Vol. 14: 175–183, 2000 | CLIMATE RESEARCH Clim Res | Published May 2

Simulating the economic impacts of climate change in the Mid-Atlantic Region

Adam Rose*, Yiqing Cao, Gbadebo Oladosu

Department of Energy, Environmental, and Mineral Economics and Center for Integrated Assessment, The Pennsylvania State University, University Park, Pennsylvania 16802, USA

ABSTRACT: This paper provides an overview of the Mid-Atlantic Region (MAR) economy and of models that can be used to analyze how climate change will affect it. A regional input-output (I-O) table, downscaled from its national counterpart, provides insight into the extent of the MAR's internal interdependence, as well as its dependence on trade with the rest of the US and the rest of the world. The table indicates that climate-sensitive sectors play a relatively small direct role in the MAR, but multiplier and other types of general equilibrium effects could result in some small, but not insignificant, impacts on other sectors and other regions. An application of the I-O model to climate variability impacts on forest-related sectors illustrates this point. Although I-O analysis is a useful tool for setting the stage for an impact analysis, limitations of the methodology are identified. A general equilibrium approach is presented as an alternative that captures the best features of I-O, yet is able to incorporate non-linearities, input substitution, behavioral considerations, and the workings of prices and markets.

KEY WORDS: Climate change · Mid-Atlantic Region economy · Economic impacts · Economic downscaling · Input-output analysis · Computable general equilibrium analysis

1. INTRODUCTION

Climate change has the potential to significantly affect national and regional economies. Climate impacts on ecosystems and human activities are the basis for the 5-sector physical classification used in the US National Assessment (see Fisher et al. 2000, in this issue). Although the assessment of physical impacts is an imperative first step, an economic analysis is equally important. First, a translation of physical impacts into dollars provides a convenient basis for comparison of impacts and a bottom-line unit of account.[1] Second, the ultimate welfare effects of the physical impacts of climate change depend on economic choices made from available response options.

Moreover, the interdependence of economic activity implies that climate impacts would extend far beyond resources, activities, and regions where physical effects are initially observed. For example, damage to one sector may decrease the quality or quantity of its services to others, which in turn affects still other sectors in terms of inputs, outputs, incomes, and prices. These economy-wide multiplier and other general equilibrium effects have been found to be several times the size of direct impacts, on either the positive or the negative side (see, e.g., Rosenberg 1993). Furthermore, these impacts are likely to spill over regional boundaries. A prerequisite to understanding the regional impacts of climate change is an understanding

*E-mail: azr1@psu.edu

[1] All 5 sectors of focus in the US National Assessment have either formal designations in widely used economic databases and models or can be mapped into them. Agriculture and Forestry appear in the US Department of Commerce Standard Industrial Classification (SIC). Coastal areas can be mapped into Real Estate and various tourism-related sectors (e.g., Hotels, Restaurants), human health can be mapped into Household Welfare and the Healthcare sector, and even ecosystems can be mapped into Recreation and imputed values for aesthetic benefits and wildlife preservation. However, other sectors are important in analyzing adaptation and mitigation, such as construction (dredging for beach nourishment), pump and pipe manufacturing (irrigation and flood control)

of the economy in which they take place, including its relation to other regions.

This paper presents an analysis of the current MAR (Mid-Atlantic Region) economy in terms of its direct and indirect vulnerability to climate change and in terms of its ability to affect or to be affected by other regions. First, we introduce economic models that we believe to be most useful for these purposes. Second, we provide an overview of the MAR economy in terms of features that influence its vulnerability and resiliency, such as its sectoral composition, internal and external interdependence, and sub-regional character. Third, we illustrate the usefulness of one of these models by analyzing some impacts of potential Forestry sector productivity losses on the MAR economy. We conclude with a brief summary of on-going work to develop a model that overcomes many of the methodological limitations identified in the course of our analysis.[2]

2. MODELING APPROACHES

In this section, we describe 2 related economic methodologies that provide insight into the workings of the MAR economy and that can be used to simulate the regional effects of long-term climate change or short-term climate variability. These models are in a class of multi-sector, macroeconomic models focusing on general economic interdependence or general economic equilibrium. The multi-sector feature is important because of sizeable differences between segments of the economy in terms of vulnerability. The macroeconomic feature means the models are comprehensive. The interdependence and equilibrium features capture chain reactions of impacts.

2.1. Input-output analysis

In its most basic form, input-output (I-O) is defined as an operational, static, linear model of all market purchases and sales between sectors of an economy, based on the technical relations of production. Several decades of refinement since its initial development by Nobel laureate Wassily Leontief, however, have led to the ultimate form, defined as a dynamic, non-linear model of all purchases and sales between sectors and institutions of an economy or economies, based on the technical relations of production and other important quantifiable variables (Rose & Miernyk 1989). This version is unwieldy from a computational standpoint, but the computable general equilibrium modeling approach described below encompasses nearly all of the capabilities of the ultimate I-O version and in a more manageable fashion.

Basic I-O models are the most widely used tools of regional economic impact analysis today. Moreover, they have been used in some prominent climate impact analyses, such as the MINK study (Rosenberg 1993), which analyzed direct and indirect climate impacts on agriculture, forestry, water, and energy in 4 midwestern states of the US. The basic production relations of an I-O model are comprehensive with respect to all inputs, not just primary factors (capital and labor), so these models are especially useful in evaluating resource-use implications of economic trends and policies (Rose et al. 1994). In addition, linear and even nonlinear pollution relationships can be incorporated or appended to them so that waste flows and other 'environmental indicators' can be readily estimated (Duchin & Lange 1994). However, a major limitation of most I-O models is the inability to analyze price and quantity impacts simultaneously.

Bowes & Crosson (1991) stated that: '…it can be awkward to use the input-output model to assess changes that are driven by productivity and cost changes on the supply side. For these reasons, the input-output models are not ideally designed to deal with natural resources.' However the supply-side variant of the I-O model (discussed and applied below) can overcome this limitation.

2.2. Computable general equilibrium analysis

The inherent linearity of the more basic I-O models and the absence of market and price considerations have caused analysts, especially at the national and international levels, to favor computable general equilibrium (CGE) models. These are multi-market simulation models based on the simultaneous optimizing behavior of individual consumers and firms, subject to economic account balances and resource constraints (Shoven & Whalley 1992).

With only a few exceptions (see, e.g., Scheraga et al. 1993, who examined the general equilibrium impacts of climate-induced increases in agricultural production costs, electricity rates, and coastal protection measures), most of the climate-related applications of CGE models have been to mitigation policy (see, e.g., Jorgensen & Wilcoxen 1993, Kamat et al. 1999), but recent

[2]The focus of this paper is on climate impacts, but economics is also crucial to other aspects of climate change. For example, the economy is one of the main drivers of the generation of greenhouse gases (GHGs). Economics is also important in analyzing policies oriented toward mitigating greenhouse gas emissions. Models of the MAR economy are useful in these regards as well

applications have included impacts of short-term climate variability in the form of riverine flooding (Rose et al. 1999) and longer-term climate change primarily affecting agriculture and health (Abler et al. 1999). Moreover, advances are being undertaken to incorporate non-market inputs and environmental amenities (see, e.g., Smith & Espinosa 1996, Oladosu 2000). The use of I-O and CGE models is not necessarily mutually exclusive. The production sector database of a CGE model is typically an I-O table, and in most cases the fixed-input requirement (i.e., lack of input substitutability) is carried over for intermediate goods. The production sector classification is also similar.[3]

2.3. Strengths and weaknesses

The strengths of I-O and CGE models include their disaggregation, which is readily able to delineate climate-sensitive sectors; the comprehensive accounting of resource inflows, which helps determine the economy's carrying capacity needs; the general equilibrium nature, which is able to trace multiplier or feedback effects; the technological basis, which provides a solid grounding in production requirements; the socioeconomic dimensions, which offer the capability to perform distributional impact analysis; and the empirical orientation, which provides an immense data and computational software base.

The major weakness of these models is their lack of standard statistical properties. Regional I-O models are usually based on non-survey (secondary) data techniques whose general reliability has been evaluated, but whose application to individual models has not (see, e.g., Jensen 1980). Even those based on primary data samples use the ratio estimator, which has relatively poor statistical properties (Gerking 1976).

CGE models are typically based on an underlying downscaled I-O table and social accounting matrix (SAM), an expansion of production accounts to include institutions. Moreover, several additional parameters, such as input and import substitution and elasticities, are almost always based on values gleaned from the literature, which means they are usually transferred from another region or the national level, often ignoring unique regional characteristics. These models can, however, more readily incorporate technological change than can standard, time-series-based econometric models, which typically extrapolate the past.

3. ECONOMIC DOWNSCALING

The extensive detail of I-O and CGE models is one of their strengths, but also one of their liabilities when it comes to model construction. For example, what are called 'benchmark' I-O tables are prepared every 5 yr by the US Department of Commerce based on a full census of businesses throughout the nation, followed by extensive tabulations and reconciliations of data at a cost of 10s of millions of dollars. Originally, this 'deterministic' approach was thought to be the only legitimate way to build an I-O table (see, e.g., Leontief 1949). However, because the census data are not available at the sub-national level, regional analysts were faced with having to duplicate the data collection process at a cost of several million dollars to build a model for even a small state.

The first innovation was to use a sampling procedure, but even this was costly and time consuming (see, e.g., Miernyk et al. 1970). Such approaches are termed 'data-reduction' methods, the most popular of which has become adapting data from a national table to the regional level (see, e.g., Miller & Blair 1985). In effect, this is a type of 'downscaling' analogous to that undertaken for climate models in other papers in this Special.

The majority of these downscaled I-O tables assume that input combinations to produce a given output in the region (i.e., the production technology) are representative of the nation as a whole. The first approximation then has the region as a scaled-down version of the national economy. The second modification, however, is to distinguish inputs produced in a region versus those imported from elsewhere, since only the former category is capable of generating multiplier effects. Here, some heroic assumptions are involved to make use of control totals on regional supply and demand, the most notable being 'no cross-hauling,' which stipulates that a region either exports a good or imports a good but not both. This is realistic when a region is small in area and isolated, or when sectoring is at a fine level of detail, e.g., 4-digit SIC (Standard Industrial Classification) codes.[4] The most unrealistic extension of this assumption is that if the region as a whole imports 20% of an input then each sector's use of this input will be 20% imports and 80% regional production.

Of course, some of the limitations of the non-survey approaches can be overcome by the collection of pri-

[3]Despite the general superiority of CGE, I-O analysis may be better suited to aspects of short-run climate variability because of the more limited time for adjustment that does not allow for full equilibrium responses. For example, in the case of forests, the response is more likely to be a decrease in productivity and a cutback in production of existing species as opposed to a shift to other trees or crops

[4]For example, at the 1-digit SIC level a region could import coal and export oil, which would appear as cross-hauling for the mining sector aggregate. Separate sectoring for individual mineral commodities eliminates this problem

Table 1. MAR input-output table 1995 (in billions of 1995 dollars). Values were computed by the authors using the IMPLAN (1997) System

	Intermediate inputs										Final demand				Total gross output
	1	2	3	4	5	6	7	8	9	10	Personal consumption	Govern- ment	Investment and inventory	Exports	
(1) Agriculture & Forestry	0.9	0.0	0.3	5.8	0.0	0.0	0.1	0.7	0.1	0.0	1.7	0.3	−0.1	8.3	18.1
(2) Mining	0.0	0.4	0.3	1.1	0.0	0.7	0.0	0.0	0.0	0.0	0	0.0	−0.1	11.8	14.3
(3) Construction	0.2	0.1	0.1	3.5	1.6	2.4	1.3	9.5	4.1	3.3	0	21.9	53.7	3.2	104.8
(4) Manufacturing	0.6	0.6	10.3	50.2	3.5	0.5	6.1	0.9	10.6	0.8	51.5	7.3	16.7	284.8	444.4
(5) Transport & Communication	0.4	0.6	2.3	12.8	7.3	0.8	2.7	1.8	5.2	0.8	19.9	5.3	2.0	24.3	86.3
(6) Utilities	0.2	0.3	0.2	8.7	0.7	1.7	2.8	1.9	3.2	0.9	17.4	3.3	0.0	4.7	46.1
(7) Wholesale & Retail Trade	0.7	0.5	8.9	25.5	1.7	0.3	5.0	0.8	6.3	0.2	127	3.5	11.7	8.9	200.9
(8) Finance, Insurance & Real Estate	0.5	0.4	1.3	5.7	1.7	0.5	7.2	22.7	16.3	0.6	108.5	3.1	3.3	71.1	242.7
(9) Other Services	0.3	0.4	6.0	25.4	7.8	1.2	16.0	11.4	40.7	0.9	162.1	21.1	−2.5	45.9	336.5
(10) Government Enterprises	0.0	0.0	0.2	2.0	0.3	0.2	1.2	1.6	2.8	0.3	7.9	155.5	0.1	4.7	176.9
Non-competitive imports	0.0	0.0	0.0	1.9	2.2	0.0	0.8	0.3	0.6	0.3	5.4	0.0	0.0	0.0	(11.5)
Competitive imports	5.7	4.0	29.5	136.5	9.6	7.6	19.6	17.4	42.3	1.9	185.6	34.0	34.9	0.0	(528.6)
Labor income	3.2	3.2	32.4	97.9	26.3	6.8	82.6	37.5	155.7	135.5					
Capital income	4.7	2.7	12.5	58.8	19.9	18.9	29.1	112.0	44.0	31.4					
Indirect business taxes	0.4	1.1	0.6	8.7	3.9	4.7	26.2	24.3	4.4	0.0					
Total gross outlay	18.1	14.3	104.8	444.4	86.3	46.1	200.9	242.7	336.5	176.9	(686.9)	(255.3)	(119.9)	(467.6)	1671.1

mary data, which can readily be inserted into the regional I-O model. Several methods have been devised for maximizing the effectiveness of such an effort, but they generally emphasize attention to large sectors, those with the greatest indirect linkages to others, or those that are the focus of attention by the analysts (see, e.g., West et al. 1984). We essentially follow the latter emphasis by integrating survey-based and published data to improve the accuracy of the I-O model for sectors such as Agriculture, Forestry, Tourism, etc.

The I-O data we use in the study are obtained from the Impact Analysis for Planning (IMPLAN) System, which was developed by the US Forest Service, Federal Emergency Management Agency, and several other federal government agencies. IMPLAN consists of an extensive national and regional database, algorithms for generating non-survey I-O tables for any county or county grouping in the US, and algorithms for performing impact analyses (IMPLAN 1997). This system is based on the best of the I-O data reduction methods, and is the most widely used regional model construction package in the US. One of the major reasons for using I-O analysis and the IMPLAN System is to provide the many other researchers that will be involved in climate change impact analysis in the years ahead with a methodology that can readily be replicated.

4. THE MAR ECONOMY

4.1. Regional economic structure

The MAR contains 5% of the land area of the contiguous US and 15% of the nation's population. In 1995, the MAR gross regional product (net output) was $915.2 billion, and total gross output was $1.67 trillion, or about 13% of the national output (IMPLAN 1997). Sectoral contributions (aggregated to the 1-digit SIC level) and intersectoral linkages are depicted in the I-O table of the MAR economy (Table 1).[5] Entries in a given row represent sales from the sector labeled in the left-hand headings to sectors labeled in the top headings. Entries in a given column represent purchases by a given sector from all other sectors. Total sales (gross output) equal total purchases (gross outlays) for each sector. The most important sectors of the MAR economy are Manufacturing and Services,

[5]The 55-sector version of the MAR I-O table can be accessed through the MARA website: http://www.essc.psu.edu/MARA_econ. These 55 sectors are a mix of 1-, 2-, and 4-digit classification levels, with climate-sensitive sectors (e.g., Agriculture, Forestry, Energy) at finer delineations

accounting for 26.5 and 20.1 % of gross output, respectively. Finance, Insurance & Real Estate, Wholesale & Retail Trade, and Government Enterprises each account for a little over 10 % of regional output. Mining and Agriculture & Forestry are the smallest components of the MAR economy, followed by Construction, Transportation & Communication, and Utilities.[6]

All these economic activities would experience some direct effects from climate change in the region. Increased severity and frequency of extreme weather events would disrupt most economic and human activities. Manufacturing, Mining, Utilities and Agriculture would specifically be affected by sustained changes in water resources. Land resource changes, flooding and sea-level rise have important implications for Agriculture, as well as Forestry and Real Estate sectors. Climate-induced productivity changes due to alterations in soil and CO_2 fertilization effects would also be reflected in the costs of agricultural production. In addition, the effects of climate change on labor and capital migration in the MAR has the potential to affect its economic competitiveness.

The I-O table of the MAR economy displays strong intersectoral linkages that would spread direct climate impacts throughout the MAR. All industries except Agriculture and Mining purchase between 50 and 80 % of their intermediate inputs from regional industries. Manufacturing is the most prominent intermediate consumer of goods and services produced in the regional economy, using about 20 % of total Agriculture and Utilities outputs, as well as about 10 % of its own output. The strong interdependence between sectors means that climate change impacts will not be confined to the directly affected sectors, but will generate ripple or multiplier effects throughout the MAR. For example, climate-change-related damage to trees in the MAR would affect not only the Forest Products sector but also the Paper & Paper Products sector. Lower output in the latter sector would touch off a decrease in orders for goods and services to direct and indirect suppliers outside the Forest Industry grouping. Decreased profits and worker layoffs would result, reducing income and setting off more multiplier effects for the MAR. Thus, although climate-sensitive sectors such as Agriculture & Forestry represent only about 1 % of the direct economic activity in MAR, damage to them can spread through successive chains of upstream and downstream linkages both within and outside the MAR. The size of these multiplier effects will be explored in the following section.

[6]The relative prominence of the Manufacturing sector and a fuel balance analysis (Kamat & Rose 1997) indicate that the MAR is a relatively large contributor to GHG emissions for an economy of its size

The MAR economy is an open one, with total imports representing 32 % ($540.1 billion) of the total gross output and exports representing 28 % ($467.6 billion) of the total (see Table 1). Agriculture, Mining, and Manufacturing are the major exporters in the MAR economy, each shipping between 60 and 80 % of its outputs elsewhere. The major import sectors on a percentage basis are Mining, Agriculture, and Manufacturing as well, though of different individual commodities than the exports within these 1-digit SIC aggregates. The high import and export trade volume means that climate impacts on sectors within the MAR economy could affect other regions through changes in the price or availability of goods and vice versa (see, e.g., Sohngen & Mendelsohn 1999, who analyzed trade impacts on the US timber market stemming from climate change).

4.2. Physiographic sub-regional economies

Four different physiographic regions can be identified within the MAR: Coastal Plain, Piedmont, Ridge and Valley, and Plateau. The contributions to the MAR total gross output from these sub-regions are $611 billion, $511 billion, $190 billion, and $360 billion, respectively. Although a structural comparison of gross outputs of individual sectors indicates little variation across the sub-regions, differences in their vulnerability to climate change would lead to different sub-regional economic effects. The Coastal Plain would be the most vulnerable to sea-level rise and increased extreme weather events (see Najjar et al. 2000, in this issue). This means that sectors such as Real Estate and Tourism would experience larger impacts than other sectors in the Coastal Plain, and also larger impacts than their counterparts in other sub-regions. Thus, climate change impacts may result in both a change in the distribution of MAR output among the sub-regions, as well as structural changes in economic activities within them.

5. ILLUSTRATIVE ECONOMIC IMPACTS OF CLIMATE VARIABILITY

5.1. Basic considerations

To illustrate the strengths and limitations of the I-O modeling approach, we simulate some of the potential economic impacts from climate variability affecting mid-Atlantic forests. Two prerequisites are needed to perform such an analysis: (1) a more detailed characterization of the impacted sectors than is presented in Table 1, and (2) a set of direct sectoral impact estimates.

Table 2. Forest-related sector flows in the MAR input-output table 1995: intraregional flows (in millions of 1995 dollars). Values were computed by the authors using the IMPLAN (1997) System. *Less than $0.5 million

	1	2	3	4	5	6	7	8	9	Total forest-related intermediate inputs	Exports	Other final demand	Total gross output[a]
(1) Forest Products	0	14	0	81	59	17	0	0	0	172	38	71	293
(2) Forestry Products	0	46	2	256	189	53	0	1	0	546	119	225	906
(3) Agriculture & Forestry Services	16	305	4	*	1	1	1	1	5	334	842	392	3453
(4) Logging Camps & Contractors	0	0	0	71	611	96	70	0	345	1193	78	19	1219
(5) Sawmills	0	0	0	1	182	246	304	130	220	1083	420	12	3720
(6) Millwork & Plywood	0	0	0	0	0	122	54	48	0	224	339	32	3206
(7) Other Wood Products	0	0	0	0	4	46	156	51	9	266	2158	180	3846
(8) Wood Furniture & Fixtures	*	0	0	0	0	0	18	119	0	137	1322	2497	4212
(9) Paper & Paper Products	0	*	*	*	*	*	*	*	22	22	15939	224	20972
Forest-related subtotal	16	365	6	409	1046	581	603	350	601	3977	21296	3652	41827
Total regional intermediate inputs	160	581	215	580	1739	1131	1425	1376	6852	14059	0	797291	
Forest-related imports	5	91	6	131	670	464	639	379	5260	7645	0	5336	
Total imported inputs	71	186	108	223	814	687	1032	1226	6897	11244	0	292607	
Total value added	62	139	3130	416	1167	1388	1389	1610	7223				(16635)[b]
Total gross outlay	293	906	3453	1219	3720	3206	3846	4212	20972	41827			1671138

[a]Total gross output also includes non-forest-related intermediate inputs (not shown)
[b]Forest-related sectors only

The full-scale MAR I-O model consists of 55 sectors with a high degree of resolution for climate-sensitive ones. Forest-related sectors are not limited to those primary activities within SIC 1 (Agriculture & Forestry) but also include downstream processing components within SIC 4 (Manufacturing). The nine 4-digit SIC forest-related subsectors are presented in Table 2. The group is dominated by Paper & Paper Products, whose gross output of $20.972 billion comprises 50 % of the $41.827 billion total gross output of the entire group. Note also that the forest-related sectors have a stronger economic linkage with the rest of the US and foreign countries than the average of sectors within MAR. The $21.3 billion of exports amounts to 51 % of these sectors' production, and the $11.2 billion of imports amounts to 27 % of their production.[7]

Estimates of direct climate impact variability were obtained from a survey of over 300 forest managers in the MAR (see DeWalle & Buda 1999). The questionnaire focused on the forest impact of extreme weather events, such as high winds, high and low rainfall, heavy snowfall, and ice storms. The results indicated average production cost increases for the primary stages of the forest product chain (Forest Products, Forestry Products, and Logging Camps & Contractors) of 5.2 % for just the extreme instances that took place 1 or more times over the past 10 yr.[8] Our simulations are based on a projection that such extreme events could potentially become commonplace, i.e., take place on an annual basis in the future, admittedly a high-end estimate.

5.2 Region-wide impacts

We calculated 3 types of impacts using the MAR I-O model:

(1) Demand-driven multiplier impacts. These are the standard I-O multipliers that measure the upstream

[7]Economic interdependency with the rest of the US stems from the fact that the MAR borders other regions with extensive forest resources, and hence many mid-Atlantic businesses may be closer to suppliers and customers in other regions than to suppliers and customers within MAR itself. It also stems from the uniqueness of some resources, e.g., hardwoods, which have a broad export market both domestically and internationally. Finally, although disaggregated to the 4-digit level, the classification still obscures the production of specialty products, found, e.g., in wood furniture and printing, which are typically not self-contained with any one region

[8]Forest Products and Forestry Products both relate to timber growth, but differ in that the former pertains to traditional forests, while the latter refers to large-scale business cultivation. Note that the direct impacts differed by tree species and by sub-region, information that can be incorporated in analyses at a higher degree of resolution

stimulus to the MAR economy through the chain of suppliers to each affected forest-related subsector.

(2) Supply-driven multiplier impacts. These measure the downstream stimulus to the MAR economy through the chain of customers of each affected subsector.

(3) Price impacts. These measure the cost-push inflation for the MAR economy as a result of productivity losses in each affected sector.

This analysis represents an advance over the MINK I-O study of forest impacts (Bowes & Sedjo 1998) in that it more fully analyzes the upstream impacts of decreased forest exports and considers a more extensive set of downstream supply impacts within the region.

Before presenting the results, we note 2 important considerations. First, while demand-driven multipliers are well established, the supply-driven counterpart is a subject of some controversy because it is based on the premise that supply creates its own demand (see, e.g., Oosterhaven 1988, Rose & Allison 1989). In our context, a literal interpretation would be that businesses using forest-related products would reduce their own production somewhat for lack of availability of these inputs. Of course, there is always the possibility of utilizing imports if other regions are not affected as greatly as the MAR. To a lesser extent, it may be possible to substitute other inputs for forest-related ones. Hence the supply-driven multipliers are likely to overstate the impacts. Second, both the quantity and price multipliers fail to take into account the negative impacts on other regions of the US, which in total could be equal in magnitude to, though far lower in percentage terms than, the impacts in the MAR.[9]

Economic impacts of climate change depend on a range of considerations relating to supply and demand elasticities and the ability to shift production changes backward onto factor markets or forward onto other product markets. Estimates of these considerations vary, and, in the complete analysis (Cao 1999), sensitivity tests are performed for groups of lower-bound, upper-bound and mid-range values. Here we present a set of upper-bound estimates, which are useful in deciding whether further study or policy-making is warranted, i.e., if the upper-bound estimates do not pass the threshold of significance, then it is not necessary to fine-tune the analysis or to take action. These upper-bound estimates are based on a price elasticity of supply equal to 1.0 and a price elasticity of demand equal to –1.0 for the directly affected sectors. We also assume that half of the 5.2% cost increase is absorbed by producers and half is passed on to customers.[10]

These factors translate into a direct output decrease of \$62.9 million (see Table 3, column 1). The total (direct, indirect, and induced) demand-driven impacts are projected to result in a \$98.4 million decrease in gross output for the MAR economy as a whole. Only 45% of the indirect impacts (the difference between entries in column 2 and column 1 of Table 3) fall on the forest-related sectors. The major impacted sectors are Finance & Services, Manufacturing, and Wholesale & Retail Trade.[11]

The supply-driven analysis involves the same basic assumptions and direct impacts but yields significantly larger total impacts, amounting to –\$150.1 million (see column 3 of Table 3). Here, however, most of the impacts are contained within the grouping of forest-related sectors themselves—these are the sectors in which a restriction in timber supply is most severe. With respect to other sectors, Construction suffers the majority of the indirect impacts. Note also that the supply-driven impacts can be muted by an increase in imports (in fact the percentage offset in the direct and indirect impacts would be equal to the percentage level of the import replacement). Although a greater reliance on imports would appear to be an obvious adaptation, this may be difficult if other supplying regions are impacted by climate variability at a level equal to or greater than the MAR.

Recall that, based on the DeWalle & Buda (1999) results, we assigned half of the weather-induced cost increases to the 3 affected sub-sectors, which translated into 2.6% direct price increases. Total price impacts for the MAR economy are presented in column 4 of Table 3 and indicate that cost-push inflation is minimal for them and for the forest-related grouping as a whole. The highest indirect impact is projected to be sustained by Sawmills at 0.7%, almost as high, e.g., as the indirect impacts for Logging Camps & Contractors of 0.8% (3.4% total price increase minus the 2.6% direct price increase). Moreover, the price impacts for every sector outside the Forest group are less than 0.05%.[12]

The output impacts appear significant in absolute terms, but might appear insignificant in relative terms, since they represent a gross output reduction for the MAR of only 0.0055 and 0.0083% for the demand and supply cases, respectively. Moreover, the demand-driven and supply-driven impacts are not purely additive

[9] This conclusion concerning magnitudes is based on comparison of MAR output multipliers with US National I-O multipliers in the IMPLAN System

[10] The higher prices are modeled by adjusting forest-related input coefficients, and the absorbed costs are modeled by adjusting value-added coefficients to reflect lower profits

[11] The relationship between total and direct impacts yields an implicit multiplier of 1.34. The output multipliers of the 3 forest-related sectors is in fact a weighted average of 1.7. The difference stems from the fact that forest sector input and value-added coefficients have been changed as well (see the previous footnote)

Table 3. MAR economy-wide upper bound impacts of direct climate variability damage to forest-related sectors. *Less than 0.05%

Sector	Direct impacts (in thousands of 1995 dollars)	Demand-driven total impacts (in thousands of 1995 dollars)	Supply-driven total impacts (in thousands of 1995 dollars)	Price change total impacts (%)
Forest-related sectors				
Forest Products	−7604	−10002	−7607	2.6
Forestry Products	−23590	−31495	−25008	2.8
Agriculture & Forestry Services	0	−3765	−30	*
Logging Camps & Contractors	−31694	−33529	−41870	3.4
Sawmills	0	−156	−26766	0.7
Millwork & Plywood	0	−48	−6828	0.2
Other Wood Products	0	−40	−4783	0.1
Wood Furniture & Fixtures	0	−36	−1156	*
Paper & Paper Products	0	−12	−12811	0.1
Subtotal	−62888	−79083	−126859	0.6
Other sectors				
Agriculture	0	−403	−125	*
Mining	0	−38	−165	*
Construction	0	−1304	−12302	*
Manufacturing (except forest-related)	0	−3092	−6405	*
Transport & Communication	0	−1424	−297	*
Utilities	0	−468	−288	*
Wholesale & Retail Trade	0	−2749	−649	*
Finance & Services	0	−8375	−2036	*
Government Enterprises	0	−1449	−1007	*
Subtotal	0	−19302	−23274	*
MAR total	−62888	−98385	−150133	*

since they both include the same direct impacts, and thus $62.9 million, or 0.0035%, must be subtracted to avoid double-counting. However, the direct effect of a 5.2% output reduction (productivity loss) in forest-related sectors is likely to substantially reduce profit margins, thus forcing business closures beyond those estimated by the I-O model. On the supply-side, not only are several forest-related sectors impacted significantly, but so are sectors such as Construction, whose output is projected to decrease if it could not import replacements or if wood substitutes were not feasible or not available. Moreover, given the fact that forestry activity is not spread uniformly throughout the MAR, the relative impacts for some sub-regions are likely to be several times those presented above.[13]

Again, we note that the results presented here represent an upper bound on possible region-wide economic impacts of forest productivity losses due to short-run climate variability. They overstate impacts on the supply side if input and import substitution possibilities are extensive, though the former is limited in the short run and the latter in the long run (if forests in other regions are damaged). The demand-side impacts should, however, be reasonably accurate since decreased forest production (either through direct damage or higher prices) will result in decreased production of upstream inputs directly and indirectly.

[12] These percentages are based on a projection of the MAR economy total and sectoral output levels for the year 2010 based on data supplied by National Planning Associates (see National Planning Associates 1999 and Polsky et al. 2000, in this issue). The percentage impacts are likely to decrease over time, as forestry activities are projected to be an increasingly smaller portion of the MAR economy under baseline conditions. Of course, the structure (i.e., the technical coefficients) of an I-O table would change in addition to the shifts in the relative prominence of sectors. However, without an adequate basis for estimating such changes, we rely on the base year (1995) I-O table. Moreover, several studies have shown that despite technical coefficient change, I-O multipliers are reasonably stable for several years (Miller & Blair 1985)

[13] Again, we emphasize that the results presented here represent only a small portion of the possible impacts on the forest sector and an even much smaller portion of impacts for the economy as a whole (e.g., we have omitted several non-market impacts of forest growth, such as amenity values in sustaining wildlife, see, e.g., Oladosu 2000). Unfortunately, accurate estimates of direct climate change impacts for most sectors are not yet available for the MAR. Moreover, their presentation and analysis in the context of a region-wide model cannot be adequately addressed within the confines of a short paper

6. ONGOING RESEARCH

The authors are in the process of constructing a computable general equilibrium model for the MAR patterned after the one developed for the Susquehanna River Basin (see Oladosu 2000). It consists of 55 sectors, delineated to highlight the sensitivity of production activities to climate change and policies in the MAR. It embodies optimizing behavior on the part of consumers and producers in response to price signals. Production technologies are specified as multi-level constant elasticity of substitution (CES) functions, which allows input substitution possibilities to differ across input combinations (e.g., it is typically easier to substitute capital for labor than materials for labor). Consumer decisions are modeled in terms of a household production function, which facilitates the consideration of the role of non-market goods and environmental amenities. It will be capable of analyzing impacts not only across sectors but also across socioeconomic groups (e.g., income brackets). At the core of the CGE model is the I-O table presented here. Thus, the MAR CGE model utilizes the best features of I-O, but is able to extend the analysis to the workings of markets and behavioral responses to climate change.

Acknowledgements. The research for this paper was supported by US EPA Cooperative Agreement No. CR-824369 and National Science Foundation Grant No. SBR 9521952. We are indebted to Ann Fisher, David DeWalle, Colin Polsky, and 3 external reviewers for their helpful comments on some sections of an earlier version of this paper. The authors, however, are responsible for any errors or omissions.

LITERATURE CITED

Abler D, Shortle J, Rose A, Oladosu G (1999) Characterizing regional economic impacts and responses to climate change. Global Planetary Change (in press)

Bowes M, Crosson P (1991) Consequences of climate change for the MINK economy: impacts and responses. Resources for the Future, Washington, DC

Bowes M, Sedjo R (1993) Impacts and responses to climate change in forests of the MINK region. In: Rosenberg N (ed) Toward an integrated impact assessment of climate change. Klower, Boston, MA, p 63–82

Cao Y (1999) An economic input-output analysis of forest-related sector vulnerability to climate change in the mid-Atlantic region. MS thesis, Department of Energy, Environmental, and Mineral Economics, The Pennsylvania State University, University Park

DeWalle D, Buda A (1999) Effects of extreme weather on forest land management within the mid-Atlantic region. Environmental Resources Research Institute, The Pennsylvania State University, University Park

Duchin F, Lange GM (1994) The future of the environment: ecological economics and technological change. Oxford University Press, New York

Fisher A, Neff R, Barron EJ (2000) The Mid-Atlantic Regional Assessment: motivation and approach. Clim Res 14:153–159

Gerking S (1976) Input-output as a simple econometric model. Rev Econ Stat 58:274–282

IMPLAN (Minnesota IMPLAN Group) (1997) Impact analysis for planning. (IMPLAN) System, Stillwater, MN

Jensen R (1980) The concept of accuracy in regional input-output models. Int Region Sci Rev 5:139–154

Jorgensen D, Wilcoxen P (1993) Reducing US carbon dioxide emissions: an econometric general equilibrium assessment. Resour Energy Econ 15:7–25

Kamat R, Rose A (1997) Energy and carbon accounts for the Susquehanna river basin. Department of Energy, Environmental, and Mineral Economics, The Pennsylvania State University, University Park

Kamat R, Rose A, Abler D (1999) The impact of a carbon tax on the Susquehanna river basin economy. Energy Econ 21:363–384

Leontief W (1949) Recent developments in the study of interindustrial relationships. Am Econ Rev 39:211–225

Miernyk W, Shellhammer K, Brown D, Coccari R, Gallagher C, Wineman W (1970) Simulating regional economic development. Heath-Lexington, Lexington, MA

Miller R, Blair P (1985) Input-output analysis: foundations and extensions. Prentice-Hall, Englewood Cliffs, NJ

Najjar R and 15 others (2000) The potential impacts of climate change on the mid-Atlantic coastal region. Clim Res 14: 219–233

National Planning Associates (1998) Regional economic projection series. NPA Data Service Inc, Washington, DC

Oladosu G (2000) A non-market computable general equilibrium model for evaluating the economic impacts of climate change in the Susquehanna river basin. PhD thesis, The Pennsylvania State University, University Park

Oosterhaven J (1988) On the plausibility of the supply-driven input-output model. J Region Sci 27:203–217

Polsky C, Allard J, Currit N, Crane R, Yarnal B (2000) The Mid-Atlantic Region and its climate: past present and future. Clim Res 14:161–173

Rose A, Allison T (1989) On the plausibility of the supply-driven input-output model: some empirical evidence. J Region Sci 29:451–458

Rose A, Miernyk W (1989) Input-output analysis: the first fifty years. Econ Syst Res 1:229–271

Rose A, Stevens B, Li PC (1994) A global marketable permits approach to CO_2 mitigation: implications for US energy demand. In: van Ierland EC (ed) International environmental economics. North-Holland, Amsterdam, p 97–118

Rose A, Carmichael J, Oladosu G, Abler D (1999) Modeling the economics of natural hazard impacts and policy responses using computable general equilibrium analysis. The Pennsylvania State University, University Park

Rosenberg N (ed) (1993) Towards an integrated impact assessment of climate change: the MINK study. Kluwer, Boston, MA

Scheraga J, Leary N, Goettle R, Jorgensen D, Wilcoxen P (1993) Macroeconomic modeling in the assessment of climate change impacts. IIASA Collaborative Paper Series, CP-93–2, Laxenburg

Shoven JB, Whalley J (1992) Applying general equilibrium. Cambridge University Press, New York

Smith VK, Espinosa JA (1996) Environmental and trade policies: some methodological lessons. Environ Dev Econ 19:19–40

Sohngen B, Mendelsohn R (1999) The impacts of climate change on the US timber market. In: Mendelsohn R, Neumann J (eds) The impact of climate change on the United States economy. Cambridge University Press, Cambridge, p 94–132

West G, Morrison J, Jensen R (1984) A method for the estimation of hybrid interregional input-output tables. Region Stud 18:413–422