE framework the average increase in output is on the order of 18 percent.

One important aspect to consider is, as demonstrated by the general equilibrium approach, not all economic sectors and institutions are winners in these economic transformations. In fact, the well-being of firms and households employed in many economic sectors is affected deleteriously, if we consider well-being in terms of output and consumption, respectively. As shown above, economic sectors like mining, agriculture, and high value-added services benefit the most from the new industry, especially in Pennsylvania's counties. Results in terms of employment fall along the same lines of output performance.

As drilling occurs in Pennsylvania, household income is affected throughout the regional economy. While all household types are positively affected in Pennsylvania, the effects are concentrated in mid- to high-income groups. In New York State, however, only the lowest-income group in Tioga County (i.e., the most rural economy of the region) showed increases in their income, while all of the other household types had decreases in their income levels.

These interesting results open up the debate to the examination of several collateral effects associated with natural resource development and economic impact modelling. It is impossible to encapsulate within one region dramatic changes in small economies such as those illustrated in multiplier studies. This containment of spillover effects is one of the biggest, if often implicit, assumptions in the multiplier approaches and for which we have presented an alternative that captures the essence of markets interacting across borders.

As we have demonstrated, jurisdictional, political, and administrative boundaries have little to no effect on what happens to a regional economy. If policy regarding the extraction and exploitation of natural resources, such as natural gas, continues to be determined by state borders, players for whom regulations are not defined will inevitably be affected by the spillover effects present in a regional economy. In the case of natural gas in the Marcellus Shale, while New York awaits regulation of the new industry, the drilling in Pennsylvania is affecting the socioeconomic conditions of the Empire State population.

Finally, our analysis calls for more sophisticated methodologies to understand a problem such as the natural gas industry initiative in the Marcellus Shale region. We have only taken the first small step in the process by stating a simple and static CGE regional analysis, and more research is needed on this kind of phenomenon and using these approaches. In the future, methods that characterize longer-term dynamics and the dependence of local markets and regional physical infrastructure networks will enhance the conversation and thus contribute toward formulating more appropriate policy interventions that support local government decisions.

2.8 Appendix 1 Gas Industry Spending Pattern in PA 2008 (millions)

Sector.	Amount
Ag, Forestry, Fish & Hunting.	3.4
Mining.	334.1
Utilities.	4
Construction.	259
Manufacturing.	6.4
Wholesale Trade.	141.1
Transportation & Warehousing.	26.1
Retail Trade.	21.5
Information.	0.3
Finance & Insurance.	0.4
Real Estate & Rental.	0.6
Professional Services -Scientific & Tech	48.5
Administrative & Waste Services.	6.8
Educational Services.	0.9
Health & Social Services.	0.9
Arts -Entertainment & Recreation.	0.4
Accommodation & Food Services.	0.5
Other Services.	0.9
Total Purchasing.	855.9

Source: Considine 2009

2.9 Appendix 2 per-well spending in thousands of 2008 dollars

Sector.	Amount
Ag, Forestry, Fish & Hunting.	9.34
Mining.	917.86
Utilities.	10.99
Construction.	711.54
Manufacturing.	17.58
Wholesale Trade.	387.64
Transportation & Warehousing.	71.70
Retail Trade.	59.07
Information.	0.82
Finance & Insurance.	1.10
Real Estate & Rental.	1.65
Professional Services -Scientific & Tech	133.24
Administrative & Waste Services.	18.68
Educational Services.	2.47
Health & Social Services.	2.47
Arts -Entertainment & Recreation.	1.10
Accommodation & Food Services.	1.37
Other Services.	2.47
Total Purchasing.	2,351.37

Source: Author's calculations

3 CHAPTER THREE: AGGLOMERATION ECONOMIES IN THE U.S. GREENHOUSE AND NURSERY PRODUCTION: A SPATIAL PANEL DATA APPROACH

3.1 Introduction

The U.S. greenhouse and nursery sector or the green industry has recently emerged as a significant component of the country's agriculture, given the increase in the market value of its sales. The green industry includes food crops grown under cover as well as products associated with landscaping and home improvement (USDA, 2009). One of the most interesting aspects of the greenhouse and nursery sector has been its consolidation along the expansion of metropolitan areas in the more urbanized regions of the U.S. (Cheng et al., 2006; Brumfield, 2010). From a research perspective this spatial configuration of the industry brings interesting questions regarding the effect of urbanization processes on the development of the green industry.

This study builds on the analysis of the greenhouse and nursery sector by Cheng, Gomez, and Bills (2011) and the factors affecting its spatial distribution in the Northeast, Southeast, and Pacific regions of the U.S. Under a firm location and production model their study proves the existence of urban agglomeration externalities on the green industry production by estimating the effect of urban proximity on greenhouse and nursery sales with data from the 2007 U.S. Census of Agriculture. Recent developments of spatial econometric theory applied to agricultural economics have made it possible to control for both spatial and temporal dependencies. In this study we estimate a spatial process with a panel for the green industry using data from the agricultural census from 1982 to 2007[6]. The main objective of our analysis is to corroborate previous results on urban agglomeration externalities and show its evolution over time.

In agricultural economics where land is immobile, information normally has a spatial component, and policies are usually determined with regional political administrative boundaries; it is important to use frameworks that incorporate these characteristics into the analysis. For this reason, we drive our model by questioning about the specific factors which affect the location of the green industry. It has been well documented how greenhouse and nursery production expands as it is closer to metropolitan areas (Bills et al., 2006; Heimlich & Barnard, 1992). Proximity to a strong demand is a key element in the industry's innovation and consolidation process (Brumfield, 2010). However, we need more research in understanding the particular spatial dependencies that arise when an industry thrives from proximity to specialized and large consumer markets. The green industry has a promising potential in this aspects since it has been seen as a profitable alternative to more traditional agricultural businesses (Hall et al., 2011; Hodges et al., 2011). As the market increases its mark-ups towards more socially, and environmental forms of production the location of these industries will augment its impact on the profitability of this industry.

Empirical research on this topic will continue to gain importance as the green industry continues to concentrate near metropolitan areas. For this reason we insist on developing a framework for the analysis of geographic characteristics on the economic performance of the greenhouse and nursery agricultural sector. Frist, we present this analysis following the recent

---

[6] Data was collected for 1982, 1987, 1992, 1997, 2002, and 2007.

advances in spatial econometric panel data theory. Second, we estimate a model that captures the evolution of urbanization, localization, and firm-specific variables related to the green industry. Third, we perform some robustness checks to validate our results. Last, we present some concluding remarks where we open the discussion on the relevance of generating analysis on agricultural markets that capture both the spatial and temporal phenomena, since it enables researches to gain useful insides on the performance and evolution of fast changing sectors as the greenhouse and nursery industry.

3.2 Spatial Panel Theory

The main purpose of spatial panel data models is to capture the spatial interactions across different geographically-related entities over time. The basic static panel model includes a spatial lag of the dependent variables and a spatial autoregressive disturbance[7]. Following Anselin (2001) and (2002), and Millo and Piras (2012) we introduce a static spatial panel model of the following form:

$$y = \lambda(I_T \otimes W_N)y + X\beta + \mu$$

where y is an NTx1 vector of observations on the dependent variables, X is a NTxk matrix of observations of the independent variables, IT is and identity matrix of dimension T, WN is the NxN spatial weights matrix whose diagonal elements are zero, and lambda is the corresponding spatial parameter. The error is defined in the following manner:

---

[7] Spatial panel data models can also have dynamic versions, Anselin, Le Gallo, and Jayet (2008) have literature review on dynamic spatial models. We decided to focus our analysis on the static model since we only have six time samples.

$$\mu = \rho(i_T \otimes I_N)\mu + \varepsilon$$

where iT is a vector of ones, IN is a and NxN identity matrix, u is a vector individual specific effects not affected by time or space, and e is a the spatially autocorrelated vector of innovations that follow this structure:

$$\varepsilon = \rho(I_T \otimes W_N)\varepsilon + \vartheta$$

where ρ ($|\rho| < 1$) is the spatial autoregressive parameter, Wn the spatial weights matrix, and $\vartheta_{it} \sim IID(0, \sigma_{\vartheta}^2)$ and $\varepsilon_{it} \sim IID(0, \sigma_{\varepsilon}^2)$.

In applied literature these types of models are used to get empirical estimates of spatial reaction functions and or social multipliers (Brueckner, 2003; Glaeser et. al., 2002). Other specifications such as the ones that consider dynamic spatial errors should be consider for future research.

Perhaps the most crucial element in structure of spatial econometric models, and it is the case for its panel data extension, is the spatial interactions captured through its units by the spatial weights matrix. As we showed in equations (1) and (3) the weights matrix is an essential element in the estimation of the spatial panel model. The spatial weights matrix (W) is a square matrix of dimensions NxN. Each unit of analysis appears in both the rows and columns of the matrix, the relationship between each unit is defined by the spatial interaction used in the analysis. This spatial interaction or “neighborhood” has many different options, being contiguity or share of a border being the most common interaction used in the literature to define the degree of interaction (Baltagi, Kelejian, and Prucha, 2007). Other “forms” of spatial interaction include distance, queen, rook neighbors[8]. The neighborhood relation is often defined in a binary way, where the elements of W take the value of 1 when any of its units are neighbors and 0 otherwise. It is assume in these type of models that the diagonal of the W matrix is 0, since a unit cannot being a neighbor of its own.

For our analysis we employed distance as a measure of "neighborhood" for defining out W matrix. We used different distances measures. In particular, for our model neighboring counties were defined by those which were within the range of 25, 50, 75, or 100 miles radius. The results presented in this document refer to the W matrix specification of 100 miles of distance, which is the matrix with most neighbors. A W matrix is required to be singular, and thus have an inverse, when only few counties have neighbors, the inverse of the matrix are not defined, for this reason we decided to present the more robust matrix definition. The results of the estimation with the 75 mile matrix are available upon request.

We consider both fixed and random effects models for our framework of analysis. The classic fixed effects model (e.g.,Baltagi, 2001, pp. 12–15, and Arellano, 2003, pp. 11–18) includes an individual specific "dummy variable" to capture unobserved heterogeneity. In other, words individual effects are separately identifiable from the constant term in the estimated beta coefficients. As is well known, consistent estimation of the individual fixed effects is not possible when the sample converges to infinity, due to the incidental parameter problem. Since spatial models rely on the asymptotics in the cross-sectional dimension to obtain consistency and

---

[8] Other sorts of neighboring relations.

asymptotic normality of estimators, this would preclude the fixed effects model from being extended with a spatial lag or spatial error term (Anselin, 2001).

On the other hand, the random effects approach to modeling unobserved heterogeneity, interest has centered on incorporating spatial error correlation into the regression error term, in addition to the standard cross-sectional random component. Note that the latter induces serial correlation over time (of the equi- correlated type). The addition of a spatial lag term in these models is straightforward, by specifying the proper error variance covariance structure. In contrast to the fixed effects case, asymptotics along the cross-sectional dimension, when the sample is too large, present no problem for random effects models.

3.3 Data and Approach

In this article we extend Cheng, Gomez and Bills (2011) analysis on agglomeration economies for the greenhouse and nursery production industries by implementing a spatial data panel approach. In this analysis we implement a similar model specification as in Schlenker, Haneman, and Fisher (2006), using county-level data from the last six U.S. Agricultural Census (1982, 1987, 1992, 1997, 2002, and 2007) for the Northeast region (243 counties). The dependent variables for the analysis is greenhouse and nursery sales. We chose 14 explanatory variables in the same fashion as Cheng, Gomez, and Bills (2011). See their results for the Northeast region in Table 3.1.

During the data cleaning process we excluded some variables that appear in the non-panel analysis since we were not able to find them for the complete series. In order to get a balanced panel we decided to drop 17 counties from the analysis because of missing values. We decided to leave counties with at least 1 value within a decade. In counties with a missing value we decided to impute the same value for both samples in the decade. For example, if a county had information for year 1987 and not for 1982, we assume the 1987 value for the 1982 missing value. A number of 148 imputations were made, representing less than 5% of the total number of data values included in the panel.

Table 3.2 shows the variables used for our model. Additional to the variables employed in the non-panel analysis we decided to include the harvested land and cropland area in their natural logarithm form as measures of the degree of non-green industry related production in each county. The summary statistics for our panel are presented Table 3.3.

Table 3.1 Spatial lag model for the Northeast (the dependent variable is the logarithm of county-level greenhouse/nursery sales in 2007)

Variable	Coefficient		S.E.[a]
Constant	-12.220	***	2.222
Localization Economies			
Spacelag	0.486	***	0.073
Intersector	0.440	***	0.072
Urbanization			
Population Growth	-0.001		0.013
Housing	0.001		0.001
Directmkt	0.271	**	0.131
Land Values	0.028	*	0.015
Firm-Specific			
Labor	0.233	***	0.083
Greenhouse Glass	0.191	***	0.025

Socioeconomic Conditions			
Income	1.081	***	0.316
Occupation other	0.017	*	0.010
Land	0.145		0.134
Soil	-0.059		0.133
Model Diagnostics			
Number of Observations			194
R-squared			0.76
Akaike (AIC)			491.8
LaGrange Multiplier Test Statistic			0.26
p-Value LM test			0.604

*, **, *** denote statistical significance at the ten, five, and one percent levels, respectively.

[a] S.E. = Standard Error.

3.4 Results

We estimate seven different panel data specifications following Baylis, Paulson, and Piras (2011) and using the *splm* R routine developed by Millo and Piras in 2012[9] to implement different panel data structures. Results of our analysis can be seen in Table 3.4. The first three models do not consider spatial effects, we estimated a pooled, and fixed and random effects versions of the panel. As expected in the county fixed effects model the constant is dropped.

---

[9] We used the Generalized Methods (GM) approach for our analysis. As a complementary analysis we estimated the models with the Maximum Likelihood (ML) approach, with not much difference in the estimators. The results presented in this document are the GM estimators, the LM estimators are available upon request.

Table 3.2 Description of variables used in the analysis, 1982-2007

Variable	Definition	Data Source
Greenhouse sales	Natural logarithm of sales of greenhouse and nursery products ($1,000)	Census of Agriculture
Greenhouse farms	Natural logarithm of number of farms with nursery & greenhouse activities	Census of Agriculture
Greenhouse glass	Natural logarithm of greenhouse/nursery production under glass or other protection (square feet)	Census of Agriculture
Total sales	Natural logarithm of total sales ($1,000)	Census of Agriculture
Harvested area	Natural logarithm of harvested land area (acres)	Census of Agriculture
Cropland area	Natural logarithm cropland area (acres)	Census of Agriculture
Land value	Natural logarithm of estimated market value of land and buildings ($1,000)	Census of Agriculture
Labor	Natural logarithm of hired farm labor ($1,000)	Census of Agriculture
Property tax	Natural logarithm of property taxes paid ($1,000)	Census of Agriculture
Occupation farming	Natural logarithm of operators principal occupation-Farming (farms)	Census of Agriculture
Occupation other	Natural logarithm of operators principal occupation-other (farms)	Census of Agriculture
Population	Natural logarithm of population in 1982, 1987, 1992, 1997, 2002, 2007 (persons)	Bureau of Economic Analysis
Population growth	Percent population growth, 77-82, 82-87, 87-92, 92-97, 97-02, 02-07	Bureau of Economic Analysis
Employment	Natural logarithm of number of employed people	Bureau of Economic Analysis
Income	Natural logarithm of personal income per capita ($1,000)	Bureau of Economic Analysis

Table 3.3 Summary statistics of variables used for the analysis

Variables	Minimum	Maximum	Median	Mean	Standard Deviation
Greenhouse sales	0.69	12.90	6.75	6.72	2.02
Greenhouse farms	0.00	17.01	3.50	4.42	3.04
Greenhouse glass	8.72	17.01	12.31	12.33	1.42
Total sales	6.53	13.55	10.03	9.91	1.15
Harvested area	4.64	12.65	10.52	10.26	1.33
Cropland area	4.17	12.77	10.82	10.53	1.28
Land value	8.88	15.19	12.10	12.04	0.93
Labor	3.91	11.93	8.13	8.09	1.13
Property tax	3.58	9.97	7.26	7.17	0.90
Occupation farming	2.20	8.28	5.69	5.54	0.86
Occupation other	1.61	7.58	5.54	5.44	0.78
Population	8.48	14.23	11.48	11.60	1.10
Population growth	-0.99	89.84	-0.12	2.29	7.07
Employment	7.10	13.88	10.73	10.89	1.19
Income	8.96	11.28	9.96	9.95	0.46

Spatial interaction models in the fourth to seventh column represent the spatial panel data results. The spatial error models under the random and fixed effects frameworks are shown in columns four and five, while spatial lag models with both random and fixed effects are presented in columns six and seven respectively. As we can see from Table 3.4 there is presence of spatial correlation by the estimated spatial error coefficients in columns four and five. Analogously, the spatial lag estimates show significance at the 1% level, indicating that our data shows strong symptoms of spatial correlation. As in the non-panel analysis there is evidence that corroborates the existence of localization economies in the Northeast.

In terms of the effects of urbanization for the green industry in the Northeast, there are mixed results. On the one hand, when we cannot capture different phenomena in this arena over time, since we don’t have enough information to that shows the ability of urban structures to affect the

Table 3.4 Regression Results from Different Panel Specifications

	Pooled OLS	County Fixed Effects	Random Effects	Spatial Error Random Effects	Spatial Error Fixed Effects	Spatial Lag Random Effects	Spatial Lag Fixed Effects
Constant	-2.726		-4.590 *	-14.445 ***		-2.239	
	(1.874)		(2.134)	(3.357)		(1.490)	
Greenhouse farms	0.041 *	0.033 *	0.038 **	0.036 *	0.026	0.001	-0.007
	(0.017)	(0.014)	(0.014)	(0.019)	(0.016)	(0.009)	(0.010)
Greenhouse glass	0.197 ***	0.065	0.139 *	0.147 **	0.119 *	0.152 ***	0.117 *
	(0.049)	(0.063)	(0.054)	(0.051)	(0.052)	(0.046)	(0.054)
Total sales	-0.385 ***	-0.405 ***	-0.367 ***	0.067	-0.005	0.115 *	0.132 **
	(0.073)	(0.064)	(0.061)	(0.080)	(0.072)	(0.047)	(0.051)
Harvested area	1.315 ***	-0.075	0.627 .	0.603 .	-0.279	-0.319	-0.432
	(0.354)	(0.407)	(0.349)	(0.351)	(0.361)	(0.273)	(0.322)
Cropland area	-1.742 ***	-1.453 ***	-1.106 **	-0.856 *	-0.884 *	0.278	-0.283
	(0.380)	(0.428)	(0.373)	(0.392)	(0.388)	(0.289)	(0.345)
Land value	0.340 **	0.765 ***	0.608 ***	0.044	0.172	-0.192 .	-0.026
	(0.121)	(0.161)	(0.132)	(0.163)	(0.161)	(0.103)	(0.123)
Labor	0.928 ***	0.376 ***	0.638 ***	0.503 ***	0.353 ***	0.397 ***	0.218 *
	(0.087)	(0.111)	(0.091)	(0.089)	(0.092)	(0.074)	(0.093)
Property tax	0.258 *	0.419 *	0.401 **	0.084	-0.024	0.149	-0.042
	(0.126)	(0.183)	(0.144)	(0.163)	(0.166)	(0.107)	(0.143)
Occupation farming	-0.192	0.746 **	0.415 *	0.002	0.305	-0.017	-0.028
	(0.183)	(0.236)	(0.199)	(0.209)	(0.229)	(0.154)	(0.174)
Occupation other	0.294 *	-0.844 ***	-0.470 ***	0.317 .	0.012	0.208 .	0.094
	(0.134)	(0.166)	(0.140)	(0.168)	(0.184)	(0.107)	(0.126)
Population	0.328	0.273	0.348	0.874 *	0.523	-0.185	-0.950 .
	(0.230)	(0.695)	(0.346)	(0.367)	(0.655)	(0.281)	(0.523)
Population growth	-0.002	0.006	0.003	0.001	0.004	-0.002	-0.002
	(0.006)	(0.007)	(0.006)	(0.006)	(0.005)	(0.005)	(0.006)
Employment	-0.276	0.068	-0.201	-0.763 *	-0.725	0.340	0.360
	(0.215)	(0.606)	(0.325)	(0.339)	(0.550)	(0.268)	(0.466)
Income	0.073	0.019	0.135	1.264 ***	1.335 ***	-0.551 ***	-0.415 *
	(0.195)	(0.254)	(0.188)	(0.314)	(0.302)	(0.131)	(0.191)
Number of obaservations	1356	1356	1356	1356	1356	1356	1356
Spatial lag coefficient						1.070692 ***	1.083433 ***
Spatial error coefficient				0.74892	0.68308	-0.54781	-0.66223

. ,*, **, *** denote statistical significance at the ten, five, and one percent levels, respectively.

Note: Standard errors are reported in parentheses below the coefficient estimates.

performance of greenhouse and nursery sales. We can only sustain that *Population Growth* continues to have no significant effect on green industry sales, the results hold with both panel specifications (spatial and non-spatial). As before we argue that the Northeast being the most densely region of the U.S. and having the lowest average population growth rate is a direct explanation on this result. On the other hand, we found that *Land Values* only have a significant effect under the non-spatial panel specification. However, as we introduce both the spatial and temporal effect on this explanatory variable this effects diminishes and even turns negative. What this result suggests is that the green industry's concentration has been a recent phenomenon, especially in the coastal corridor of the region.

Regarding input variables to account for the firm-internal economies of scale, Average payroll per worker *Labor*, capturing relative cost of labor by county, is highly significant and positively associated with the greenhouse/nursery production level in the Northeast. This result is hold even when we control for the spatial correlation over time. One might argue that this result is a direct consequence of the fact that greenhouse/nursery production depends heavily on a relatively more costly but reliable and skilled work force. As it was estimated in the non-panel analysis, effect of *Greenhouse Glass* is positively significant for the region under all specifications. In other words, the production levels are higher when counties have larger specialized operation areas under glass or other protection. This results, corroborates the fact that as colder temperatures in the Northeast makes its agricultural operations depend heavenly on greenhouses for crop production.

Income levels of residents in a county have significantly positive influence on the greenhouse/nursery production of the Northeast only in the spatial panel specifications. Beyond the difference between the fixed vs. random effects models, what we see is that controlling for space makes a difference in terms of the absolute value of these coefficients. The absolute values of both fixed and random effects are much larger than the non-spatial models. The spatial error models show highly significant coefficients with large values, implying in a way that taking into account the spatial correlation of income has a strong effect on green industry's sales. If we think about it, local economies with higher incomes have higher capacity of consuming high value-added goods as products from greenhouses and nurseries. It makes sense for the green industry to locate and thus concentrate in places with higher purchasing power.

Primary livelihood occupations have only been recently affecting greenhouse/nursery production. As in the non-panel specification showed farmers declaring a nonfarm occupation as their primary livelihood (*Occupation Other*) is associated to higher greenhouse/nursery production. This result can no longer be sustained for the panel models, even though the results are significant under the non-spatial approach, but show a negative effect. There is no clear sense in what has being the effect of occupation on green industry's sales, even if farm operators declare themselves as farming for the main occupation (*Occupation Farming*) it has no clear impact on the industry's sales.

Lastly, there is no clear sign that other characteristics of urbanization such as levels of employment have a direct effect on greenhouse/nursery sales. One might argue that the industry is not driven by the labor supply of urban areas, but more for the income levels of the employed, as the *Income* variable showed.

We perform a series of Lagrange Multiplier joint and marginal tests for random effects and a spatial error correlation in the same spirit as Baltagi et. al. (2003). We also perform Hausman tests in order to compare fixed versus fixed effects models. The results are shown in Table 3.5.

As we can see by the p-value of the LM1 and LM2 tests we cannot reject the alternative hypothesis of no random regional effects as well as no spatial autocorrelation. The results are confirmed when we perform the conditional tests LMlambda and LMmu where we hold the alternative hypothesis of random regional effects and spatial autocorrelation. Finally, when we compare both random versus fixed effects under the spatial error and spatial lag specification we can only support the random regional effects under the spatial error model.

Table 3.5 Robustness checks

Test	p-value
LM1	0.9864
LM2	0.9877
LMlambda	1.02E-06
Lmmu	2.20E-16
Hausman spatial error	0.9998
Hausman spatial lag	6.34E-05

3.5 Discussion and conclusions

We developed an econometric panel data extension to the findings about agglomeration economies in the greenhouse/nursery industry in the Northeast. As before, the results imply that urban agglomeration economies are important for the spatial structure of greenhouse/nursery production in the region. First, production of these high-value commodities may benefit from spatial clustering of firms at the both intra-sector and inter-sector levels. This suggests that county and state public policies aimed at encouraging spatial concentrations of high-valued agricultural production (i.e. local tax incentives, or investments to develop local human capital) would enhance the positive externalities created by localization economies. The spatial correlation dependence of our data is a proof for this argument.

In terms of the urbanization factors affecting the greenhouse/nursery production. We corroborate that that between 1982 and 2007, higher levels of income, labor supply, and infrastructure have been associated with higher greenhouse/nursery production levels in the Northeast. However, the results also illustrate the subtleties of urban development pressure on farming operations, since variables such as population growth, or property tax seem to have positive effects under the panel framework in the green industry's performance. We explain this through the pressure that higher land prices have in production costs. For example, the findings suggest higher land values are associated with higher greenhouse/nursery production in the Northeast. Thus, the econometric results demonstrate that a critical element in assuring the continued economic vibrancy of greenhouse/nursery businesses in the Northeast is the capacity to adjust to increased competition for land in metropolitan areas, while exploiting the marketing opportunities offered by proximity to urban consumers.

As to the debate about fixed vs. random effects, we do observe that fixed effects appear to generate larger and/or positive coefficients under the spatial lag specification, while random effects coefficients are larger for the spatial error model. Having said this, these results should be treated very cautiously, noting that we are not weighting our observations by any measure of importance of agriculture in the county, so we should be more focused on signs and significance rather than magnitudes.

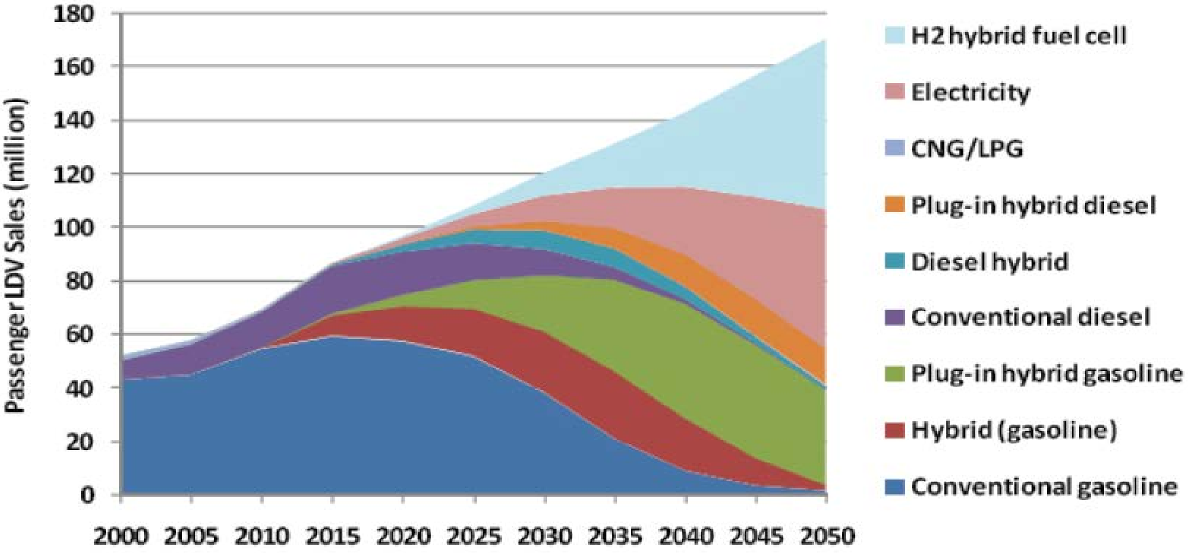
In conclusion, we argue that given the importance of recently developed spatial panel methods applied research fields, such as agricultural economics, an extension in this spirit for the green industry’s analysis is relevant. As we demonstrated the incorporation of these methods corroborates past results, but also gives clues about different phenomena related agglomeration and its impact over greenhouse/nursery’s growth over time. The results obtained in this study pave the way for additional efforts to dealing with spatial relationships and devising methods to accurately measure them over time. For example, as future advances are made in terms of seemingly unrelated regressions for spatial panel data, spatial panel estimators for discrete choices, these tools have great potential to benefit applied agricultural economics research. Doing so will better inform policy decisions on public support for metropolitan agriculture and the steps needed to ensure its vibrancy in the years ahead.

4 CHAPTER FOUR: ECONOMIC BENEFIT ASSESSMENT ASSOCIATED WITH CONVERTING TO HYDROGEN AS A VEHICLE FUEL

4.1 Introduction

Hydrogen (H2) fuel cell vehicles (FCVs) are widely considered to be an important part of the transformation of a vehicle fleet that is almost entirely petroleum dependent to one that uses mostly non-fossil fuels. For example, a recent study by the International Energy Agency (IEA, 2008) forecasts (see Figure 4.1) that global light duty vehicle (LDV) sales may be more than three times as large in 2050 as in 2000, and that these vehicles will be largely plug-in hybrids (using either gasoline or diesel as the range-extending fuel), electric vehicles, and FCVs.

Figure 4.1 One forecast of changing fuel mix for new vehicle sales over the period 2000-2050.



Source: IEA, 2008

However, fuel cell technology is relatively new and evolving rapidly. Bringing successful FCVs to market will require substantial investment in research and development, as well as a new refueling infrastructure. As with many alternative fuels for LDV use, the need for a new refueling infrastructure is a major impediment to widespread adoption, and there is a classic "chicken and egg" problem between vehicles and the refueling infrastructure to support them. Overcoming the barriers to investment in both the vehicle technology and the infrastructure will require an active government role, and governments (whether at the local, state or federal level) will find it much easier to justify investments and policy changes if there is evidence of long-term economic benefit to their citizens.

This suggests two central questions:

1) Will there be substantial economic benefits to regions that experience significant conversion to hydrogen as a vehicle fuel?

2) If so, what public policies will be most effective in encouraging that conversion and achieving the associated benefits?

Regional economic modeling is an important tool for addressing these questions. A regional macroeconomic model includes interactions among various industrial sectors, influences of changing energy prices and availability, and policies of government on household income and consumption, total economic output, employment, etc. However, these models represent each industrial sector in a very aggregate way, and by doing so make it difficult to explore the effects of discrete alternatives in technology, complicated but important constraints on production within a particular sector, or highly targeted government policies. This is an especially important issue in evaluating energy options and policies.

Böhringer and Rutherford (2009) have developed an effective means for integrating the aggregate (top-down) macroeconomic representation with a more detailed disaggregate (bottom-up) representation of the energy sector, to enable a more complete assessment of energy options and policies. We have followed this approach in the current project, using a relatively detailed model of hydrogen production, distribution, and competition with gasoline as a vehicle fuel. This bottom-up model represents one sub-sector within the energy sector of the regional economy. It is integrated with an aggregate model of the remainder of the regional economy. This integration allows assessment of the effects of relatively detailed technology changes for hydrogen production and distribution, pricing and tax incentives from the government, and assumptions regarding consumer adoption of FCVs on the regional economy.

This research focuses on Hawaii as a case study for development and application of such an integrated model. Because Hawaii is geographically isolated from the remainder of the U.S., it forms an economic region of its own and is a suitable scope for a study of this nature. Hawaii currently has the highest energy costs in the U.S. because it is almost entirely dependent on imported petroleum. There is a substantial effort underway in Hawaii to diversify from petroleum, and hydrogen has the potential to play a significant role as an alternative fuel in the long term (i.e., over the next several decades). Important technological and political decisions are likely to shape the role of hydrogen in Hawaii's economy, and assessment of overall economic effects of different decisions is vital.

The remainder of this document is organized as follows. In section 4.2, some earlier efforts to model the economic impact of hydrogen-fueled vehicles are discussed. In section 4.3, we summarize some important information about the State of Hawaii, its energy sector and use of LDVs. Section 4.4 focuses on the general character of an integrated top-down, bottom-up regional model, and its solution via an iterative algorithm. Section 4.5 contains details of the top-down model constructed for the Hawaii case study, and section 4.6 is a similar description of the bottom-up model for hydrogen production and distribution. Section 4.7 describes a series of computational experiments using the integrated model, and section 4.8 presents conclusions and opportunities for further research.

4.2 Previous Macroeconomic Analyses of Hydrogen FCVs

A few similar efforts aimed at economic assessment of hydrogen fuels have been made recently in various parts of the world. Jokisch and Mennel (2007) did an assessment of the economic effects in the European Union of adoption of hydrogen vehicles. Bae and Cho (2010) focused on broader use of hydrogen (both for vehicle fuel and other industrial uses) in the South Korean economy. Leaver and Gillingham (2010) did an integrated modeling study of alternative fuel technologies on the New Zealand economy, but using a different type of macroeconomic model based on different assumptions. Within the U.S., Wang (2011) studied the macroeconomic impact of hydrogen FCVs in California. In this section, we describe the character and findings of each of these studies briefly, and indicate how this previous work has influenced the current project.

Jokisch and Mennel (2007) used a computable general equilibrium (CGE) modeling framework to analyze potential macroeconomic effects of the use of hydrogen FCVs for passenger transport in the EU, with an analysis horizon out to 2050. Their model includes 12 geographic regions (10 specific EU member states, the rest of the EU, and the rest of the world). Within each region, consumers have demands for transport services (measured by vehicle-kilometers of travel) and an aggregate commodity representing all other consumption. The transport services are provided by either conventionally fueled vehicles or by hydrogen FCVs, and these vehicles are represented in three size classes. Hydrogen and conventionally fueled vehicles are viewed as perfect substitutes for one another, so consumers' choices between them are based strictly on relative initial costs of the vehicles, fuel and other ownership costs.

The vehicle fleet is viewed as a durable capital good that is replaced based on depreciation and investment. This reflects the fact that the auto fleet has a relatively long life and turns over slowly. Sales of FCVs as new vehicles create a penetration rate of the hydrogen technology over time, but changes occur relatively slowly.

Their model has no explicit government sector, so exploration of specific government policies, taxes and investments is limited. They are primarily focused on the evaluation of changes in the costs of producing FCVs and of producing hydrogen fuel over time, the effects of different assumed scenarios on the composition of the vehicle fleet in the various EU countries, and on broader economic measures (GDP, effective wage rate, total transport demand, etc.). Tracing differential effects in the various EU countries is of particular interest.

Not too surprisingly, they find that the penetration rate of FCVs in the vehicle fleet depends very heavily on the assumed rate of technical progress (and hence cost reduction) in both FCV manufacture and hydrogen fuel production. In general, the direction of changes induced in the macroeconomic measures is positive, but the magnitudes of the effects are very small. As the cost of hydrogen vehicles decreases over time, and more people shift to them, the net effect is a small increase in available income for consumers and that increase leads to a small increase in demand for both transport and non-transport commodities. That, in turn, leads to increases in production, investment, etc., and the economic measures change positively but with small magnitude.

Bae and Cho (2010) are focused on hydrogen use throughout the economy of South Korea, as a general energy source and not just as a transportation fuel. They also use a dynamic CGE model to represent the Korean economy, with three sectors: energy, transportation and all other industrial activities. The energy sector is divided into seven sub-sectors: coal, petroleum, natural gas, electricity, heat, renewable and hydrogen.

One of the interesting elements of the Bae and Cho study is the use of a vintage model of energy production technology, based on the earlier work of Mulder, et al. (2003). This model explicitly allows varying vintages of production technology to be in use simultaneously, as investments are made over time. It also incorporates a learning-by-using effect, where production technology becomes more efficient as it has been in use for a longer time.

Their baseline analysis (i.e., without government subsidies) projects that hydrogen will account for 6.5% of Korean primary energy in 2040, with about two-thirds of the total demand for the hydrogen being in the transportation sector. They project that production of hydrogen at that time will be 35% from coal gasification, 50% from natural gas reforming, and 15% from renewable energy sources via electrolysis. They then perform a series of experiments assuming varying levels of government subsidy for hydrogen production.

At a high subsidy level (30% of production cost), the resulting lower market price for hydrogen causes substantial shifts away from petroleum, particularly in the transportation sector, and hydrogen makes up more than 35% of total energy production in 2040. Because hydrogen is heavily used as a vehicle fuel, the subsidy reduces the overall cost of transportation, and total transportation activity increases somewhat.

In their analysis, the increased taxes required to fund the hydrogen subsidy cause total household income to fall slightly and consumption of non-transportation products and services to decrease. However, total GDP rises slightly as a result of increased output of the transportation sector as well as increased exports. All of these projected changes are of very small magnitude – less than 1% of the baseline values.

It is also interesting to note that their analysis forecasts little effect of the hydrogen subsidy policy on overall CO2 emissions from the Korean economy by 2040, even though that is one of the underlying arguments for encouraging a shift from petroleum fuels to hydrogen. The reason for this is that the production of hydrogen is predicted to be predominantly from natural gas reforming and coal gasification, and these technologies continue to emit CO2. (The model assumes no carbon sequestration technology for the hydrogen production.) There may be other overall air quality benefits from reducing vehicle emissions in densely populated Korean cities, but overall CO2 emissions from the economy are not reduced very much.

The study of economic impact of alternative vehicle technologies in New Zealand by Leaver and Gillingham (2010) uses a system dynamics model of the economy, rather than a CGE model. A system dynamics model focuses on accumulators and flows in the economy over time, rather than on the market-clearing interaction of prices and quantities that is at the heart of CGE models. The model used by Leaver and Gillingham represents three energy sectors of the New Zealand economy (fossil fuels, electricity production and hydrogen production), along with a transport sector, creating four primary modules within the model. New Zealand is divided into 13 regions, and the model simulates regional interactions within the four modules over time. The model does not attempt to measure overall income, investment, GDP, etc. in the economy; its focus is on vehicle numbers and fleet composition, greenhouse gas emissions, and the wholesale electricity price. The intent of the authors is to examine the sensitivity of these outputs to CO2 emission fees and the price of oil (as exogenous inputs).

The vehicle fleet is divided into 12 categories, based on fuel and propulsion technology and vehicle weight. Consumers’ choices for new vehicle purchases are represented with a logit model based on relative costs of the alternatives and qualitative differences among them. In their baseline scenario, by 2050 FCVs make up 41% of the light vehicle market and 91% of the heavy vehicle market. In the light vehicle market, the remainder is a mix of standard internal combustion vehicles (ICEVs) and hybrid ICEVs. Although they considered battery electric vehicles (BEVs), these vehicles do not capture much of the market in New Zealand because population density is low and limited range mitigates against their widespread use. In this baseline scenario, by 2050 more than half of total transportation fuel consumed is hydrogen.

One of the interesting findings from this analysis is that although New Zealand has considerable capacity to generate electricity from hydropower and wind, most of this capacity is used to satisfy residential and commercial demand for electricity. If hydrogen production is to be mounted on a large scale, much of it is likely to be from coal-fired cogeneration with electricity, and this does not produce much reduction in CO2 emissions unless most of the carbon is captured and sequestered. In that finding, the results of the New Zealand analysis are quite similar to the Korean assessment.

Furthermore, the increasing demand for hydrogen from co-generation is likely to drive electricity prices up. If the government were to mandate that hydrogen be produced from renewable sources, the effect on electricity prices would be much more severe.

Leaver and Gillingham find that their conclusions are quite sensitive to assumptions regarding the price of oil. Their baseline assumption is a 3% annual increase in the real price of oil, starting from an assumed price of US$90/barrel. If the oil price rise over time is lower, it delays adoption of the alternative fuel technologies. They also find that the carbon emission tax has much less effect on the overall outcome than does the price of oil.

Wang’s (2011) analysis of the effects of FCV use in California is another important recent study. It investigates the potential impacts of varying levels of FCV penetration over the period 2010-2030 on state GDP, personal income and employment, as well as the effects on transportation energy use and fuel mix. This study uses a detailed California-specific model, the Costs for Advanced Vehicles and Energy (CAVE) model, to estimate fuel consumption and vehicle/fuel costs associated with varying FCV penetration scenarios. These estimates are linked to a California-specific CGE model (EDRAM, the Environmental Dynamic Revenue Analysis Model) to estimate state-level macroeconomic impacts.

In a baseline scenario, FCVs are assumed to become available in 2020, and to increase to 20% of new vehicle sales by 2030. Under the fleet replacement assumptions in the CAVE model, this implies that by 2030, FCVs would make up approximately 8% of the light vehicle fleet in California. A more aggressive scenario in which FCVs are available beginning in 2018 and increase to 58% of new auto sales in 2030 is also investigated. In this scenario, FCVs make up 23% of the on-road vehicle fleet in 2030. In both scenarios, initial production of hydrogen is assumed to be distributed (i.e., at the refueling locations) and to be equally divided between electrolysis and steam methane reforming (SMR). However, as the number of FCVs grows, the production is assumed to shift to centralized SMR with pipeline delivery to refueling stations. A learning-curve model is used to estimate vehicle cost reductions over time after introduction. This model assumes that at introduction FCVs cost approximately $50,000/car, and their cost declines to a final value of $24,600/car over 6 years.

The scenario assumptions run through the CAVE model produce an estimate of annual net changes in cash flows within the personal transportation sector of the EDRAM model. The EDRAM model then computes the effects of these changes on the collection of economic sectors represented in its CGE model and summarizes those effects in terms of statewide macroeconomic indicators. Unlike the analyses done for the EU (Jokisch and Mennel, 2007) and for Korea (Bae and Choi, 2010), there is no modification of the energy production sector in this analysis to reflect introduction of new demands for hydrogen. The connection to the statewide CGE model is only through the changes in the costs of personal transportation.

The assumption of relatively rapid penetration of the FCVs in new car sales (even in the baseline scenario), combined with the much higher initial vehicle costs (as compared to ICEVs), imply a net increase in personal transportation costs over most of the planning horizon, and this translates to a small negative impact on the economic measures at the state level. However, these projected changes are very small – much less than 1%. Projected changes of this magnitude, looking nearly 20 years into the future, are probably negligible.

This collection of previous studies points to two important underlying issues. First, because there is no history of FCV sales, forecasting the demand for these vehicles and their market penetration over time is highly uncertain. Different studies have handled this problem in different ways. Jokisch and Mennel (2007) assumed that FCVs would be perfect substitutes for existing ICEVs, and that demand would be strictly based on relative prices of the different vehicle types. Leaver and Gillingham (2010) postulated a logit model of consumer choice that includes qualitative differences as well as price differences, but they recognize that parameter estimation for such a model is little more than guesswork at this point. Wang (2011) adopts a different strategy that simply postulates a rate of FCV sales (and market penetration) over time, and computes the net costs of that level of FCV use in the California economy. The way in which the uncertain demand for FCVs is addressed can have an important impact on the results of the analysis, but there is no generally accepted "correct" way of doing this at present.

The second important issue relates to assumptions made about hydrogen production technology, associated costs, and resulting environmental implications (especially CO2 emissions). This has also been incorporated into the previous analyses in different ways, and with different implications. Some include learning-curve ideas for reduction of production cost over time, while others do not. Some make the technology choice price-sensitive, while others do not. Some have market mechanisms for hydrogen as a sub-sector of energy production, while others do not. All of these differences highlight the difficulty of forecasting how hydrogen will be produced and distributed, at what cost, and with what environmental impacts.

In the current study, we do not have "magic" answers to these issues, but we have tried to address them in a constructive way. Part of the approach we have adopted is to take advantage of an innovative way of including both "top-down" macroeconomic relationships and "bottom-up" representation of technology options and choices for hydrogen production. This is a technique pioneered by Böhringer and Rutherford (2009). The general outline of that method is described more fully in section 4.4.

We have constructed an explicit way of modeling the demand for FCVs and hydrogen fuel, as well as a representation of the hydrogen production sub-sector within the energy sector of the economy. These sub-models are described more fully in section 4.6. In both cases, we cannot claim to have achieved accurate calibration of the models, but they are based on realistic assumptions and as much specific data pertaining to Hawaii as we can assemble within the scope of this project.

Before proceeding to further discussion of the methodological issues in this study, it is important to gain a better understanding of the context of the study in Hawaii. This is the subject of section 4.3.

4.3 The Hawaiian Economy, Energy and Transportation

Hawaii's population is approximately 1.4 million, about two-thirds of whom live on the island of Oahu. Honolulu, the capital and largest city, has a population of approximately 350,000 (about 40% of the Oahu population, and about 25% of the state total).

The state is organized into five counties: Honolulu (the island of Oahu), Kauai (the island of Kauai and smaller islands to the northwest of Oahu), Hawaii (the Big Island), Maui and Kalawao. Kalawao county is a part of the island of Molokai and has almost no resident population, being mostly a national historical park. The county of Maui includes all the rest of the islands between Oahu and the Island of Hawaii. For most data reporting, Maui and Kalawao counties are combined.

For the following summary, we have drawn data from a variety of sources, including datasets and publications from the U.S. Departments of Agriculture, Commerce, Energy, Labor and Transportation, as well as from several Hawaii departments and offices: the Department of Business, Economic Development and Tourism, the Department of Commerce and Consumer Affairs, the Department of Transportation, the State Energy Office, and the Department of Customer Services. Because there are so many sources, individual citations for specific numbers are not given, but the collection of individual statistics paints an overall picture of relevant aspects of the Hawaiian economy.

In 2010, the average annual income per capita in Hawaii was approximately $41,000, which ranks 17th among U.S. states. The state Gross Domestic Product (GDP) (2010 data) is about $66.8 billion. The five largest sectors of the economy are government (23%), real estate (18%), tourism (9%), retail trade (7%), and health care (6%). The very large military presence in Hawaii is a primary driver of the large government sector. Although there are some very well known agricultural products from Hawaii (pineapples, coffee, macadamia nuts, etc.), the agricultural sector contributes a very small portion of state GDP (less than 1%).

Hawaii has the highest electricity costs in the U.S. (about three times the U.S. average) because most of the electricity is produced by burning oil, and nearly all the oil in Hawaii is imported. In fact, about 86% of all primary energy in Hawaii is from imported petroleum. In addition to creating very high electricity prices, this also results in gasoline prices that are much higher than in the continental U.S. Of the total demand for petroleum and petroleum products in Hawaii, about one-third is for electric power generation, and two-thirds is for transportation. Within the transportation category, the demand is about equally split between jet fuel and gasoline, plus a relatively small amount of diesel. The large demand for jet fuel is partly a reflection of military use, and partly for refueling commercial jets (domestic flights to/from the mainland, as well as trans-Pacific international flights).

There are two oil refineries in Hawaii, both located in the southwest part of Oahu. One is tuned to maximize gasoline output, and the other to maximize jet fuel output.

There is modest capacity to produce hydrogen, primarily on Oahu and connected to the production of synthetic natural gas (SNG) from petroleum by-products. SNG consists of 77% methane, 11% hydrogen, 6% butane and 6% carbon dioxide. The Gas Company (TGC – the gas utility for Hawaii) manufactures approximately 60,000 short tons annually of SNG and distributes it (mostly via pipeline on Oahu) to about 35,000 commercial and residential customers.

Given Hawaii's location, climate and volcanic origins, there is potential for electricity production from a variety of renewable sources (solar, wind, geothermal, biomass), but most of this potential is as yet untapped. In theory, at least, electricity from renewable sources can be used to produce hydrogen (by electrolysis of water) and fuel vehicles with effectively zero emissions. However, at present, the cost of hydrogen produced this way is prohibitive. From a cost perspective, the production of hydrogen from biomass is most attractive, but given the limited agricultural land in Hawaii and the competition from more valuable food crops, large scale biomass-based production does not seem reasonable.

There are about 1.1 million registered vehicles in Hawaii, and total vehicle-miles traveled (VMT) is about 10 billion annually. This represents annual VMT per vehicle of approximately 9000, and annual VMT per capita of approximately 7300. These values are lower than what is typical in the continental U.S. because of the limited distances that are traveled on each island.

There are about 60,000 new car registrations annually. This statistic provides some sense of limits on the potential rate of adoption of FCVs. Because of the climate and relatively low annual mileage, cars tend to last longer in Hawaii than in the rest of the U.S., so the fleet turns over more slowly.

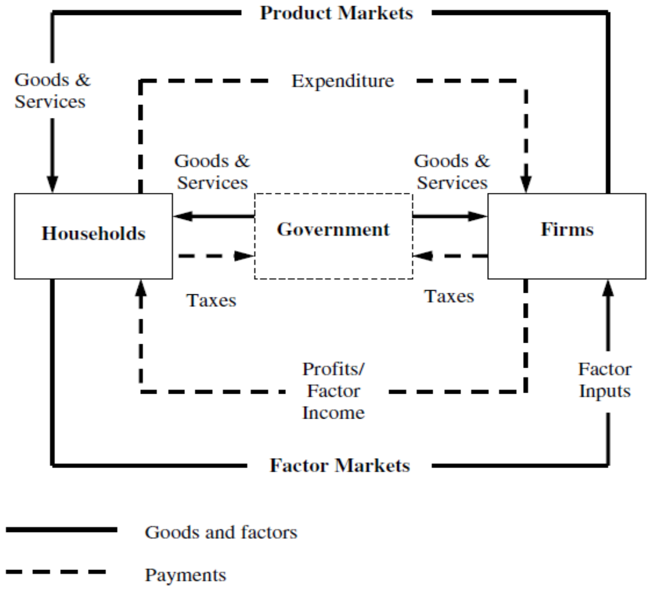
With the information from this section as context, we can turn our attention to the general structure of an integrated regional economic model.

4.4 The Top-Down, Bottom-Up Modeling Approach

A “top-down”, or aggregate model of the economy focuses on the flow of products and payments, as illustrated in Figure 4.2. Households are the source of the factors of production (labor and capital services), and are the final consumers of the goods and services produced. Firms purchase the factors of production (creating household income) and produce goods and services to be consumed. Government occupies a middle role, collecting taxes from both households and firms, and creating goods and services to both.

If the economy is in equilibrium, all of the goods and services produced must be consumed (market clearing). Second, the total revenue received by firms for goods and services must be expended either to purchase factors from households, to purchase intermediate products from other firms, or to the government as taxes. This ensures an accounting balance for firms. Third, a similar accounting balance must hold for households, so income must equal expenditures (including savings). The last two conditions are sometimes referred to as conservation of value. A model that solves for the flows of goods, factors and payments to achieve these conditions is known as a computable general equilibrium (CGE) model.

Figure 4.2 Circular flow of products and payments in an economy.



Source: Sue Wing, 2004.

Suppose the firms are divided into N different industrial sectors, and each sector produces a single composite product that can be consumed either by households or by other sectors as an intermediate good. Suppose also that the households are the source of F different factors of production and have demand for D different types of final consumption. D may include different categories of households, include government as a consumer, etc. Then the structure of the economic model can be specified in terms of four basic variables and three sets of equations. The variables are all expressed as total values of the flows in the economy (i.e., price multiplied by quantity) for each category. These are:

$\overline{y}_i$ = value of the aggregate supply of the ith commodity (sector)

$\overline{x}_{ij}$ = value of commodity i used as an intermediate good by commodity (sector) j

$\overline{g}_{id}$ = value of commodity i used in creation of final demand activity d

$\overline{v}_{fj}$ = value of factor f used in production of commodity (sector) j

The market clearing condition requires that the value of output produced must equal its value in use (either as an intermediate product or for final demand):

$$\overline{y}_i = \sum_{j=1}^{N} \overline{x}_{ij} + \sum_{d=1}^{D} \overline{g}_{id} \qquad i = 1, ..., N \tag{1}$$

The value of total output for each sector must also equal the value of the inputs used in its production:

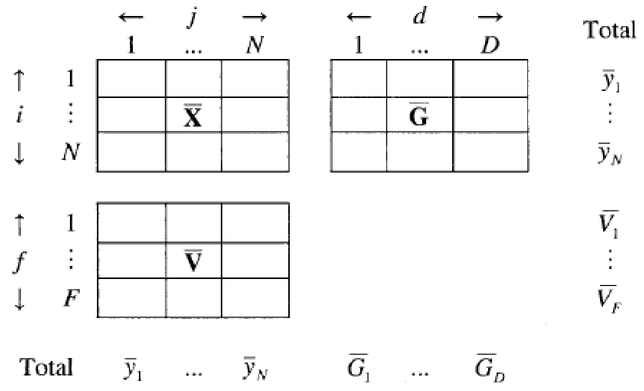
$$\overline{y}_j = \sum_{i=1}^{N} \overline{x}_{ij} + \sum_{f=1}^{F} \overline{v}_{fj} \qquad j = 1, ..., N \tag{2}$$

Third, the income received for the household sector must equal the expenditures for final demand:

$$\sum_{j=1}^{N} \sum_{f=1}^{F} \overline{v}_{fj} = \sum_{i=1}^{N} \sum_{d=1}^{D} \overline{g}_{id} \tag{3}$$

The structure of these accounting relationships suggests a structure built around three matrices, , , and , representing the collections of the respective variables. This overall structure, designated a Social Accounting Matrix (SAM), is shown in Figure 4.3. The row totals of the first N rows are the total output values, by eq. (1). Similarly, eq. (2) requires that the first N column totals are the same values. Figure 4.3 introduces the notation as the row totals of the matrix, and as the column totals of the matrix. Eq. (3) requires that the sum of the values must equal the sum of the values. This sum is the total income in the economy.

Figure 4.3 Construction of a Social Accounting Matrix.



Source: Sue Wing, 2004.

The SAM is a framework for organizing the flows of value in the economy. Within this framework, producing sectors operate to maximize profit from their activities, and consumers make consumption decisions to maximize their utility. To represent the decisions of producers and consumers, we separate the flows of value into prices and quantities of factors, goods and services. We will assume a set of prices, p_i, $i = 1, \ldots, N$, for the outputs of the production sectors, and a set of prices (sometimes referred to as wage rates or rents), w_f, $f = 1, \ldots, F$, for the factors. If production sector j has a production function (a function describing how output is created from inputs) defined by: $y_j = \phi_j\left(x_{1j}, \ldots, x_{Nj}; v_{1j}, \ldots, v_{Fj}\right)$, then the general profit maximization problem for a representative firm in production sector j can be written as follows.

In this problem, y_j, x_{ij}, and v_{fj} represent the physical quantities of products, intermediate inputs and factors, as contrasted to the *values* of those quantities, $\bar{y}_j$, $\bar{x}_{ij}$ and $\bar{v}_{fj}$, as represented in the SAM.

$$\max_{y_j, x_{ij}, v_{fj}} \quad p_j y_j - \sum_{i=1}^{N} p_i x_{ij} - \sum_{f=1}^{F} w_f v_{fj} \tag{4}$$

s.t. $$y_j = \phi_j\left(x_{1j}, ..., x_{Nj}; v_{1j}, ..., v_{Fj}\right) \tag{5}$$

On the consumer’s side, the representative consumer maximizes utility by choosing consumption levels of the N products, given the prices, p_i, and an income constraint (which is related to the w_f coefficients). The consumer choices also must reflect a structure of a utility function.

The CGE model uses the representation of the producer’s problem (eqs. 4 and 5), the consumer’s problem, and the constraints in the SAM to formulate a constrained optimization problem whose solution determines prices and quantities. Because the solution is at a very aggregate level and focuses on the general measures within the economy rather than on the specifics of a particular industry, the CGE modeling is considered to be a “top-down” approach.

For many policy studies, however, there is interest in representing the characteristics of a specific industry or sector in more detail so that more targeted policies can be evaluated. The energy sector has been of particular interest because of the pervasive influence energy has on all other economic sectors. Regardless of whether the specific sector of interest is energy or some other, this more detailed modeling focuses on expanding eqs. (4) and (5) to reflect specific technology options, constraints, etc. within the sector. This additional detail in a chosen sector reflects a “bottom-up” perspective that needs to be integrated with the overall CGE model of the economy.

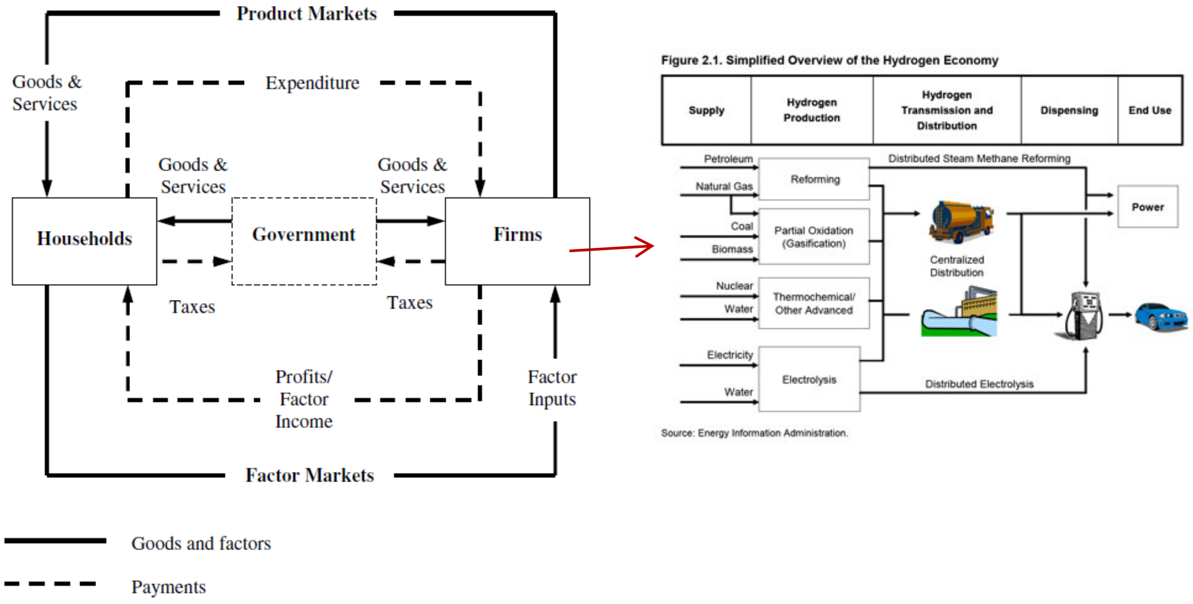
Böhringer and Rutherford (2009) describe an approach to such integration that involves iterative computations in the aggregate and detailed portions of the model. The detailed sector model takes prices (for products and factors) as given and solves for the output of that sector (or sub-sector). This output is then treated as given by the aggregate model, as it solves for a new equilibrium set of prices and outputs from other sectors. The prices are input to the detailed model for the next iteration. This process continues until the aggregate and detailed models provide consistent results.

In the Böhringer and Rutherford approach, the producer model for the detailed sector or sub-sector is represented as a linear programming problem. This representation reflects eqs. (4) and (5), with the assumption that the prices (pi and wf) are given as inputs and that the production function is represented as a set of linear constraints (equalities and inequalities). These constraints relate the various inputs, reflect technology options and capacity limits, etc.

In this study, because we are interested particularly in the production of hydrogen and its use in transportation as well as other industries, the detailed “bottom-up” model is a break-out of the firms’ portion of the CGE structure, as shown in Figure 4.4. The hydrogen model is a sub-sector of energy, and reflects source materials for hydrogen, various technologies for hydrogen production, distribution to points of consumption and end uses.

The detailed results of the hydrogen sub-sector model are then aggregated into the overall energy sector, which produces a composite output that enters the top-down model. The following two section describe the specific form of the aggregate model used to represent the Hawaiian economy and the disaggregate model of hydrogen production and distribution in Hawaii.

Figure 4.4 Breaking out the hydrogen production sub-sector.



4.5 The Aggregate Macroeconomic Model for Hawaii

The CGE benchmark economic data were taken from IMPLAN's (Economic Impact Analysis) 2010 county social accounts for the State of Hawaii. The baseline information was calibrated in such a way that the given SAM accounts could represent an equilibrium.

The CGE model had the following characteristics:

a) It is static in temporal orientation.

b) The economy is open to trade (there are imports and exports).

c) There is an aggregate macro-good composed of both non-energy and energy related sectors.

d) The economic sectors which define the macro-good are: Agriculture, Manufacturing, Wholesale and Retail Trade, Transportation, Services, Accommodations and Food, Fossil Fuels, Electricity, Governments, and Hydrogen.

e) At first we introduce the hydrogen sector into the SAM structure by assuming it to be a composite of the Fossil Fuel and Electricity sectors.

f) The initial share assumed for the hydrogen sector is taken from the bottom-up model.

g) Under these assumptions the model is calibrated and the SAM is balanced by adjusting the trade accounts.

h) Production uses the macro-good, imported goods, and factors of production (capital and labor) under constant returns to scale.

i) Final consumption demand includes the macro-good, and imported goods.

j) We consider an economy with taxes and public goods provision with the inclusion of a government agent.

The elasticities used for the production and consumption patterns of the Hawaiian economy are shown in Table 4.1:

Table 4.1 Elasticities of Substitution in the CGE model

Elasticities of substitution (ESUB)	
ESUB in final consumption	4.0
ESUB between capital and labor in Y production	1.0
ESUB between imported inputs in Y production	4.0
ESUB between imported goods in consumption	4.0

It is important to mention that these elasticities are standard in the literature related to Top-down and Bottom-up models dealing with IMPLAN’s social accounts and energy economics (Bohringer and Rutherford, 2007).

Once the model has been calibrated from the data we are able to recreate a benchmark equilibrium, which guarantees both the data and the model assumptions are in accordance with economic theory. In Section 4.7 we will employ the top-down model with its bottom–up counterpart, to be discussed next, to consider different scenarios for which we will track the main changes in prices, quantities, and measures of welfare in terms consumption by households with different income levels.

The simulation scenarios will be driven by an initial shock or change in the benchmark conditions of the model. These changes affect the initial values of the activity and income levels, as well as the market prices, which in subsequent rounds are sent to the Bottom-up model in order to obtain new production levels for the Hydrogen sector. This iterative process continues until we obtain convergence in the decision variables and thus a new equilibrium.

4.6 The Disaggregate Model of Hydrogen Production and Distribution

The hydrogen sector model has two major elements:

1) A demand sub-model that relates prices of fuels and vehicles to the amount of hydrogen demanded for use as a vehicle fuel; and

2) An optimization sub-model that uses factor prices from the aggregate model to determine the production and distribution pattern for hydrogen to meet the demand from the first sub-model.

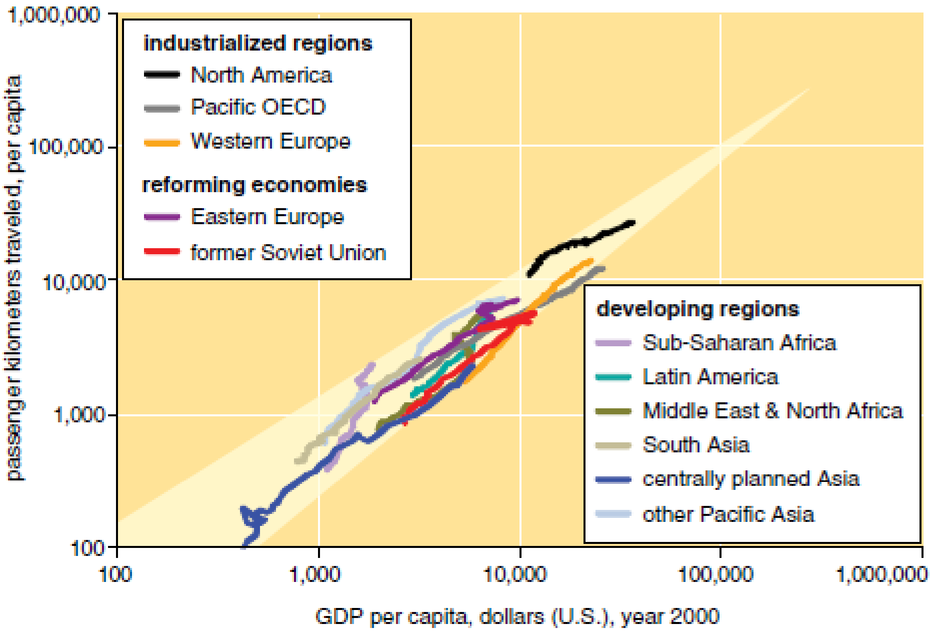
These two sub-models work together to create the bottom-up model of the hydrogen sector, and they will be discussed in turn.

4.6.1 The Vehicle Fuel Demand Sub-Model

To achieve integration of the top-down and bottom-up models, the demand model relates the price and income variables in the top-down model to VMT that will drive the production of gasoline and hydrogen in the bottom-up model. Because estimating such a demand model directly is well outside the scope of the current project, we need to build a plausible demand structure based on evidence we can gain from literature and previous models. There are a few useful general characteristics that we can extract from earlier analyses of travel and automobile purchasing decisions.

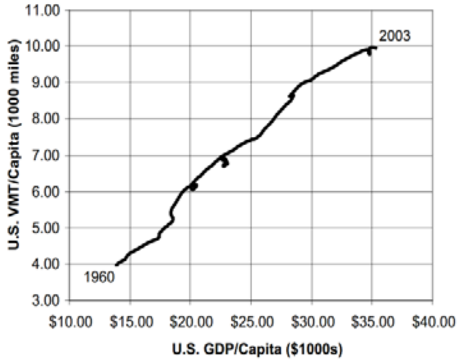
Shaefer, et al. (2009) describe an analysis of aggregate travel (passenger-km per year) as a function of GDP per capita, across a large sample of countries and a long time frame (1950-2005). Their finding, illustrated in Figure 4.5, is that total travel increases approximately linearly with GDP/capita. Figure 4.5 uses a logarithmic scale because of the very wide disparity among different regions of the world over a long time period. However, the slope of the general trend is approximately 1, indicating a relationship that is approximately linear.

Figure 4.5 Aggregate travel related to wealth.



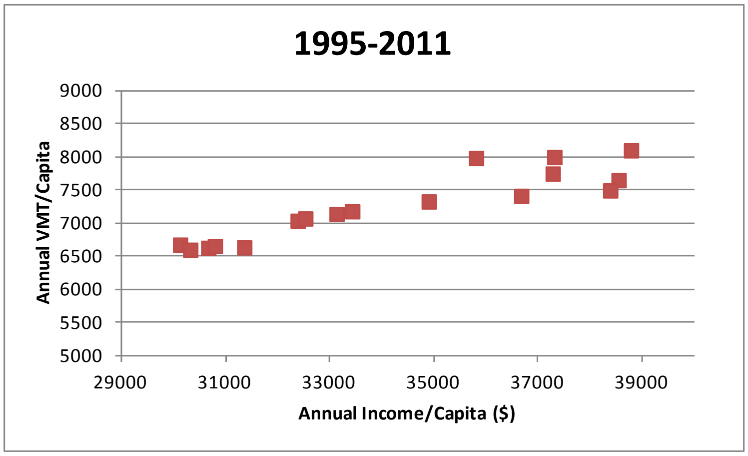
Extracting the data for the U.S. from the larger set shown in Figure 4.5, Ehlig-Economides and Longbottom (2008) illustrate the linear trend in a U.S. context, as shown in Figure 4.6.

Figure 4.6 Aggregate travel related to wealth in the U.S.



For Hawaii, there are data available on income per capita and vehicle-miles of travel (VMT) per capita from 1995-2011. These data are plotted in Figure 4.7, using constant 2005 dollars for the income variable. Although the Hawaii data measure income per capita rather than GDP per capita, the data in Figure 4.7 confirm the basic hypothesis that rising income is associated with more travel, and that the relationship is approximately linear.

Figure 4.7 Relating aggregate travel to income in Hawaii (1995-2011).



A linear regression for the data in Figure 4.7 results in the equation:

$$Annual\ VMT/capita = 2062 + 0.1516\ (Annual\ Income/capita) \quad (1)$$

The value of R2 for this regression is 0.843, and the t-statistic for the income slope coefficient is 8.97. In light of this strong empirical relationship between income and VMT in Hawaii, we can use this as part of our demand estimate.

Bordley and McDonald (1993) studied income elasticity for purchases of specific automobile makes and models in the U.S., and found that the aggregate income elasticity is approximately 2, with individual makes/models ranging from about 1.4 to about 5.0. The elasticity values for smaller and less expensive cars are lower, and the values for more expensive luxury and sports cars are higher.

The own-price elasticity for specific makes/models of automobiles is quite high because there are many competing models that are close substitutes. Bordley (2006) estimated car-line elasticities for different sizes of vehicles and observed a value of -3.0 for compact vehicles, -3.3 for midsize vehicles, and -3.8 for large vehicles.

Elasticity of VMT to fuel price is relatively low. The TRACE study (1999) in Europe estimated a value of -0.2 for commuting trips and -0.29 overall. de Jong and Gunn (2001) , also working with European data, found similar results: -0.23 for commuting and -0.26 overall.

Putting these (relatively sparse) pieces of evidence together, we might construct a demand model for VMT by FCVs that is based on a mobility variable (VMT/capita), total population, and the share of the vehicle market that is FCVs. The model is:

$$FCV\_VMT = (VMT/capita)\,(population)\,(FCV\_Share) \qquad (2)$$

This assumes that FCVs would be driven in the same way as ICEVs, so that the share of the vehicle fleet that is FCVs is the same as the share of total VMT that is accounted for by FCVs.

The VMT/capita term in eq. (2) can be specified by eq. (1). In 2011, the average income per capita in Hawaii was \$42,925, or \$37,275 in constant 2005 dollars. For 2011, eq. (1) then implies an estimate of 7713 miles/capita of vehicle travel. The 2011 population of Hawaii was approximately 1.38 million, so the total VMT for that year can be estimated at 10.6 billion, which aligns quite closely to the observed value. In the model proposed in eq. (2), as population increases the total VMT will also increase linearly (at constant income).

The proposed FCV_Share model is designed to incorporate effects of income, relative prices of ICEVs and FCVs, and relative fuel prices. It takes the form:

$$FCV\_Share = b\,Y\left(\frac{P_{FCV}}{P_{ICEV}}\right)^{-3}\left(\frac{f_{FCV}}{f_{ICEV}}\right)^{-0.2} \qquad (3)$$

where:
Y = income/capita (\$)
P_{FCV} = purchase price of a fuel cell vehicle (\$)
P_{ICEV} = median purchase price of an internal combustion engine vehicle (\$)
f_{FCV} = fuel cost for FCV (\$/mile)
f_{ICEV} = fuel cost for an ICEV (\$/mile)
b = scaling constant

This expression contains the assumption of an own-price elasticity for FCVs of -3, and a fuel price elasticity of -0.2. Combined with the income effect in the VMT/capita term above, the overall effect of income on FCV_VMT is quadratic. The income elasticity for the model in eq. (2) is:

$$\varepsilon_Y = \frac{\beta_0 + 2\beta_1 Y}{\beta_0 + \beta_1 Y} \tag{4}$$

where β_0 and β_1 are the estimated coefficients in the VMT/capita model. Using the estimated values $\beta_0 = 2062$, $\beta_1 = 0.1516$ and Y = 37,275, the income elasticity is 1.7, which is consistent with Bordley's (1993) range of estimates.

If we assume:

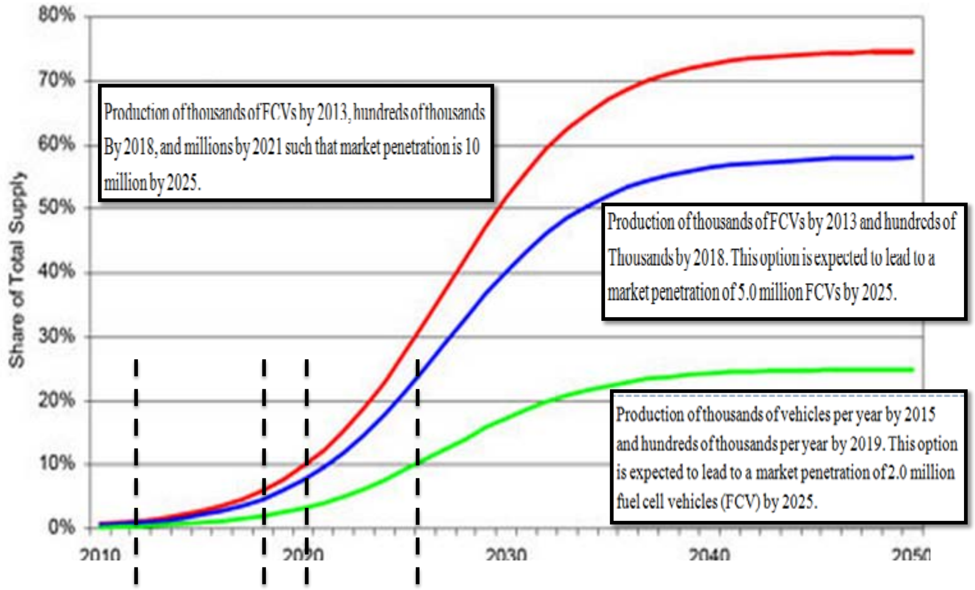
a) the median purchase price of an ICEV is $23,000
b) the purchase price of an FCV is $35,000
c) the fuel cost for an ICEV is $0.076 per mile (based on gasoline price, without taxes, of $3.80 per gal, and efficiency of 50 miles/gal)
d) the fuel cost for an FCV is $0.035 per mile (based on hydrogen price of $3.00 per kg, and a fuel efficiency of 85 miles/kg)

then a value of b = 4.1x10-6 would yield an FCV_share of approximately 5% of the Hawaiian passenger car fleet in 2025. This is somewhat lower than the DOE "Scenario 3" estimate (about 10%) for 2025 for national penetration of FCV technology (see the green curve in Figure 4.8), but probably represents a more likely situation. A penetration of 5% of the passenger car fleet translates into approximately 57,000 FCVs in the overall vehicle fleet in 2025.

Taken together, the overall estimate of VMT for FCVs (from eq. 2) is approximately 546 million per year (at the current population, income, and with the prices assumed above), implying a demand for about 6.4 million kg of H2 annually.

The 95% of total demand for VMT (10.6 billion in 2011) not provided by FCVs is provided by ICEVs, implying a demand for approximately 200 million gallons of gasoline annually.

Figure 4.8 US DOE scenario estimates for FCV market penetration in the overall U.S. market.



Production of thousands of FCVs by 2013, hundreds of thousands By 2018, and millions by 2021 such that market penetration is 10 million by 2025.

Production of thousands of FCVs by 2013 and hundreds of Thousands by 2018. This option is expected to lead to a market penetration of 5.0 million FCVs by 2025.

Production of thousands of vehicles per year by 2015 and hundreds of thousands per year by 2019. This option is expected to lead to a market penetration of 2.0 million fuel cell vehicles (FCV) by 2025.

This overall structure is useful for expressing the demand inputs to the bottom-up model, even though the empirical support for the specific form of the function and its parameters is limited. The inputs from the top-down model are:

- Income/capita
- Fuel price for H_2
- Fuel price for gasoline

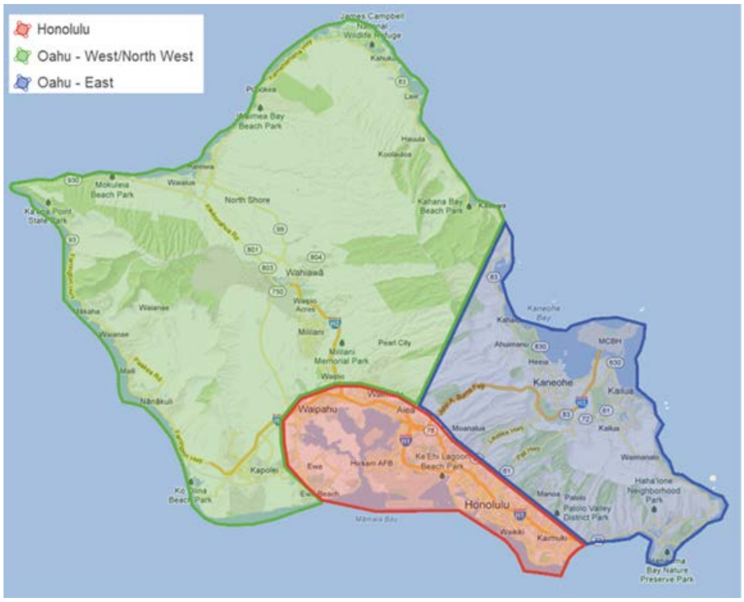
Exogenous inputs are:

- Population total
- Purchase price of an FCV
- Median purchase price of an ICEV
- Efficiency for H_2 (VMT/kg)
- Efficiency for ICEVs (VMT/gallon of gasoline)

The vehicle purchase prices are likely to be exogenous because Hawaii does not produce cars. This also allows using the model in a straightforward way to explore policy changes (subsidies, taxes, etc.) that affect the prices seen by consumers.

To use the demand sub-model to drive the production-distribution sub-model, we introduce a spatial disaggregation, based on a zone structure. The aggregate top-down model is at the statewide level, but the production-distribution model operates at a finer level of detail. For this purpose, we define a set of four zones. Three of the four are subdivisions of Oahu, as illustrated in Figure 4.9. The fourth zone is all the other islands. The subdivision of Oahu allows representation of the main population centers on the island, as well as location of the production centers for hydrogen and gasoline (in the WNW zone) as being separate from the largest demands (in the Honolulu zone), and the need for transportation of the fuels.

Figure 4.9 Zone structure for Oahu.



The primary output of the demand model is the annual demand for H2, broken down by zone based on population. For the current estimates of parameters, the total H2 demand is approximately 6.4 million kg annually, and is broken out by zone (using population proportions in each zone) as shown in Table 4.2.

Table 4.2 Base level hydrogen demand by zone.

Zone	Annual H2 demand (millions of kg)
Honolulu	1.6
Oahu – East	0.6
Oahu – West and NW	2.2
Other Islands	2.0
Total	6.4

4.7 The Hydrogen Production-Distribution Sub-Model

The H2 demand values drive the optimization model of production and distribution, which is a linear program (LP). The LP model treats the demands for H2 (both for vehicle fuel and industrial uses) as fixed inputs, and minimizes the cost of H2 production and distribution to meet those demands by selecting production quantities at different production locations, using available processes and feedstocks. These quantities are distributed to the demand locations, and both production and distribution are subject to capacity constraints.

The model formulation described below refers to the following sets:

4 Locations (or zones): Honolulu
Oahu-East
Oahu- West/NW
Other Islands

6 Processes: Distributed steam methane reforming
Distributed electrolysis
Centralized steam methane reforming
Centralized electrolysis
Gasification

Industrial supply

3 Feedstocks: Natural gas for reforming processes
Biomass for gasification
Renewable electricity for electrolysis processes

3 Distribution Modes: Pipeline
Truck
Barge

The formulation indexes locations using *i* and *j*; processes by *k*; feedstocks by *f*; and distribution modes by *m*. The set of processes for producing H_2 is further subdivided into the processes that are distributed (i.e., produce H2 at the site of consumption), and those that are centralized (i.e., produce H2 at a large facility and distribute the product to sites of consumption). The set of distributed process technologies (the first two in the list above) is referred to as Φ, and the set of centralized technologies (the last four in the list) is referred to as Θ.

The model input values, parameters, and output values (decision variables) are summarized as follows. The names in brackets are the variable names in the GAMS expression of the model, which translates the model into code for solution.

Input Values
H_i^I = H_2 demand for industrial use in zone *i* [H2IndDem]
H_i^{FCV} = H_2 demand for vehicle fuel in zone *i* [H2FCVDem]

Parameters
c_k = unit production cost for process *k* [UnitProdCost]
d_{ijm} = unit distribution cost from zone *i* to zone *j* using mode *m* [UnitDistCost]
F_{fk} = unit fuel cost for process *k* using feedstock *f* [H2FuelCost]

Q_{ifk} = capacity limit on H_2 production in zone *i* using process *k* and feedstock *f* [H2Cap]

V_{ijm} = capacity limit on H_2 distribution from zone *i* to zone *j* using mode *m* [FlowCap]

Outputs

q_{ifk} = H_2 production in zone *i* using process *k* and feedstock *f* [H2Prod]

v_{ijm} = flow of H_2 from zone *i* to zone *j* using mode *m* [Flow]

The model formulation is:

$$\text{Min} \quad \sum_i \sum_k \sum_f \left(F_{fk} + c_k\right) q_{ifk} + \sum_i \sum_j \sum_m d_{ijm}\, v_{ijm} \tag{5}$$

$$\text{s.t.} \quad \sum_f \sum_{k \in \Theta} q_{ifk} = \sum_j \sum_m v_{ijm} \qquad \forall\, i \tag{6}$$

$$\sum_i \sum_m v_{ijm} + \sum_f \sum_{k \in \Phi} q_{jfk} = H_j^I + H_j^{FCV} \qquad \forall\, j \tag{7}$$

$$0 \le q_{ifk} \le Q_{ifk} \qquad \forall\, i,\ f, k \tag{8}$$

$$0 \le v_{ijm} \le V_{ijm} \qquad \forall\, i,\ j, m \tag{9}$$

Eq. (5) is the cost function (production plus distribution) to be minimized. Eq. (6) ensures that all H2 produced by centralized processes in zone i is distributed somewhere. Eq. (7) specifies that demand in zone j (industrial plus vehicle fuel) must be met, either through distribution from centralized production facilities or through distributed production on-site within the zone. Eqs. (8) and (9) impose the capacity constraints on production and distribution.

Table 4.3 shows the assumed fuel costs for producing hydrogen by feasible feedstock/process combinations. In addition to fuel costs, each process has a production cost as shown in Table 4.3. The values in Tables 4.3 and 4.4 have been constructed from estimated costs in a variety of sources and should be realistic, but since there is little experience with many of these process-feedstock combinations in Hawaii, other estimates could also be used.

Table 4.3 Fuel costs for hydrogen production by feasible process-feedstock combinations.

Process	Feedstock	Fuel Cost ($/kg H2)
Distributed SMR	Natural Gas	2.01
Distributed Electrolysis	Biomass	5.00
	Renewable Electricity	2.20
Centralized SMR	Natural Gas	2.01
Centralized Electrolysis	Biomass	5.00
	Renewable Electricity	2.20
Gasification	Biomass	0.54
Industrial Supply	Natural Gas	0

Table 4.4 Production costs (other than fuel) for hydrogen production by feasible processes.

Process	Non-fuel Production Cost ($/kg H2)
Distributed SMR	0.50
Distributed Electrolysis	1.20
Centralized SMR	0.34
Centralized Electrolysis	0.90
Gasification	0.38
Industrial Supply	0.50

Not all the process-feedstock combinations are likely to be feasible in every zone. For example, it is unlikely that use of biomass gasification would be feasible within the City of Honolulu. Table 4.5 shows the assumed capacity (thousand kg per year) for the production alternatives that are considered feasible in each zone.

Table 4.5 Capacities for hydrogen production by feasible zone-process-feedstock combinations.

Zone	Process	Feedstock	Annual Capacity (000 kg H2)
Honolulu	Distributed SMR	Natural Gas	600
	Distributed Electrolysis	Renewable Electricity	600
Oahu -- East	Distributed SMR	Natural Gas	600
	Distributed Electrolysis	Renewable Electricity	600
	Gasification	Biomass	1000
Oahu – West/NW	Distributed SMR	Natural Gas	600
	Distributed Electrolysis	Renewable Electricity	600
	Centralized SMR	Natural Gas	2100
	Centralized Electrolysis	Renewable Electricity	1000
	Gasification	Biomass	1000
	Industrial Supply	Natural Gas	1200
Other Islands	Distributed SMR	Natural Gas	600
	Distributed Electrolysis	Renewable Electricity	600
	Gasification	Biomass	1000

The assumed distribution costs and capacities are shown in Figure 4.10. The use of large costs ($1000 per kg) and zero capacities indicates origin-destination-mode combinations that are not feasible. A null mode is represented for distributed production because production is at the site of consumption so no distribution costs are necessary. However, the capacity for this distribution mode is only available within each zone (non-zero capacities only on the diagonal of the matrix). Trucking within the Other Islands zone is allowed, representing distribution on each island, but this does not imply that H2 could be trucked between islands.

The costs of using barges between islands are relatively large because the barge movement also includes a local truck movement at each end of the trip.

Figure 4.10 Example of H2 distribution parameters as input to the LP model.

Unit Costs ($/kg)	Pipeline			
	To Zone			
From Zone	Honolulu	Oahu - East	Oahu - WNW	Other Islands
Honolulu	1000	1000	1000	1000
Oahu - East	1000	1000	1000	1000
Oahu - WNW	0.1	1000	0.1	1000
Other Islands	1000	1000	1000	1000

	Truck			
	To Zone			
From Zone	Honolulu	Oahu - East	Oahu - WNW	Other Islands
Honolulu	0.09	0.45	0.47	1000
Oahu - East	0.45	0.09	0.58	1000
Oahu - WNW	0.47	0.58	0.45	1000
Other Islands	1000	1000	1000	0.6

	Barge			
	To Zone			
From Zone	Honolulu	Oahu - East	Oahu - WNW	Other Islands
Honolulu	1000	1000	1000	0.69
Oahu - East	1000	1000	1000	1.05
Oahu - WNW	1000	1000	1000	1.07
Other Islands	0.69	1.05	1.07	1000

Null (local production)				
	To Zone			
From Zone	Honolulu	Oahu - East	Oahu - WNW	Other Islands
Honolulu	0	0	0	0
Oahu - East	0	0	0	0
Oahu - WNW	0	0	0	0
Other Islands	0	0	0	0

Capacity (000 kg)	Pipeline			
	To Zone			
From Zone	Honolulu	Oahu - East	Oahu - WNW	Other Islands
Honolulu	0	0	0	0
Oahu - East	0	0	0	0
Oahu - WNW	1000	0	1000	0
Other Islands	0	0	0	0

	Truck			
	To Zone			
From Zone	Honolulu	Oahu - East	Oahu - WNW	Other Islands
Honolulu	3000	3000	3000	0
Oahu - East	3000	3000	3000	0
Oahu - WNW	3000	3000	3000	0
Other Islands	0	0	0	3000

	Barge			
	To Zone			
From Zone	Honolulu	Oahu - East	Oahu - WNW	Other Islands
Honolulu	0	0	0	3000
Oahu - East	0	0	0	3000
Oahu - WNW	0	0	0	3000
Other Islands	3000	3000	3000	0

Null (local production)				
	To Zone			
From Zone	Honolulu	Oahu - East	Oahu - WNW	Other Islands
Honolulu	10000	0	0	0
Oahu - East	0	10000	0	0
Oahu - WNW	0	0	10000	0
Other Islands	0	0	0	10000

The results of the optimization for this set of input values are shown in Table 4.6 and Figure 4.11. Table 4.6 summarizes the H2 production quantities, by location, process and feedstock. The values shown are in thousands of kg annually. The industrial supply is cheapest because the H2 is a by-product, and that is used up to available capacity. Production via biomass gasification is also used to capacity where it is an available option. Distributed SMR is used to capacity in three of the zones, but not used in Oahu-East. This is because the gasification has sufficient capacity in Oahu-East to meet all demand in that zone. There is use of distributed electrolysis in the islands other than Oahu in order meet the local demand and avoid the high costs of shipping by barge from Oahu.

Figure 4.11 shows the distribution pattern associated with this production plan and set of demands to be met. The available pipeline capacity on Oahu, linking the Oahu--WNW production to Honolulu and other intra-zonal locations, is used where possible. The remaining transportation needs on Oahu are met by truck. The production from biomass gasification in

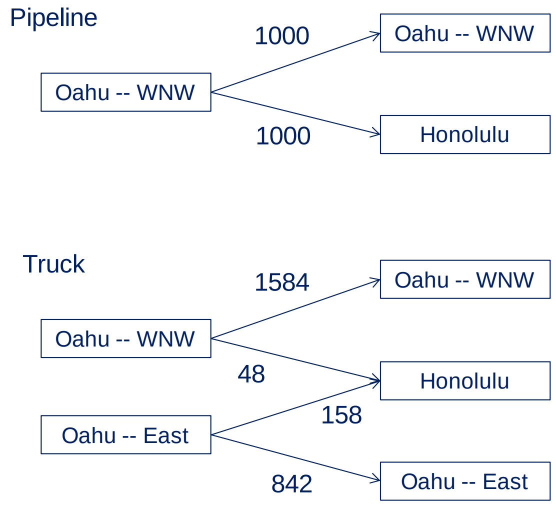
Oahu-East is mostly distributed by truck within that zone for local demand. The remainder goes to Honolulu. Within the Oahu-WNW zone, the H2 that cannot be distributed by pipeline is also trucked to meet local demand. The remainder of production in the Oahu-WNW zone is trucked to Honolulu. No barge distribution is used among the islands. The model also reports the local trucking of production from biomass gasification in the Other Islands zone, but that is not shown in Figure 4.11.

The output results from H2 production and distribution shown in Table 4.6 and Figure 4.11 should be considered illustrative, and not as the results from any particular run of the top-down, bottom-up integrated model. Those results are discussed more fully in Section 4.7.

Table 4.6 Hydrogen production by feasible zone-process-feedstock combinations.

Zone	Process	Feedstock	Annual Production (000 kg H2)	Annual Capacity (000 kg H2)
Honolulu	Distributed SMR	Natural Gas	600	600
	Distributed Electrolysis	Renewable Electricity	0	600
Oahu -- East	Distributed SMR	Natural Gas	392	600
	Distributed Electrolysis	Renewable Electricity	0	600
	Gasification	Biomass	1000	1000
Oahu – West/NW	Distributed SMR	Natural Gas	438	600
	Distributed Electrolysis	Renewable Electricity	0	600
	Centralized SMR	Natural Gas	1046	2100
	Centralized Electrolysis	Renewable Electricity	0	1000
	Gasification	Biomass	1000	1000
	Industrial Supply	Natural Gas	1200	1200
Other Islands	Distributed SMR	Natural Gas	600	600
	Distributed Electrolysis	Renewable Electricity	0	600
	Gasification	Biomass	1000	1000

Figure 4.11 H2 distribution pattern output for zones on Oahu.



4.8 Experiments and Results

In this section we develop a set of experiments related to the introduction of hydrogen in the Hawaiian economy. First, we change the initial conditions in the Top-down model by shocking activity and income levels, as well as prices which in turn have an impact on the variables from the Bottom-up model, which determines the Hydrogen demand level, which is then adjusted in the CGE model.

We begin our simulation exercises by considering different shares of hydrogen in the aggregate energy sector. As mentioned earlier we assume an energy related sector, constituted by the fossil fuels, electricity, and hydrogen sector. At the initial equilibrium of our model the hydrogen sector represents 1.6% of the total demand for the energy related sectors. Since we are interested in the effects of a progressive adoption of hydrogen as the main source of energy in Hawaii, we exogenously increase the share of hydrogen in the energy sector. In particular, we focus our analysis where the hydrogen sector goes from 1.6% through 5%, 20%, 50%, up to a 90% share of the energy related sectors. We concentrate our analysis in the behavior of prices, and output of different economic sectors, consumption levels of different income level households; as well as gross domestic product and wages.

For each progressive increase in hydrogen's share in aggregate energy composition, the integrated model is iterated until convergence in the variables of interest is achieved. Due to the static nature of the model, convergence is obtained after 10 iterations at most. In the following subsections we will display the results from different scenarios relevant to consideration of hydrogen as fuel for vehicles in Hawaii and the introduction of the new hydrogen industry.

4.8.1 Scenario 1: Increases in fossil fuel prices

Table 4.7 shows the effect of a 10% increase of fossil fuel prices under different hydrogen shares. There are several aspects to highlight under this simulation. First, as fossil fuel prices increase, prices on all other goods increase when hydrogen has less than 20% share of the energy sector. This outcome is to be expected, since fossil fuels are an input in many different goods. When the hydrogen share is less than 20%, we can see that the manufacturing and electricity sectors seem to be the most affected by the increases in fossil fuel prices. One could infer that fossil fuels have a more significant role in the production structure of these two sectors.

The story is some way different when the hydrogen share is either 50 or 90 percent, since under these shares we start seeing that for certain goods, prices start to decrease. This is the case for goods in the agriculture, wholesale/retail trade, transportation, services, and accommodation/food, and government sectors. The intuition behind this result is that as fossil fuel prices increase in an economy where fossil fuels do not hold a large share in energy production, substitution towards alternative sources of energy such as hydrogen becomes easier.

Table 4.7 Percentage changes in prices and output levels at different hydrogen shares

	H2 = 1.6%		H2 = 5%		H2 = 20%		H2 = 50%		H2 = 90%	
	P	Q	P	Q	P	Q	P	Q	P	Q
Agriculture	0.22	1.67	0.22	1.66	0.22	1.59	-0.02	1.3	0.01	1.29
Fossil Fuels	2.9	-2.88	2.77	-2.63	2.31	-1.81	1.51	-0.95	1.06	-0.35
Manufacturing	1.29	-0.53	1.28	-0.53	1.27	-0.54	1.07	-1.97	1.03	-1.39
Wholesale/Retail Trade	0.15	0.31	0.15	0.31	0.14	0.3	-0.12	0.23	-0.13	0.28
Transportation	0.19	0.2	0.18	0.2	0.18	0.19	-0.06	0.18	-0.04	0.18
Electricity	0.84	-0.89	0.83	-0.85	0.8	-0.71	0.41	-0.33	0.33	-0.17
Hydrogen	0.34	0.31	0.35	0.28	0.39	0.17	0.82	-0.68	1.08	-0.78
Services	0.14	0.25	0.14	0.25	0.13	0.24	-0.14	0.35	-0.11	0.31
Accommodations/Food	0.19	0.01	0.19	0.01	0.18	0.01	-0.07	0.03	-0.04	0.01
Government	0.1	-0.29	0.1	-0.29	0.09	-0.28	-0.25	-0.07	-0.21	-0.13

In terms of sector specific output we see that production in the agriculture and hydrogen sectors is higher than in all other sectors. There is a clear substitution in energy resources from electricity and fossil fuels to hydrogen, as fossil fuel prices increase. This result supports policies which promote the use of hydrogen as an alternative energy source in Hawaii. It is important to mention that the non-energy related sector of manufacturing decreases its output progressively as fossil fuel prices increase. It would be relevant to prepare this sector in the event of the development of a hydrogen industry, since it seems that it has a strong dependence with sources of energy derived from fossil fuels.

In terms of wealth, the effects of increases in fossil fuel prices under the introduction of a hydrogen industry has some interesting effects on household income. As Table 4.8 shows, all income level households, show decreases in their income levels when hydrogen progressively increases its share in the energy sector. One result to highlight in terms of incomes, is the fact that as hydrogen increases its share on the energy sector, the effects of increases of fossil fuel prices start to have a higher impact on mid to high income households. As we can see from Table 4.8, their income decreases up to 0.85 percent. We might infer that these households have the capital to adjust to new sources of energy, given the increases in fossil fuel prices, but this capacity to adjust is only able to hold on to a point when fossil fuels are so scarce that shocks on prices affect households of all income levels.

Table 4.8 Percentage changes in income levels at different hydrogen shares

	H2 = 1.6%	H2 = 5%	H2 = 20%	H2 = 50%	H2 = 90%
Less than $50,000	-0.19	-0.19	-0.2	-0.25	-0.26
$50,000 - $100,000	-0.11	-0.12	-0.12	-0.28	-0.27
More than $100,000	-0.03	-0.03	-0.04	-0.88	-0.85

Finally, it is interesting to see the effects of this shock on fossil prices on GDP and wages. Table 4.9 summarizes the effects on these variables. First, we can see that gross domestic product increases with increases in input prices, however as hydrogen has a bigger share on the energy sector the effect is lower. GDP increases around 5 percent when Hydrogen holds up to 20 percent share, and this growth is around 2 percent when the share is 90 percent. Wages increase when hydrogen has up to a 20% share on the energy aggregate, but wages start to decrease when hydrogen has more than a 50% share on the energy sector.

Table 4.9 Percentage changes in GDP and wages at different hydrogen shares

	H2 = 1.6%	H2 = 5%	H2 = 20%	H2 = 50%	H2 = 90%
GDP	4.0	5.0	5.0	1.0	2.0
Wages	0.06	0.06	0.05	-0.32	-0.28

The effects of increases in fossil fuel prices have almost no effect on the production and distribution patterns of hydrogen in Hawaii. Table 4.10 shows the effect of increases in fossil fuel prices to the production pattern of hydrogen in the island under the 50% share results from scenario 1. From Table 4.7 we saw how fossil fuel prices had a smooth negative effect on hydrogen demand, and an increase y hydrogen’s production costs, -0.68% and 0.82% respectively. This resulted in a decrease in production from the East and West-Northwest zones in Hawaii. More specifically, it involved a decrease in the distributed SMR from natural gas in both zones, -2.4% and -6.2% respectively, and a decrease of -4.1% in the West-Northwest centralized SMR production process. The remaining production processes at different zones kept their baseline levels.

Table 4.11 shows the effects of increases in fossil fuel prices to the distribution pattern under the 50% hydrogen share for scenario 1. As the production results from table 4.10 showed, there were few changes compared to the baseline levels. In particular, the distribution pattern showed some small changes in the barge transportation mode for hydrogen being transported from the West-Northwest and Other islands in Hawaii. While hydrogen transported with barges to Honolulu and Other islands from the Other islands and West-Northwest zones in Hawaii decreased by -1% and -5% respectively; hydrogen carried with barged to the West-Northwest zones from Other islands increased by 1.7%.

As we can see there are no significant changes in the production and distribution pattern with fossil fuel prices increases under an optimistic hydrogen energy share of 50%. This results holds even when hydrogen represents 90% of the energy sector. In this sense, changes in fossil fuel prices have almost no effect on the baseline production and distribution levels.

Table 4.10 Hydrogen production by feasible zone-process-feedstock combinations under Scenario 1

Zone	Process	Feedstock	Baseline Production (000 kg H2)	New Production (000 kg H2)	% variation
Honolulu	D. SMR	Natural Gas	600	600	0.00
	D. Elec.	Renewable Electricity	0	0	0.00
East	D. SMR	Natural Gas	392	382.5	-2.42
	D. Elec.	Renewable Electricity	0	0	0.00
	Gas.	Biomass	1000	1000	0.00
West/NW	D.SMR	Natural Gas	438	410.5	-6.28
	D. Elec.	Renewable Electricity	0	0	0.00
	C.SMR	Natural Gas	1046	1003.3	-4.08
	C. Elec.	Renewable Electricity	0	0	0.00
	Gas.	Biomass	1000	1000	0.00
	I. Supply	Natural Gas	1200	1200	0.00
Other	D. SMR	Natural Gas	600	600	0.00
	D. Elec.	Renewable Electricity	0	0	0.00
	Gas.	Biomass	1000	1000	0.00

Table 4.11 H2 distribution pattern output under Scenario 1

Origin	Mode	Destination	Baseline (000 kg H2)	New (000 kg H2)	% Variation
West/NW	Pipe Line	Honolulu	1000	1000	0.00
West/NW	Pipe Line	West/NW	1000	1000	0.00
East	Truck	East	1000	1000	0.00
West/NW	Barge	Other	1246	1233	-1.04
Other	Barge	Honolulu	2460	2334	-5.12
Other	Barge	West/NW	7540	7665	1.66

4.8.2 Scenario 2: The effects of subsidies to promote hydrogen production

Given the current state of affairs and the potential of hydrogen as an alternative energy source for transportation, it is important to consider the role of subsidies. In the following scenario we consider two subsidy frameworks. First we conduct an experiment where the government subsidizes the price of hydrogen. Second, we recreate a public-private subsidy scheme where the government subsidizes hydrogen prices and the private sector subsidizes part of the cost of the hydrogen fuel-cell vehicles in order to make them more competitive with the fossil fuel vehicles.

Tables 4.12, 4.13, and 4.14 show the effect of a $1 dollar subsidy on (reduction in) the price of 1 kilogram of hydrogen. In the baseline bottom-up model we assumed the price per kilogram of hydrogen to be on average $3 dollars. A subsidy of this sort would mean a 33% subsidy on the price of the new sectors product, which would also represent a $560 million dollar expense for the Hawaiian government, given the initial demand for hydrogen. The results show that a price subsidy by the government alone may induce some adverse effects on the economy.

Table 4.12 Percentage changes in prices and output levels at different hydrogen shares

	H2 = 1.6%		H2 = 5%		H2 = 20%		H2 = 50%		H2 = 90%	
	P	Q	P	Q	P	Q	P	Q	P	Q
Agriculture	-0.04	-0.23	-0.13	-0.7	-0.47	-2.5	-1.18	-5.38	-1.53	-7.84
Fossil Fuels	-0.4	0.4	-1.16	1.13	-3.57	2.92	-6.02	3.06	-6.92	1.78
Manufacturing	-0.19	0.08	-0.58	0.24	-2.19	0.97	-4.91	0.75	-7.46	2.66
Wholesale/Retail Trade	-0.03	-0.04	-0.09	-0.13	-0.32	-0.47	-0.97	-0.89	-0.74	-1.73
Transportation	-0.03	-0.03	-0.1	-0.09	-0.36	-0.31	-0.93	-0.66	-1.07	-1
Electricity	-0.12	0.11	-0.36	0.32	-1.26	0.93	-2.59	1.27	-3.03	0.82
Hydrogen	-0.06	-0.04	-0.19	-0.11	-0.79	-0.18	-2.03	-0.1	-4.78	1.94
Services	-0.03	-0.04	-0.08	-0.11	-0.29	-0.42	-0.81	-0.86	-0.8	-1.53
Accommodations/Food	-0.04	0	-0.11	0	-0.42	0	-1.08	0.01	-1.3	0.07
Government	-0.02	0.04	-0.06	0.13	-0.21	0.5	-0.62	1.31	-0.35	1.92

Table 4.13 Percentage changes in income levels at different hydrogen shares

	H2 = 1.6%	H2 = 5%	H2 = 20%	H2 = 50%	H2 = 90%
Less than $50,000	0.03	0.09	0.38	1.1	-0.26
$50,000 - $100,000	0.02	0.05	0.22	0.74	-0.27
More than $100,000	0	0.01	0.06	-0.57	-0.85

Table 4.14 Percentage changes in GDP and wages at different hydrogen shares

	H2 = 1.6%	H2 = 5%	H2 = 20%	H2 = 50%	H2 = 90%
GDP	-1	-2	-9	-23	2
Wages	-0.01	-0.04	-0.14	-0.43	-0.28

As we can see there is a decrease in output for most cases. Only when hydrogen’s share of the energy aggregate is 90% do we observe some increases in output especially in the fossil fuels, manufacturing, electricity, hydrogen, accommodations/food, and government sectors. In this case the GDP is able to increase by 2%. Finally, income levels increase for all households when hydrogen has less than 50% of the energy aggregate.

On the other hand, when we recreate the public-private subsidy approach where we continue to subsidize the price of hydrogen, but we also are able to bring down the prices of fuel-cell vehicles from $35,000 to $30,000 in order to make them more competitive against the average fossil fuel vehicle which costs $23,000; we are able to see different results.

Tables 4.15, 4.16, and 4.17 show how under the combined public-private subsidy framework we can identify economic sectors which see benefits from this policy. In particular, if hydrogen has up to a 50% of the energy sector we can see that the fossil fuels, manufacturing, government, and of course the hydrogen sector see increases in their outputs. These effects only hold for the manufacturing and hydrogen sector when the hydrogen share is 90%. In the economy as a whole we can see that GDP increases in average 29% and in the most optimistic scenario it could increase 45% when the hydrogen share is 90%. It is important to mention that the hydrogen demand increases simultaneously with its share in the economy, which means that the costs associated with the public-private subsidy framework would increase as well. This cost has to be internalized in order to have a full picture of the impact of this sort of policy.

Income levels increase constantly in all cases. The effect gets concentrated in high income level households which see increases in their income levels go up to a 30.6% when hydrogen is the largest sector in the energy aggregate. We infer from this result that the public-private subsidy scheme benefits households that can easily convert to the hydrogen alternative at first, this has a significant impact on their income as hydrogen becomes the dominant source of energy.

Table 4.15 Percentage changes in prices and output levels at different hydrogen shares

	H2 = 1.6%		H2 = 5%		H2 = 20%		H2 = 50%		H2 = 90%	
	P	Q	P	Q	P	Q	P	Q	P	Q
Agriculture	-0.03	-0.25	-0.08	-0.76	-0.23	-2.8	-0.04	-6.6	3.18	-11.84
Fossil Fuels	-0.39	0.42	-1.12	1.18	-3.3	2.9	-4.67	2.33	-0.7	-1.82
Manufacturing	-0.18	0.08	-0.54	0.24	-2	0.96	-4.07	0.66	-4.29	2.39
Wholesale/Retail Trade	0	-0.07	0.02	-0.2	0.24	-0.81	1.27	-1.73	7.44	-3.8
Transportation	0	-0.04	-0.01	-0.12	0.1	-0.49	0.87	-1.22	5.74	-2.79
Electricity	-0.07	0.03	-0.2	0.06	-0.5	-0.13	-0.07	-1.27	6.52	-5.55
Hydrogen	-20.1	66.09	-20.64	66.36	-22.94	68.27	-27.83	78.06	-35.13	117.8
Services	0	-0.07	0.02	-0.23	0.22	-0.99	1.22	-2.58	6.81	-6.81
Accommodations/Food	-0.01	0	-0.04	-0.01	-0.03	-0.05	0.46	-0.02	4.84	-0.2
Government	0.02	0.03	0.06	0.1	0.4	0.34	2.13	0.09	10.28	-3.14

Table 4.16 Percentage changes in income levels at different hydrogen shares

	H2 = 1.6%	H2 = 5%	H2 = 20%	H2 = 50%	H2 = 90%
Less than $50,000	0.05	0.17	0.75	1.87	4.94
$50,000 - $100,000	0.05	0.16	0.77	2.11	6.95
More than $100,000	0.04	0.12	0.66	6.37	30.63

Table 4.17 Percentage changes in GDP and wages at different hydrogen shares

	H2 = 1.6%	H2 = 5%	H2 = 20%	H2 = 50%	H2 = 90%
GDP	32	30	23	15	45
Wages	0.02	0.06	0.4	2.44	11.51

Subsidies have important effects on the production and distribution patterns of hydrogen in Hawaii. While the public subsidy had almost no impact on hydrogen's production and distribution patterns, the public-private subsidy scheme had significant changes in the production and distribution processes. As in the first scenario we decided to analyze the changes in production and distribution when hydrogen represents 50% of the energy sector, but in this case we used the public-private scenario results where hydrogen demand increased by 78% while costs decreased by 27%. Tables 4.18 and 4.19 summarize the variations in production and distribution from the baseline levels. From these results we can highlight the fact that many production zones that had no activity under the baseline assumption start to produce hydrogen and for all cases to maximum capacity. This is the case for distributed electrolysis from renewable energy in all four zones; and centralized electrolysis from renewable electricity and distributed SMR from biomass in the West-Northwest and Other islands zones respectively. Other production processes show significant increases such as distributed SMR from natural gas in the West-Northwest zones which doubles its hydrogen production levels.

In order to hold the significant increases in hydrogen demand levels distribution patterns show that most of the baseline levels are raised to maximum capacity and other un-operating distribution systems start to distribute hydrogen. Table 4.19 summarizes these results. We can see that truck transportation becomes a feasible transportation model for hydrogen from West-Northwest to Honolulu and East and from East West-Northwest. On the other hand, it is interesting to see that transporting hydrogen with barges loses its weight with the new hydrogen demand. In particular, we can see how hydrogen from Other islands to West-Northwest zones transported with barges decreases by 86.7% with respect to the baseline levels, and the Other islands stop sending hydrogen with barges to Honolulu. Honolulu is able to satisfy its hydrogen demand with the West-Northwest production.

As we can see, the increases in hydrogen demand resulting from the public-private subsidy scheme have significant changes in the production and distribution patterns of our model. In particular, there are production processed such as distributed electrolysis from renewable electricity which start to operate and transportation of hydrogen by truck becomes a more attractive transportation mode than using barges. The implications of such results are straightforward since we can assume that the new process and transportation mode behave in the same fashion as a new industry which translates into new jobs and income for the Hawaiian economy.

Table 4.18 Hydrogen production by feasible zone-process-feedstock combinations under Scenario 2

Zone	Process	Feedstock	Baseline Production (000 kg H2)	New Production (000 kg H2)	% variation
Honolulu	D. SMR	Natural Gas	600	600	0.00
	D. Elec.	Renewable Electricity	0	600	
East	D. SMR	Natural Gas	392	600	53.06
	D. Elec.	Renewable Electricity	0	600	
	Gas.	Biomass	1000	1000	0.00
West/NW	D.SMR	Natural Gas	438	600	36.99
	D. Elec.	Renewable Electricity	0	600	
	C.SMR	Natural Gas	1046	2100	100.76
	C. Elec.	Renewable Electricity	0	1000	
	Gas.	Biomass	1000	1000	0.00
	I. Supply	Natural Gas	1200	1200	0.00
Other	D. SMR	Natural Gas	600	600	0.00
	D. Elec.	Renewable Electricity	0	600	
	Gas.	Biomass	1000	1000	0.00
	D. SMR	Biomass	0	600	

Table 4.19 H2 distribution pattern output under Scenario 2

Origin	Mode	Destination	Baseline (000 kg H2)	New (000 kg H2)	% Variation
West/NW	Pipe Line	Honolulu	1000	1000	0.00
West/NW	Pipe Line	West/NW	1000	1000	0.00
East	Truck	East	1000	552	-44.80

East	Truck	West/NW	0	447	
West/NW	Truck	Honolulu	0	1086	
West/NW	Truck	East	0	726	
West/NW	Barge	Other	1246	1486	19.26
Other	Barge	West/NW	7540	1000	-86.74

4.9 Conclusions and Further Directions

Hydrogen has the potential to become an important source of energy for Hawaii in the near future. We have demonstrated through the bottom-up top-down modeling approach we have adopted how one can study the macroeconomic impacts of introducing a production and distribution system for hydrogen in Hawaii. We have been able to examine how the evolution of the demand for hydrogen might affect such economic variables as output of different economic sectors, income, wages, and GDP.

In our thought experiments we considered two policy scenarios relevant to the inclusion of hydrogen in the Hawaiian economy. In the first scenario rising fossil fuel prices drive adoption of hydrogen as an alternative fuel. Results from this scenario suggest that as fossil fuel prices increase the economic benefits of larger shares of hydrogen in the energy aggregate get concentrated in sectors which rely strongly on fossil fuels as an intermediate input. This concentration of benefits is particularly apparent in the case of agriculture and of the hydrogen sector itself. Generally speaking, increases in fossil fuel prices have a negative effect on household incomes in every income level household. Although there are mixed results in terms of sectoral output, the Hawaiian economy can see increases in its GDP with a transition to hydrogen as a main source of energy resulting from increases in fossil fuel prices, the economy as a whole can grow by as much as 5% under moderate penetration by hydrogen as a fuel.

We also examined the role of subsidies in promoting a transition towards a hydrogen-dependent economy. Our results suggest that if such a transition is subsidized solely by the government then no significant benefits from adopting the hydrogen technology are likely. However, if both government and the private sector were to subsidize fuel prices and vehicle prices respectively, there might be some benefits from adopting the new technology. Results from the public-private partnership scenario indicate rapid growth of the hydrogen sector and benefits associated with increases in output in the energy related sectors and in manufacturing. From a production and distribution perspective, this scenario represents the development of a new hydrogen production process such as distributed electrolysis from renewable electricity as well as transportation by truck becoming a more attractive transportation alternative. This results indicate that the potential of a public-private subsidy is significant given its push in for hydrogen demand and the inclusion of new production and distribution systems.

For households, having cheaper sources of energy would translate into increases in disposable income. Policy makers should be aware, however, that this income effect would be concentrated in high-level income households. Finally, results obtained for this scenario indicate that there would be benefits in the economy as whole since GDP and wages would increase as hydrogen is used increasingly as a source of energy in Hawaii. In subsequent work, we hope to give our modeling scheme a dynamic cast so as to be able to capture learning-by-using effects on HFCV adoption.

5 CHAPTER 5: CONCLUDING COMMENTS

5.1 Overall Conclusions

In conclusion, the key purpose of this research was to inform the planning process of areas with potential of natural resource development by providing models that better reflects the nature of the problem and the possible courses of action to be taken. Modeling and incorporating the market, economic, and space interdependencies in different natural resource industries such as natural gas extraction by fracking, hydrogen fuel for vehicles, and greenhouse production, is critical for the understanding of policies that engage more sustainable practices in the development of natural resources.

On the one hand the research showed in chapter 2 how the Marcellus Shale's natural gas development will bring significant changes to the regions that embrace the drilling industry. But moreover, the results indicate that there is sufficient information to believe that static multiplier analysis based on I-O models overestimate the impact of new industry. Since demand-driven analyses fail to capture the leakage of the multipliers, they fail to account for supply-side adjustments and substitution and price effects; thus, they are incapable of considering interactions with the economies of surrounding areas.

The Computable General Equilibrium approach offers a more comprehensive analysis of the potential costs and benefits associated with the fracking industry. In particular, this type of analysis is able to capture the spillover effects of the new economic activity. This comes into advantage when we take into account the fact that there are parts of the United States where fracking has been given a green light, such as Pennsylvania, but it has affected cross border regions such as the southern part of New York State, where drilling is not allowed.

The CGE approach also shows that not all economic sectors and institutions are winners from these economic transformations. In fact, the well-being of firms and households employed in many economic sectors is affected deleteriously, if we consider well-being in terms of output and consumption, respectively. Economic sectors like mining, agriculture, and high value-added services benefit the most from the new industry, especially in Pennsylvania's counties.

Chapter 3 used data from the United States' Agricultural Census from 1982 to 2007 to build a panel with information relevant to the impact of space on the evolution of greenhouse and nurseries' sales over this period. The main goal was to look for evidence regarding agglomeration economies in this industry in the Northeast region.

The results showed how between 1982 and 2007, higher levels of income, labor supply, and infrastructure have been associated with higher greenhouse/nursery production levels in the Northeast. However, the results also illustrate the subtleties of urban development pressure on farming operations, since variables such as population growth, or property tax seem to have positive effects under the panel framework in the green industry's performance. The econometric approach demonstrated that a critical element in assuring the continued economic vibrancy of greenhouse/nursery businesses in the Northeast is the capacity to adjust to increased competition for land in metropolitan areas, while exploiting the marketing opportunities offered by proximity to urban consumers.

In chapter 4 we highlight the fact that hydrogen has the potential to become an important energy source, especially in places with high energy prices such as Hawaii. We used the bottom-up top-down modeling approach to analyze the impacts of introducing this new industry in the Hawaiian economy. We were also able to analyze different scenarios for the adoption of this new technology and identify the short term cost and benefits of the Hydrogen economy and recreate possible distribution and production capabilities in different zones in the island.

The thought experiments showed how subsidies from both government and the private sector, in the form of hydrogen fuel and fuel-cell vehicle prices respectively, represent the fastest track for the adoption of hydrogen as a viable source of energy. In this scenario, the hydrogen sector had the highest growth rates and it was able to pull economic sectors such as manufacturing and into this pattern of growth. Moreover, it had a significant impact in the welfare increase for different income-level households as well as in the growth of GDP and wages.

5.2 Research Contributions

In order to continue informing people about natural resource development we need to provide them with richer information about the consequences of adopting new energy-related technologies. Today many regions across the United States face the risk of making decisions without integrating the time and spatial dimension in their analysis. The present research has offered a variety of analytical structures that explicate the potential consequences of different courses of action among stakeholders, while incorporating the behavior of agents involved in natural resource development. Introducing a framework that captures agents' interaction through diverse economic, social, and spatial interdependencies is the first step towards further research on natural resource management in the transitional energy agenda.

One of the main contributions of this research is that jurisdictional, political, and administrative boundaries have little to no effect on what happens to a regional economy. If policy regarding the extraction and exploitation of natural resources continues to be determined by state borders, players for whom regulations are not defined will inevitably be affected by the spillover effects present in a regional economy.

Tools such as regional CGEs, bottom-up top-down modeling techniques, and recently developed spatial panel methods in applied research fields, demonstrate their utility in the analysis of different natural resource development phenomena. For example, we have been able to identify sources of agglomeration and externalities in industries that promise low-carbon emissions and more sustainable practices in the near futures. The results obtained in this study pave the way for future advances in terms of modeling approaches through spatial tools that benefit applied research. Doing so will better inform policy decisions on public support for natural resource development and the steps needed to ensure its vibrancy in the years ahead.

5.3 Future Research

We exposed in this study how natural resource development the current energy agenda needs to be address as a complex and large-scale subject of research. Having said this, there were many issues and aspects left to address in future research. Perhaps one on the main features which we were unable to introduce in our regional approach to Computable General Equilibrium modeling was the dynamics of this real-world problems. Having limited our analysis to static versions of the models limited our experiments results to only short term impacts of the development of new industries such as natural gas through fracking and vehicle transportation with hydrogen.

On the other hand, further investigation needs to be done in spatial panel data analysis such as the incorporation of discrete choices and seemingly unrelated regressions in order to reflect a more accurate picture of the behavior of the greenhouse/nursery industry in the United States.

Finally, a more elaborated analysis introducing real-world features such as the role of the built environment in the natural resource development’s spatial dynamics have an enormous potential for understanding the broader socioeconomic implications of different courses of action in this matter. For example, the incorporation infrastructure interdependencies could provide more detailed information on the effects of promoting “greener” energy related industries while subscribing to the physical constraints we face in the wider adoption of these new technologies. Models and planning platforms which are able to capture these characteristics will better inform communities and policy-makers in the energy transition era.

REFERENCES

Anselin, L. (2002). Under the hood: issues in the specification and interpretation of spatial regression models. *Agricultural Economics, 27*(3), 247–267.

Anselin, L. (2001). Spatial Effects in Econometric Practice in Environmental and Resource Economics. *American Journal of Agricultural Economics, 83*(3), 705–710.

Anselin, L., J. Le Gallo, and H. Jayet. (2008). Spatial Panel Econometrics. In L. Matyas and P. Sevestre (Eds) *The Econometrics of Panel Data, Fundamentals and Recent Developments in Theory and Practice 3rd ed* (pp. 624–660). Berlin, Germany: Springer-Verlag.

Aragon, F. and Rud, J.P. (2010). Natural Resources and Local Economic Development: Evidence from a Peruvian Gold Mine. *Discussion Papers dp10-04*, Department of Economics, Simon Fraser University.

Baltagi BH, Song SH, Koh W (2003). Testing Panel Data Regression Models with Spatial Error Correlation. *Journal of Econometrics, 117*(1), 123-150.

Baltagi, B., H. Kelejian, and I. Prucha. (2007). Analysis of Spatially Dependent Data. *Journal of Econometrics, 140*(1), 1–4.

Barth, Jannette M. (2010). Unanswered Questions about the Economic Impact of Gas Drilling in the Marcellus Shale: Don't Jump to Conclusions.

Baylis, K., Paulson, N., Piras, G. (2011). Spatial Approaches to Panel Data in Agricultural Economics: A Climate Change Application. *Journal of Agricultural and Applied Economics, 43*(3), 325-338.

Bergman, L. (2005). CGE Modeling of Environmental Policy and Resource. In M. Karl-Göran and R.V. Jeffrey (Eds.) *Management Handbook of Environmental Economics Volume 3*.

Bills, N., B. Gloy, W. Uva, G. White, and M. Cheng (2006). 2007 Farm Bill: Policy options and consequences for northeast specialty crops industries, small farms, and sustainability programs. *Research Bulletin 06-04, Department of Applied Economics and Management, Cornell University.* Accessed July 2013, available at: http://www.aem.cornell.edu/research/researchpdf/rb/2006/Cornell_Dyson_rb0604.pdf

Brueckner, Jan K. (2003). Strategic interaction among governments: An overviewof empirical studies. *International Regional Science Review, 26*(2),175–188.

Brumfield, R.G. (2010). Strategies producers in the northeastern United States are using to reduce costs and increase profits in tough economic times. *Hort Technology, 20*(1), 836-843.

Chazen, G. (2012). Shale Gas Boom Leads to Sharp Drop in US Carbon Emissions. *Financial Times*, May 24, 2012, p. 1.

Cheng, M., Gomez, M., Bills, N. (2011). Urban Agglomeration Economies in the U.S. Greenhouse and Nursery Production. *Cornell University Dyson School of Applied Economics and Management Working Papers. WP 2011-18*.

Cheng, M., N. Bills, J.D. and Francis (2006). Historical and spatial analysis of high-valued crop production in the U.S. *Department of Applied Economics and Management, Cornell University Working Paper 06-23*. Accessed July 2013, available at: http://www.aem.cornell.edu/research/researchpdf/wp/2006/Cornell_Dyson_wp0623.pdf

Christopherson, S and N. Rightor. (2012). Local Consequences of Natural Gas Drilling in the US Marcellus Shale. *International Journal of City and Town Management* (forthcoming).

Connors, S.R., Hezir, J.S., McRae, G.S., Michaels, H., Ruppel, C. (2010). The Future of Natural Gas: An Interdisciplinary MIT Study. *Interim Report. MIT Energy Initiative*.

Considine, Timothy (2010). The Economic Impacts of the Marcellus Shale: Implications for New York, Pennsylvania, and West Virginia: A Report to the American Petroleum Institute.

Considine, Timothy et al. (2009). An Emerging Giant: Prospects and Economic Impacts of Developing the Marcellus Shale Natural Gas Play. Report produced for the Marcellus Shale Committee by the Department of Energy and Mineral Engineering of Penn State University.

Considine, Timothy et al. (2011). The Pennsylvania Marcellus Natural Gas Industry: Status, Economic Impacts and Future Potential. Report produced for the Marcellus Shale Coalition by the John and Willie Leone Family Department of Energy and Mineral Engineering of Penn State University.

Considine, Timothy, Robert Watson, and Seth Blumsack. (2010). The Economic Impacts of the Pennsylvania Marcellus Shale Gas Play: An Update.

Donaghy, K.P., T. Friesz, and J. Perez-Burgos (2010). Analyzing Short- and Long-term Impacts of Natural Gas Drilling in the Marcellus Shale with a Spatial Dynamic CGE Model of the Regional Economy. *Paper presented at the North American Meetings of the Regional Science Association International,* November 10-13, Denver, Colorado.

Food and Water Watch Report (2011). Exposing the Oil and Gas Industry’s False Jobs Promise for Shale Gas Development: How methodological flaws grossly exaggerate jobs projections.

Glaeser, Edward L., Sacerdote, Bruce I., and Scheinkman, Jose A. (2002). The social multiplier. Technical Report 9153, NBER, Cambridge, MA 02138.

Hall, C., A. Hodges, and M. Palma (2011). Sales, Trade Flows and Marketing Practices within the U.S. Nursery Industry. *Journal of Environmental Horticulture, 29*(1), 14–24.

Heimlich, R.E., and C.H. Barnard (1992). Agricultural adaptation to urbanization: Farm types in northeast metropolitan areas. *Northeastern Journal of Agricultural and Resource Economics, 21*(1), 50-60.

Hodges, A.W., C.R. Hall, and M.A. Palma, (2011). Economic contributions of the green industry in the United States in 2007–08. *Hort Technology, 21*(5), 628-638.

James, Alex and David Aadland (2010). “The curse of natural resources: An empirical investigation of U.S. counties.” *Resource and Energy Economics* (forthcoming).

Kay, David (2010). A Comprehensive Economic Impact Analysis of Natural Gas Extraction in the Marcellus Shale. Green Choices Working Papers Series. Cornell University.

Kay, David (2011). The Economic Impact of Marcellus Shale Gas Drilling: What Have We Learned? What are the Limitations? Green Choices Working Papers Series. Cornell University.

Milo, G., Piras, G. (2012). Splm: Spatial Panel Data Models in R. *Journal of Statistical Software, 47*(1), 1-38.

Partridge, M.D. and Rickman, D.S. (2007). CGE modeling for regional economic development analysis. ECOMOD Workshop: *State of the Art in Regional and Urban Modeling*.

Rausch, S., Rutherford, T. (2008). Tools for Building National Economic Models Using State-Level IMPLAN Social Accounts. MIT Joint Program on the Science and Policy of Global Change.

Schlenker,W., W.M. Hanemann, and A.C. Fisher. (2005). Will U.S. Agriculture Really Benefit from Global Warming? Accounting for Irrigation in the Hedonic Approach. *American Economic Review 95*(1), 395–406.

Sue Wing, I. (2006). Representing Induced Technological Change in Models for Climate Policy Analysis, *Energy Economics 28*(1), 539-562.

Sue Wing, I., and W.P. Anderson (2007). Modeling Small Area Economic Change in Conjunction with a Multiregional CGE Model. In R.J. Cooper, K.P. Donaghy and G.J.D. Hewings (Eds.) *Globalization and Regional Economic Modeling*, Springer-Verlag.

U.S. Department of Agriculture (USDA) (2009). The 2007 Census of Agriculture. National Agricultural Statistics Service. Accessed November 2013, available at: http://www.agcensus.usda.gov/index.php.

Weinstein, Bernard L. and Terry L. Clower (2009). Potential Economic and Fiscal Impacts from Natural Gas Production in Broome County, New York.