

Incorporating Climate Change Feedbacks into a General Economic Equilibrium Model

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Abstract:

To incorporate market and non-market effects of climate change into a computable general equilibrium (CGE) model, we begin with the basic data that supports CGE models, the Social Accounting Matrix (SAM). We identify where environmental damage appears in these accounts, estimate the physical loss, and value the loss within this accounting structure. Our approach is an exercise in environmental accounting, augmenting the standard national income and product accounts to include environmental damage. Examples of applying the approach in two areas are provided: air pollution health effects and economy-atmosphere-land-agriculture interactions.

We estimate market and non-market effects of air pollution on human health for the U.S. for the period from 1970 to 2000. The pollutants include tropospheric ozone, nitrogen dioxide, sulfur dioxide, carbon monoxide, and particulate matter. The health effects from exposure to air pollution are integrated into the MIT Emissions Prediction and Policy Analysis (EPPA) model, a computable general equilibrium model of the economy that has been widely used to study climate change policy. Benefits of air pollution regulations in USA rose steadily from 1975 to 2000 from \$50 billion to \$400 billion (from 2.1% to 7.6% of market consumption). We also estimate the economic burden of uncontrolled levels of air pollution over that period. In another case study, we examine the health-related economic benefits and costs of policy actions for China. We found that economic burden of uncontrolled levels of air pollution is lower than in the U.S. because of lower wage rates but macroeconomic impact is bigger than in the U.S. (in 2000 the economic burden in the USA is 4.7% of market consumption, in China - it is 10% of market consumption).

For assessing the impacts of environmental change on vegetation (crop productivity, forest productivity, pasture), we have augmented the EPPA model by further disaggregating the agricultural sector. This allows us to simulate economic effects of changes in yield (i.e., the productivity of cropland) on the regional economies of the world, including impacts on agricultural trade. We examine multiple scenarios where tropospheric ozone precursors are controlled or not, and where greenhouse gas emissions are abated or not. In general, a change in food consumption is smaller than a change in agriculture yield due to resource reallocation from or to the rest of the economy.

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1. Introduction

General equilibrium analysis accounts for the intersectoral reallocation of resources that could occur as a consequence of climate change. A key strength of Computable General Equilibrium (CGE) models is their ability to model economy-wide effects of policies and other external shocks, rather than just on individual markets or sectors. In this paper we present a methodology for incorporating market and non-market effects of climate change into a CGE model. We begin with the basic data that supports CGE models, the Social Accounting Matrix (SAM) that includes the input-output tables of an economy, the use and supply of factors, and the disposition of goods in final consumption. We identify where environmental damage appears in these accounts, estimate the physical loss, and value the loss within this accounting structure. Our approach is an exercise in environmental accounting, augmenting the standard national income and product accounts to include environmental damage.

We provide examples of applying our approach in two areas: air pollution health effects and economy-atmosphere-land-agriculture interactions. We integrate the health effects from exposure to air pollution into the MIT Emissions Prediction and Policy Analysis (EPPA) model (Paltsev *et al.*, 2005), a computable general equilibrium model of the economy that has been widely used to study climate change policy. We apply the model to estimate the benefits of air pollution regulations and the economic burden uncontrolled levels of air pollution in USA in China for 1975 to 2000.

Agriculture is another area where environmental change is likely to have important effects. Multiple changes that may occur over the next century will affect vegetation (crop productivity, forest productivity, pasture). Some of these effects are

likely to be positive (CO₂ fertilization), some negative (tropospheric ozone damage), and some may be either positive or negative (temperature and precipitation). Climate effects may operate in either direction because the direction of change may differ across regions (more precipitation in some areas and less in others) and warming may increase growing season lengths in cold-limited growing areas while acting as a detriment to productivity in areas with already high temperatures. Here we use the MIT Integrated Global Systems Model (IGSM) (Sokolov *et al.*, 2005) to analyze the economic impact of environmental change effects on vegetation. For this work we have augmented the EPPA model by further disaggregating the agricultural sector. This allows us to simulate economic effects of changes in yield (i.e., the productivity of cropland) on the regional economies of the world, including impacts on agricultural trade. The EPPA model includes multiple channels of market-based adaptation, including input substitution and trade. We are thus able to examine the extent to which market forces contribute toward adaptation and thus modify the initial yield effects.

In the next section we describe a basic structure of a SAM and discuss a link between economic value and supplemental physical flows. Section 3 presents the changes in the SAM and the structure of our CGE model, which we have made to assess the health impacts of air pollution. We also provide our estimates of the benefits of air pollution regulations and the economic burden uncontrolled levels of air pollution in USA in China for 1975 to 2000. In Section 4 we then provide a description of the changes in the model structure for the analysis of climate change impacts on agriculture. We examine several scenarios where tropospheric ozone precursors are controlled or not, and where greenhouse gas emissions are abated or not, and show the impacts on

agriculture yield, food consumption and total macroeconomic consumption. Section 5 concludes.

2. Expanded Social Accounting Matrix and Linkage to Physical Flows

Data for a particular country or region are often organized in the form of a Social Accounting Matrix (SAM), which presents a static image of the economy. The information contained in the SAM provides a basis for the creation of a plausible CGE model. A SAM describes the flows among the various sectors of the economy. It represents the value of economic transactions in a given period of time. Transactions of goods and services are broken down by intermediate and final use. A SAM also shows the cost structure of production activities: intermediate inputs, compensation to labor and capital, taxes on production. Figure 1 illustrates a general structure of a SAM, where Matrix *A* represents an intermediate demand. Rows in the matrix *A* describe production sector outputs. Columns represent sectors which use outputs of production as intermediate inputs. As such, a number in a cell A_{ij} tells the amount of sector *i*'s output used in the production of a sector *j*. A breakdown of a final demand on private consumption, government consumption, investment, and export is shown in Matrix *B*. Matrix *C* gives the information on total domestic production. Matrices *D*, *E* and *F* give the corresponding information on imported goods and services. Payments to labor and capital, depreciation, and indirect taxes are presented in Matrix *G*. Matrix *H* is normally empty, and summation over rows in Matrix *I* gives information on value-added. If a SAM is balanced, then columns of Matrix *J* should be the same as the rows of Matrix *C* because total input equals total output for production sectors.

A SAM illustrates the circular process of demand leading to production leading to income, which in turn leads back to demand. There is an exact correspondence between rows and columns in a balanced SAM. This means that supply equals demand for all goods and factors, tax payments equals tax receipts, there are no excess profits in production, the value of each household expenditure equals the value of factor income plus transfers, and the value of government tax revenue equals the value of transfers.

To build a CGE model, a modeler needs additional information on elasticities of substitution between inputs in production and between goods in consumption. A SAM does not provide this information. For importance of information on elasticity of substitution for building a CGE model see Rutherford (1995). Another choice for a CGE modeler is a structure of production and consumption bundles (i.e., a nesting structure of substitution possibilities) and functional forms for production and utility functions. In this paper we use the elasticities, nesting structures, and functional forms of the EPPA4 model as documented in Paltsev *et al.* (2005). We do not repeat them here, but we discuss the changes and additions to the EPPA production and consumption structure we use for incorporating climate change feedbacks in the consecutive sections.

The first step is to identify where environmental damage appears in a SAM, estimate the physical loss, and value the loss within this accounting structure. For health effects, one needs to account for lost productivity, a decrease in labor force, and changes in expenditure in the health sector at the expense of other sector of the economy. For agriculture productivity effects, one needs to keep track of land use database, to estimate the changes in vegetation due to changed climate and pollution, and to introduce these agriculture productivity changes back into an economic system. For a sea-level change,

which would affect the quantity and the value of land, an additional database on the area and value of the coastal land, and estimates of protection of urban and agricultural land, as well as costs of relocation of agriculture and urban areas are needed.

In many cases, it is important to include supplemental accounting of physical and biological variables. For example, in EPPA we use such supplemental tables for physical energy use, as they are necessary for accounting of carbon dioxide emissions and tracking of physical depletion of energy resources. For impact on agriculture we disaggregate agriculture to explicitly treat land use and feedbacks impacts on vegetation.

A SAM provides the data in value form, i.e., using total expenditure or sales as a measure of the quantity of inputs and outputs in the economy. That is, these data do not report quantities in tons of wheat, coal, iron ore, or steel produced or the hectares of land, hours of labor, or exajoules of energy used to produce them. Instead they report the total expenditure on energy or labor, rental payments to land and capital, and the total sales or purchases of goods and services.

Measuring inputs and outputs in terms of expenditure or of the total value of sales greatly facilitates aggregation. The economic theory underlying this practice holds that the prices of goods reflect their marginal value as inputs into production or of consumption.¹ Different prices for varying grades of a particular commodity thus reflect their differential value as a production input or for consumption. One might ideally desire a fine disaggregation of inputs and outputs, but of course there are different varieties and

¹ Problems of aggregation are eliminated in a base year, but they resurface when comparisons of real economic growth are to be made over time. One then must worry about the quality (and implicitly) the mix of products of different qualities in any aggregation. Much economic work has been devoted to creating prices indices that capture accurately the changing mix, but there remain difficult problems of changing quality that bedevil efforts to identify real growth and changes in the price level. To solve these problems requires going back to more fundamental and disaggregated observations.

grades of even such basic commodities as, for example, apples, wheat, coal or crude oil. Similarly, the labor force is composed of individuals with widely varying skills, and land has a wide range of characteristics that are more or less useful for different purposes. In manufacturing and services, product differentiation is the rule rather than the exception, and no one would believe it made much sense to measure hair cuts and financial services in their natural units and add them together.

In economic models the problem of adding together apples and oranges (or different varieties of apples) is solved by using price weights. For example, consider a land owner with three different parcels of land: parcel #1 is 300 hectares and rents for \$75 per hectare, parcel #2 is 150 hectares and rents for \$150 per hectare, and parcel #3 is 75 hectares and rents for \$300 per hectare. Most people would sum together the hectares and conclude that the total land owned is 525 hectares. Economists are interested, however, in the contribution this land makes to the economy, and they would thus observe that parcel #2 is twice as valuable per hectare as parcel #1, and parcel #3 twice as valuable as parcel #2. They use the rental value as an appropriate weight to sum these together. Parcel 1's annual value to the economy is $\$75 \times 300 = \$22,500$; parcel 2 is $\$150 \times 150 = \$22,500$, and parcel 3 is $\$300 \times 75 = \$22,500$. The example here is constructed so that when weighted by price, the three parcels are equal in size in terms of their input into the economy, which is a very different conclusion than using hectares directly which would indicate that parcel #1 is four times bigger than parcel #3.

The approach of weighting inputs and products by their marginal value allows agricultural or steel production or energy input to be aggregated in an economically meaningful manner. Agriculture output is composed of commodities like corn, wheat,

beef, lamb, apples, oranges, raspberries, and asparagus. It would be nonsensical to add together total tons because that would mean that fruit and vegetable production is a minor component of agriculture when in value terms it is as important as grain crops. Output of the iron and steel industry includes specialty alloy products, cast iron, and more common sheet or bar products. Similarly, an exajoule of coal is of less value to the economy than an exajoule of oil, gas, or electricity.

Formally, a CGE model such as EPPA measures all inputs and outputs in the economy in billions of dollars. Given the use of value as the quantity measure, all prices are unit-less ($=1.0$) in the base year and so when multiplied times the input quantity one then gets back expenditure or income as a monetary measure.² Simulating the model forward, or in a counterfactual case, is a process of finding prices that clear the markets given some exogenous change or limitation on how the economy can use its resources. Market-clearing prices in these simulations will typically vary from 1.0. If, for example, the labor force is estimated to increase by 20% from \$10 billion this will be simulated as a labor input of \$12 billion. The base year wage rate is defined as 1.0 and so wage income (and the wage bill for employers in the economy) is \$10 billion in the base year. But in the future year if the market clearing wage rate falls to 0.95 relative to the numeraire good then labor income will have increased by $0.95 \times \$12 \text{ billion} = \11.4 or only 14% but we still measure the “physical” increase in labor to be the 20% increase from \$10 to \$12 billion.

If the focus is on purely economic results over the short and medium term, this approach to economic modeling has proven useful. Changes in physical inputs are implied by economic modeling but are not explicitly tracked. The limitation of this

² For an introduction to the analytic procedures underlying CGE models see Sue Wing (2004).

approach for earth system and longer-term economic modeling is that there is no straightforward way to keep track of important physical flows such as emissions of pollutants, depletion of resources, changes in land use, and the efficiency of physical processes such as conversion of fuels to electricity. This feature further limits the use of engineering data on new technologies. For example, the electric sector data includes multiple fuels, capital, labor, and intermediate inputs that lead to the fossil-based production and transmission of electricity, but also includes technologies such as nuclear and hydroelectric power that do not use fossil fuels. Engineering cost data for new electricity technologies such as wind, natural gas combined cycle, or integrated coal gasification with sequestration typically focus on generation cost rather than the broader costs of running an electric utility company and transmitting and distributing the product. Moreover, an aggregate electricity sector that includes both fossil sources and hydro, nuclear, and other renewable sources cannot be evaluated directly to determine the efficiency of energy conversion. Engineering estimates of future efficiency of conversion and the technological costs of key options as they depend on resource availability and quality is useful information that can help constrain and inform longer run economic-energy forecasts. Finally, one must also recognize that environmental feedbacks on the economy through changes in the productivity of crops and forests and impacts on the human population will be mediated through impacts on physical systems. For all of these reasons it is essential in climate analysis to link the changes in the physical and biological environment of the earth system to the underlying economic variables.

3. Health Effects

The conventional approach to estimating health damage from air pollution is to multiply a predicted illness or death by a constant value meant to capture the value of lost life or the cost of the health care. However, health costs do not affect the overall economy equally. When people get sick and miss work, their lost productivity will negatively affect certain sectors. In addition, people buy medicine and use medical services, an expenditure that will require more resources to be used in the health sector at the expense of other sectors. People sometimes get ill not due to air pollution levels in a single day or year but rather due to their lifetime exposures to pollutants. And if people die prematurely due to pollution exposure, their contribution to the workforce is lost in every year from their death until their normal retirement date.

To reflect these complexities in a CGE model, several steps are needed:

1. The model should be able to generate an estimate of emissions depending on the changes in economic activity (this step is needed for projections into the future);
2. The air pollution model should be able to convert these emissions into concentrations, because the existing epidemiological estimates reflect health impacts due to a change in a concentration of a pollutant, not to a change in emissions (this step is needed for projections into the future);
3. Expand SAM to include valuation of health effects;
4. Create a production structure for a pollution health service;
5. Get epidemiological estimates of the relationships between air pollution and health;
6. Create relationships on lost labor, leisure, and increase/reduction in medical services;

7. Run the model with a scenario of pollution without air-pollution policy, a scenario with air pollution policy, and a scenario with a “natural” pollution, and compare the results;

Steps 1 and 2 are not needed if one tries to estimate the effects of historic regulations and the data on pollutant concentrations are available. For more details on these steps see Matus *et al.* (2006). Here we focus on presentation of the changes in the SAM and CGE structure. Extending the model to included health effects involves valuation of non-wage time (leisure) and inclusion of a household production of health services, which we represent in a SAM as shown in Figure 2. The extensions of model are highlighted in *italic bold*. We add a household service sector that provides a ‘pollution health service’ to final consumption to capture economic effects of morbidity and mortality from acute exposure. This household service sector is shown as ‘household mitigation of pollution health effects.’ It uses ‘medical services’ (i.e., hospital care and physician services) from the SERV sector of EPPA and household labor to produce a health service. The household labor is drawn from labor and leisure and thus reduces the amount available for other uses; i.e., an illness results in purchase of medical services and/or patient time to recover when they cannot work or participate in other household activities. We use data from traditional valuation work to estimate the amount of each of these inputs for each health endpoint as discussed in the following sections. Changed pollution levels are modeled as a Hick’s neutral technical change: higher pollution levels require proportionally more of all inputs to deliver the same level of health service, or lower levels require proportionally less.³

³ Modeled here as a negative technical change, greater expenditure *due to more pollution* draws resources from other uses and thus reduces consumption of other goods and leisure—more pollution is thus bad. The increased expenditures combat the pollution effects, and do not increase consumption and welfare. Of course, greater expenditure for a *fixed level of pollution* will generate more health benefits.

As presented in Figure 3, the EPPA model includes 16 countries/regions, 6 non-energy sectors, and 15 energy sectors/technologies., but the model does not have household production sector. Figure 4 shows the household service (production) structure with the added components in bold italics. The key new additions are (1) leisure as a component of consumption and (2) the Household Healthcare (HH) sector that includes separate production relationships for health effects of each pollutant. The elasticity, σ_L , is parameterized to represent a labor own-price supply elasticity typical of the literature, as discussed in more detail later. The HH sector is Leontief in relationship to other goods and services and among pollutant health endpoints. Mortality effects simply result in a loss of labor and leisure, and thus are equivalent to a negative labor productivity shock.

Impacts on health are usually estimated to be the largest air pollution effects when measured in economic terms using conventional valuation approaches, dominating other losses such as damage to physical infrastructure, crops, ecosystems and loss of visibility (e.g., US Environmental Protection Agency, 1999). The health effects of air pollution present themselves as both a loss of current well-being (an illness brought on by acute exposure to air pollution that results in temporary hospitalization or restricted activity) and as an effect that lasts through many periods (years of exposure that eventually lead to illness, and deaths where losses to society and the economy extend from the point of premature death forward until that person would have died of other causes had they not been exposed to pollution). Thus, we are faced with accounting both for stocks and flows of labor endowment in the economy and the population's exposure to pollution. Health effects also present themselves as both market and non-market effects. Death or illness of someone in the labor force means that person's income is no longer part of the economy,

clearly a market effect. Illness also often involves expenditure on medical services, counted as part of the market economy. Death and illness also involve loss of non-paid work time, a non-market impact. This likely involves a loss of time for household chores or a loss of time spent on leisure activities. The health effects area thus is both a large component of total air pollution damages and provides an opportunity to develop methods to handle a variety of issues faced in valuing changes in environmental conditions.

Epidemiological relationships have been estimated for many pollutants, as they relate to a variety of health impacts. The work has been focused on a set of substances often referred to as ‘criteria pollutants,’ so-called because the U.S. EPA developed health-based *criteria* as the basis for setting permissible levels. These same pollutants are regulated in many countries. For more on epidemiological relationships that we use in our study, see Matus *et al.* (2006).

As presented in Figure 5, the benefits from air pollution regulation in USA rose steadily from 1975 to 2000 by our estimate. In terms of additional market consumption + leisure, the benefits rose steadily from 1975 to 2000 from around 50 billion of 1997 USD to 400 billion of 1997 USD. It is worthwhile to note that in the expanded accounting a true willingness to pay estimate of benefits should be income constrained. In our approach, benefits are not necessarily constrained by market income but by the total resources available to the household including market income plus the value of leisure. Faced with illness or death to a member, households will use their non-market resources as well as income to combat the disease, and thus exhibit a willingness to pay (or use) these resources.

Figure 5 also shows the remaining costs of pollution over the period of 1975-2000. The results are less dependent on a projection of a counter-factual case. Essentially, background levels of pollution are so low that slightly different assumptions about background levels would have little effect on our estimates. Because the actual pollution levels are falling over time, due to regulations, exposure to pollution per person is falling. This alone would reduce pollution costs over time. The urban population is growing slowly, but the more important factor is that the economy and wage rates are growing over the period. As the value of lost work and leisure rise over time, the absolute economic cost of pollution actually rises slightly over the entire period, despite a substantial decrease in the level of pollution.

In another case study, we examine the health-related economic benefits and costs of policy actions for China, as presented in Figure 6. We found that economic burden of uncontrolled levels of air pollution is lower than in the U.S. because of lower wage rates but macroeconomic impact is bigger than in the U.S. (in 2000 the economic burden in the USA is 4.7% of market consumption, in China - it is 10% of market consumption).

For more information on benefits and costs by pollutant and a sensitivity analysis see Matus *et al.* (2005) and Matus *et al.* (2006).

4. Agriculture Effects

Agriculture is another area where environmental change is likely to have important effects. Multiple changes that may occur over the next century will affect vegetation (crop productivity, forest productivity, pasture). Some of these effects are likely to be positive (CO₂ fertilization), some negative (tropospheric ozone damage), and some may

be either positive or negative (temperature and precipitation). Climate effects may operate in either direction because the direction of change may differ across regions (more precipitation in some areas and less in others) and warming may increase growing season lengths in cold-limited growing areas while acting as a detriment to productivity in areas with already high temperatures.

The steps we have done to focus on the vegetation and economic effects of climate and ozone are as follows:

1. Disaggregate agriculture sector.
2. Get a separate food sector.
3. Get estimates on pollution in agriculture yield.
4. Run Business-As-Usual and other scenarios.

Here we use the MIT Integrated Global Systems Model (IGSM) to analyze the economic impact of environmental change effects on vegetation, in particular its TEM component, which is a process based biogeochemistry model that simulates the cycling of carbon, nitrogen, and water among vegetation, soils, and the atmosphere. For this work we have augmented the EPPA model by further disaggregating the agricultural sector. This allows us to simulate economic effects of changes in yield (i.e., the productivity of cropland) on the regional economies of the world, including impacts on agricultural trade. The EPPA model includes multiple channels of market-based adaptation, including input substitution and trade. We are thus able to examine the extent to which market forces contribute toward adaptation and thus modify the initial yield effects. We examine multiple scenarios where tropospheric ozone precursors are controlled or not, and where

greenhouse gas emissions are abated or not. This allows us to consider how these policies interact. For more information on this study, see Reilly *et al.* (2006).

In a SAM we change a productivity of land, which would be reflected in the value added for natural resources on Figure 1. We also disaggregate food processing sector and change the structure of crop, livestock, and forestry sectors as presented on Figures 7-9. We consider the following scenarios.

High Pollution: There are no efforts to control emissions of greenhouse gases (GHGs).

Emissions coefficients per unit of combustion for other pollutants decline in different regions as incomes increase based on cross-section estimates of the relationship between per capita income. The decline is estimated separately for each pollutant, and for different combustion sources including large point source, small sources, and for households. In principle, this would tend to create an environmental Kuznets' curve relationship, but the exhibited decline in emissions per unit of fuel combustion is insufficient to offset increases in use of fuels, and so pollution levels rise substantially.

Climate and GHGs only: The same climate and pollution scenario as the *High Pollution* case but with the ozone damage mechanism in TEM turned off so that we can observe the climate and CO₂ effects alone without the effect of ozone damage.

Capped pollution: Conventional pollutants (CO, VOC, NO_x, SO₂, NH₃, black carbon, and organic carbon) are capped at 2005 levels, but GHG emissions remain uncontrolled. The major effect of capping these pollutants is to reduce ozone levels because many of these are important ozone precursors and thus ozone damage to vegetation is reduced. The climate effects of reducing these pollutants are small

because of the offsetting effects from different pollutants. Sulfates are cooling substances so reducing them tends to increase the temperature but ozone is a warming substance and so reducing ozone precursors leads to less warming.

GHGs capped: Greenhouse gases are controlled along a path that starts with the Kyoto Protocol, deepening the cuts in developed countries and expanding to include developing countries on a pathway that keeps CO₂ concentrations below 550 ppm by 2100 and with continued emissions reduction that could be consistent with stabilization of concentrations at 550 ppm. This scenario is described in Reilly et al. (1999). Because combustion of fossil fuels is affected, this scenario also leads to significant reduction from reference of other pollutants including ozone precursors.

GHGs capped-no ozone: The same climate and GHG levels as in the *GHGs capped* scenario but with the ozone damage mechanism in the TEM model again turned off so that we can observe the climate and CO₂ effects alone without the effect of ozone damage.

GHGs and pollution capped: GHGs controlled as in the *GHGs capped* scenario and conventional pollutants capped as in the *Capped pollution* scenario.

We focus first on global effects on production of these yield changes. To effectively compare the global production effects with the yield changes, we construct a measure of global yield change for crops, pasture, and forestry derived from TEM to compare with estimated production change once we simulate the effect of these changes in EPPA. The global yield changes are derived by summing the total level of agroecosystem productivity (gC/year) for the globe and calculating the difference from

2000, as we did for each of the regions. Thus, the percentage change is weighted by the absolute productivity in different regions. The global sector production (crop, livestock, forestry) is measured in the total value of production in real terms in 1997 US dollars and at 1997 market exchange rates as reported in EPPA. We calculate the difference from the reference projection (without environment effects) to measure the effect on production of each of the environmental change in terms of sector production levels. These are plotted in Figures 10-12. For exposition, we have not plotted the ***GHGs capped-no ozone*** scenario because it is very similar to ***GHGs and pollution capped*** scenario.

Figure 10 reports the results for crops. As expected, positive (negative) yield effects of environmental change lead to positive (negative) production effects. However, note that the production effects are far smaller than the yield effects. The global yield effects are for an increase of over 60 percent (***Climate and GHGs only***) to a decline of nearly 40 percent (***High pollution***) while the crop production effects are no larger than ± 8 percent. This reflects relative inelastic demand for crops because of a relatively inelastic demand for food, the ability to substitute other inputs for land (adapt), and the ability to shift land into or out of crops.

Figure 11 reports results for livestock. Here the livestock production results bear little relationship to the yield effects for pasture. The pasture results are all positive whereas several of the scenarios show reductions in livestock production. In fact, the scenarios mirror closely the production effects on crops. This reflects the fact that feedgrains and other crops are important inputs into livestock production, relatively more important than pasture. A reduction (increase) in crop production is reflected in higher (lower) prices for feedgrains and other crops used in livestock, and this tends to lead to

reduced (increased) production of livestock. Again, the percentage differences in livestock production are relatively small compared with the crop production changes, even in cases where production increases are driven both by an increase in crop production and an increase in pasture productivity.

Figure 12 reports results for forestry. The general result is that the production effects are very small—less than 1 percent compared with yield effects of 3 to 15 percent.

An important result of the general equilibrium modeling of these impacts is that effects can be felt beyond the agricultural sector. We show this in Figure 13 where we have plotted macroeconomic consumption change and the change in food consumption both as a percent of food consumption in a reference case where there is no environmental feedback on the economy. To illustrate this effect, we present the results for two scenarios – *High pollution* and *Climate and GHGs only*, because those are the ones that show the biggest change. This shows that, in general, the aggregate consumption effect is bigger in absolute terms than the agricultural production effect. Thus, adaptation in the agricultural sector which was seen most clearly in the crop sector results, but by the general result that the production effects were much smaller than the yield effects, is partly the result of shifting of resources into or out of these sectors, thereby affecting the rest of the economy. Thus, we see in our results the frequently expressed view that the adaptation potential of the agricultural sector is considerable—most yield effects are offset leaving very little change in food consumption. But, we also see that this comes about through resource reallocation from or to the rest of the economy and so to focus only the changes in the agricultural sector/food consumption underestimates damages (or benefits) of the environmental change. Thus, while yield

change alone overestimates the economic effect, focusing on agricultural production or food consumption underestimates the full economic effect. Fully measuring the economic effect requires a general equilibrium approach that evaluates the impact on resource reallocation beyond the agricultural sector.

Finally, we focus on the regional economic effects for the *High pollution* and *Climate and GHGs only* scenarios for selected countries on Figure 14. These illustrate several important results. First, the impact as a percentage of the economy differs because of the different importance of these sectors in the economy. Food consumption is generally income inelastic, a feature we have approximated in EPPA, and this means agriculture is generally falling as a share of all economies over time. However, for developing country regions agriculture is currently a relatively large share of the economy, as much as 20%, compared with as little 1 or 2 percent in developed countries. Second, trade effects can be important. In the *High pollution* case, tropical, Southern Hemisphere and far northern regions (AFR, LAM, ANZ, CAN) benefit economically even though they suffer crop yield losses (or no change in the case of LAM). Economic gains result because they export agricultural products to other regions where crop yields are severely reduced due to ozone. The trade effects in the *Climate and GHGs only* scenario are less obvious from the total economic impact, but ANZ, a major agricultural exporter suffers economic loss from lower export prices even though crop yields are estimated to rise by over 80 percent. Thus, the net economic effect due to changes in agriculture, pasture, and forestry productivity are a complex combination of a changing pattern of trade among regions and resource reallocation between the agriculture sectors and other sectors of the economy.

5. Conclusion

In this paper we present a methodology for incorporating market and non-market effects of climate change into a CGE model. We begin with the basic data that supports CGE models, the Social Accounting Matrix (SAM) that includes the input-output tables of an economy, the use and supply of factors, and the disposition of goods in final consumption. We identify where environmental damage appears in these accounts, estimate the physical loss, and value the loss within this accounting structure. Our approach is an exercise in environmental accounting, augmenting the standard national income and product accounts to include environmental damage. For more information on application of this methodology and related caveats for air pollution health effects and economy-atmosphere-land-agriculture interactions, we refer a reader to Matus *et al.* (2006) and Reilly *et al.* (2006).

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Figure 1. Social Accounting Matrix

		INTERMEDIATE USE by Production Sectors				FINAL USE				OUT- PUT
						Private Consump.	Government Consumption	Investment	Export	
		1	2	...j...	n					
Domestic Production	1	A				B				C
	2									
	:									
	i									
	:									
	n									
Imports	1	D				E				F
	2									
	:									
	i									
	:									
	n									
Value added:	-labor	G				H				I
	-capital									
	- natural resources									
INPUT		J								

Figure 2. Expanded SAM for health effects.

		INTERMEDIATE USE by Production Sectors				<i>Household Services</i>		FINAL USE				OUT- PUT
		1	2	...j...	n	<i>Mitigation of Pollution Health Effects</i>	<i>Labor- Leisure Choice</i>	Private consum.	Gov't consum.	Invest.	Export	
Domestic Production	1	A				<i>Medical Services</i>		B <i>Health Services</i>				C
	2											
	:											
	i											
	:											
	<i>Medical Services for Health Pollution</i>											
	n											
Imports	1	D						E				F
	2											
	:											
	i											
	:											
	n											
<i>Leisure</i>							<i>Leisure</i>	<i>Leisure</i>				
Value added:	-labor	G				<i>Labor</i>	<i>Labor</i>	H				I
	-capital											
	- natural resources											
INPUT		J										

Added components are in bold italic.

Figure 3. Regions and Sectors in the EPPA4 Model

Country/Region	Sectors
Annex B	Non-Energy
United States (USA)	Agriculture (AGRI)
Canada (CAN)	Services (SERV)
Japan (JPN)	Energy Intensive products (EINT)
European Union+ ^a (EUR)	Other Industries products (OTHR)
Australia/New Zealand (ANZ)	Industrial Transportation (TRAN)
Former Soviet Union (FSU)	Household Transportation (HTRN)
Eastern Europe ^b (EET)	Energy
Non-Annex B	Coal (COAL)
India (IND)	Crude Oil (OIL)
China (CHN)	Refined Oil (ROIL)
Indonesia (IDZ)	Natural Gas (GAS)
Higher Income East Asia ^c (ASI)	Electric: Fossil (ELEC)
Mexico (MEX)	Electric: Hydro (HYDR)
Central and South America (LAM)	Electric: Nuclear (NUCL)
Middle East (MES)	Advanced Energy Technologies
Africa (AFR)	Electric: Biomass (BELE)
Rest of World ^d (ROW)	Electric: Natural Gas Combined Cycle (NGCC)
	Electric: NGCC w/ Sequestration (NGCAP)
	Electric: Integrated Coal Gasification with Combined Cycle and Sequestration (IGCAP)
	Electric: Solar and Wind (SOLW)
	Liquid fuel from biomass (BOIL)
	Oil from Shale (SYNO)
	Synthetic Gas from Coal (SYNG)

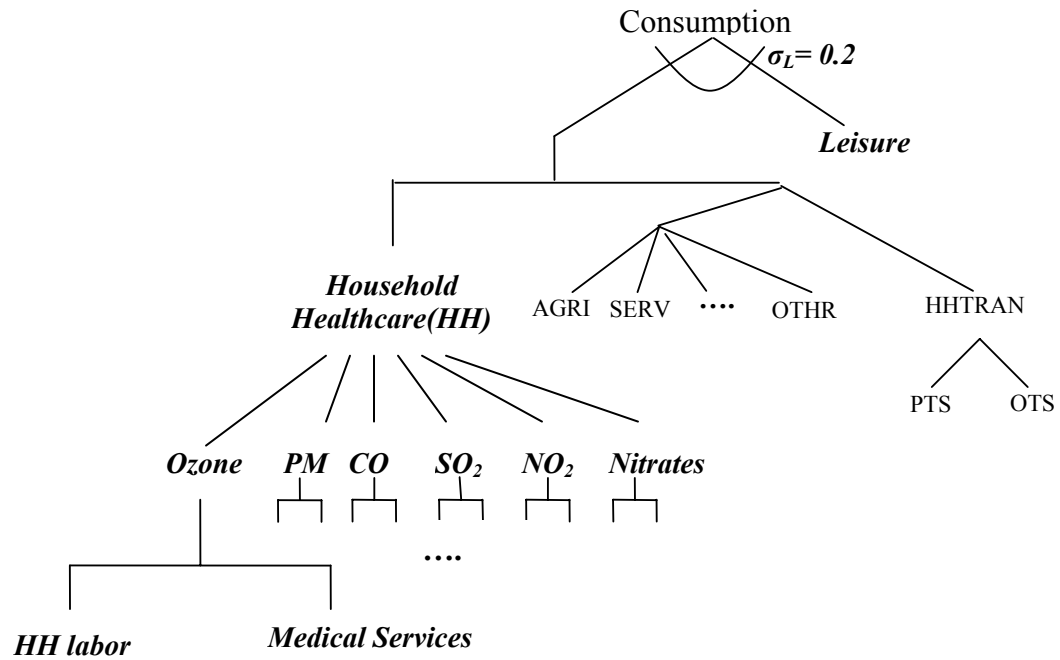
^aThe European Union (EU-15) plus countries of the European Free Trade Area (Norway, Switzerland, Iceland).

^bHungary, Poland, Bulgaria, Czech Republic, Romania, Slovakia, Slovenia.

^cSouth Korea, Malaysia, Phillipines, Singapore, Taiwan, Thailand

^dAll countries not included elsewhere: Turkey, and mostly Asian countries.

Figure 4. Expanded Consumption Structure in include health related household activities



Added health related household activities are in bold italic. Pollutant labels (Ozone, PM, CO, SO₂, NO₂, Nitrates) are used as shorthand reference to health services used to combat various health effects from the pollutant.

Figure 5. Air Pollution Health Effects for USA

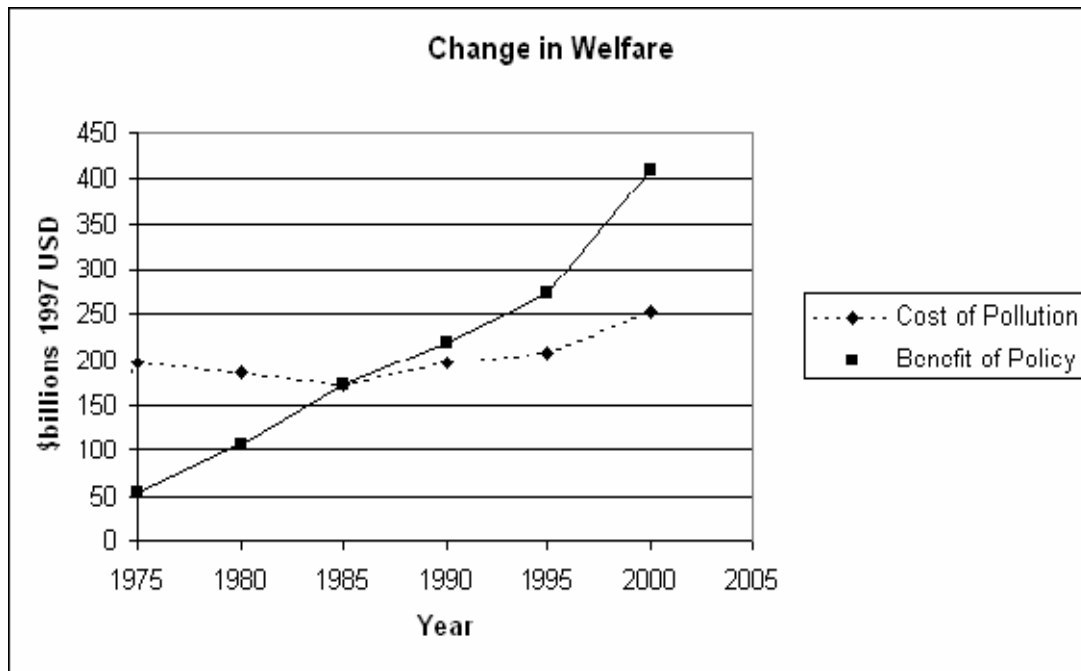


Figure 6. Air Pollution Health Effects for China

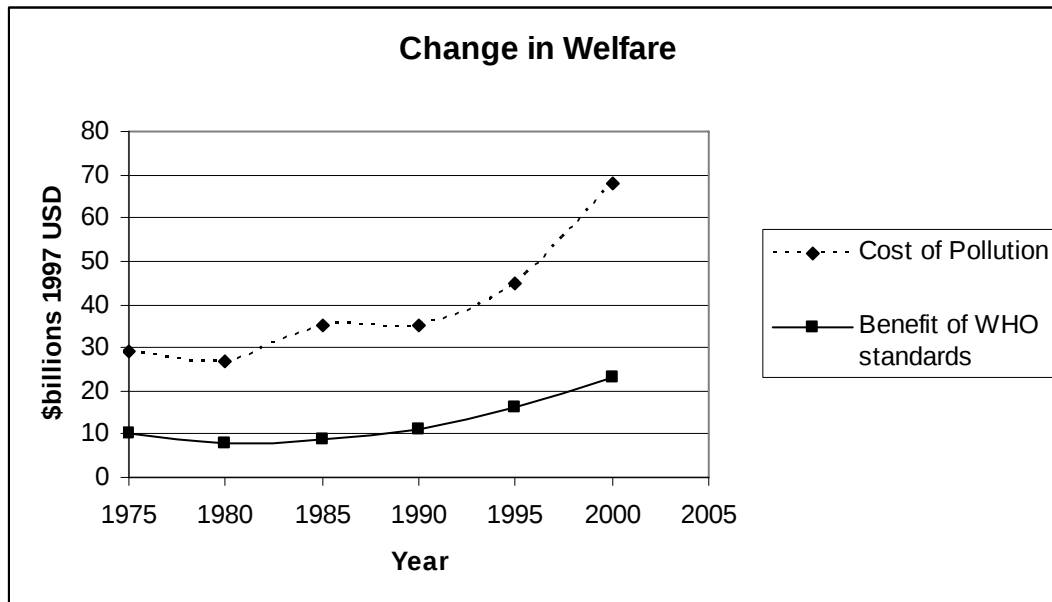
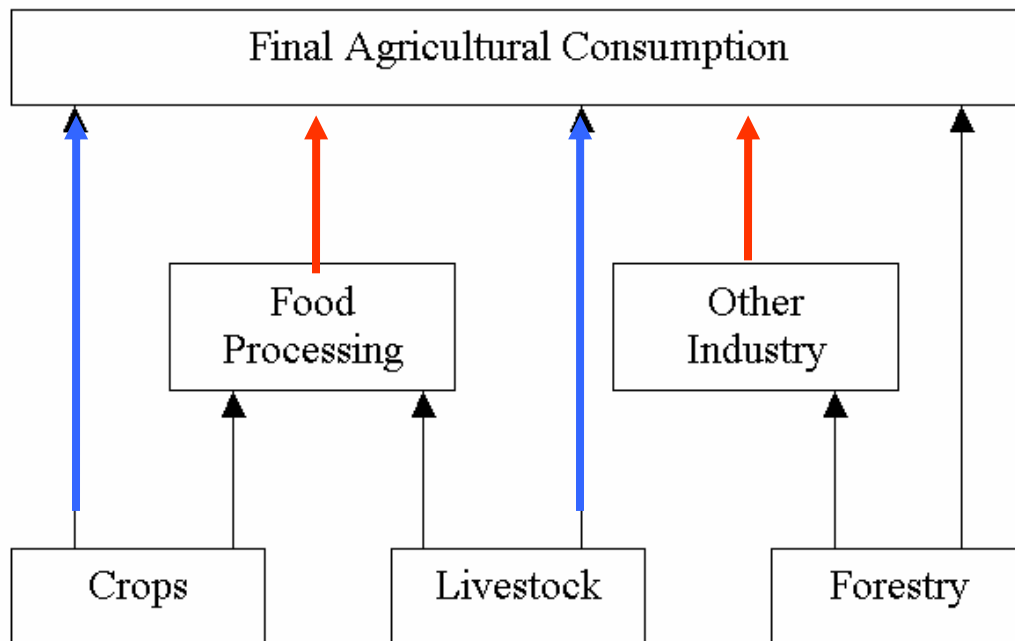


Figure 7. New Agricultural Consumption in the EPPA model



Direct consumption is important in poorer countries.
In richer countries most agricultural consumption is indirect through a Food Processing Sector

Figure 8. Production Structure for Crops, Livestock, and Forestry Sectors

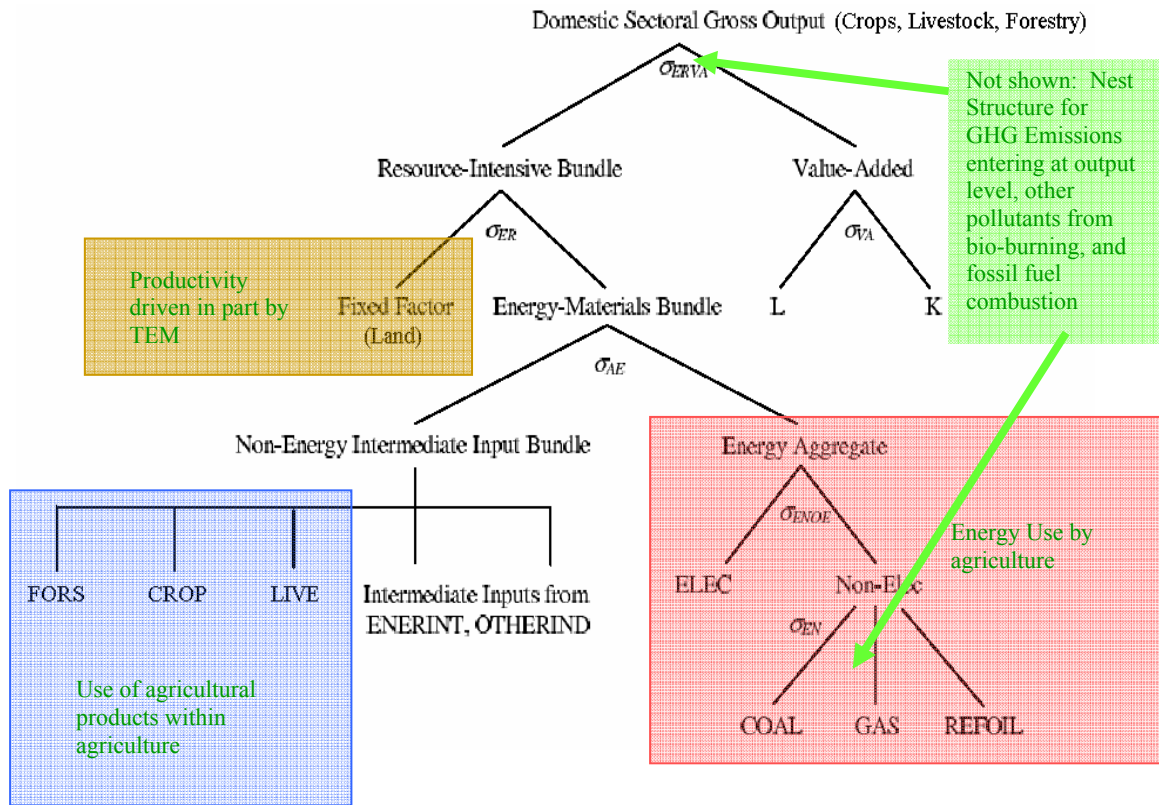


Figure 9. Production Structure for Food Processing Sector

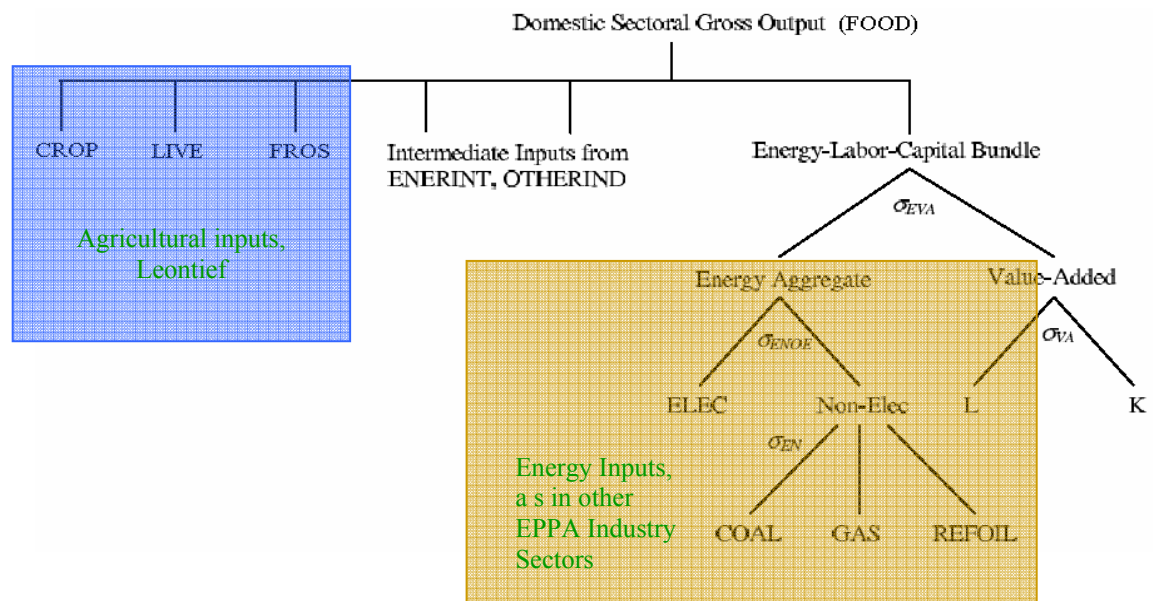


Figure 10. Index for Crop Yield and Production

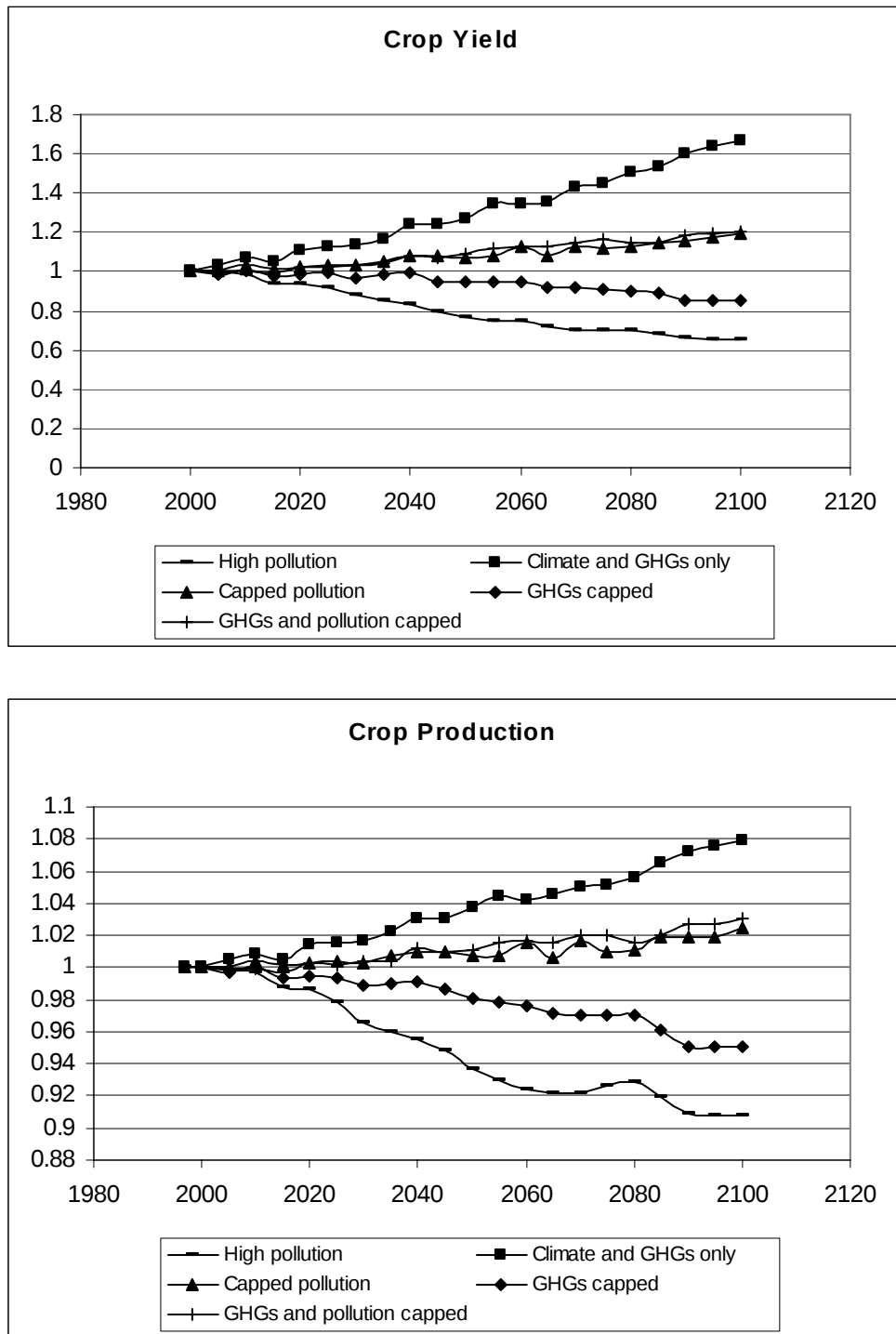


Figure 11. Index for Pasture Yield and Livestock Production

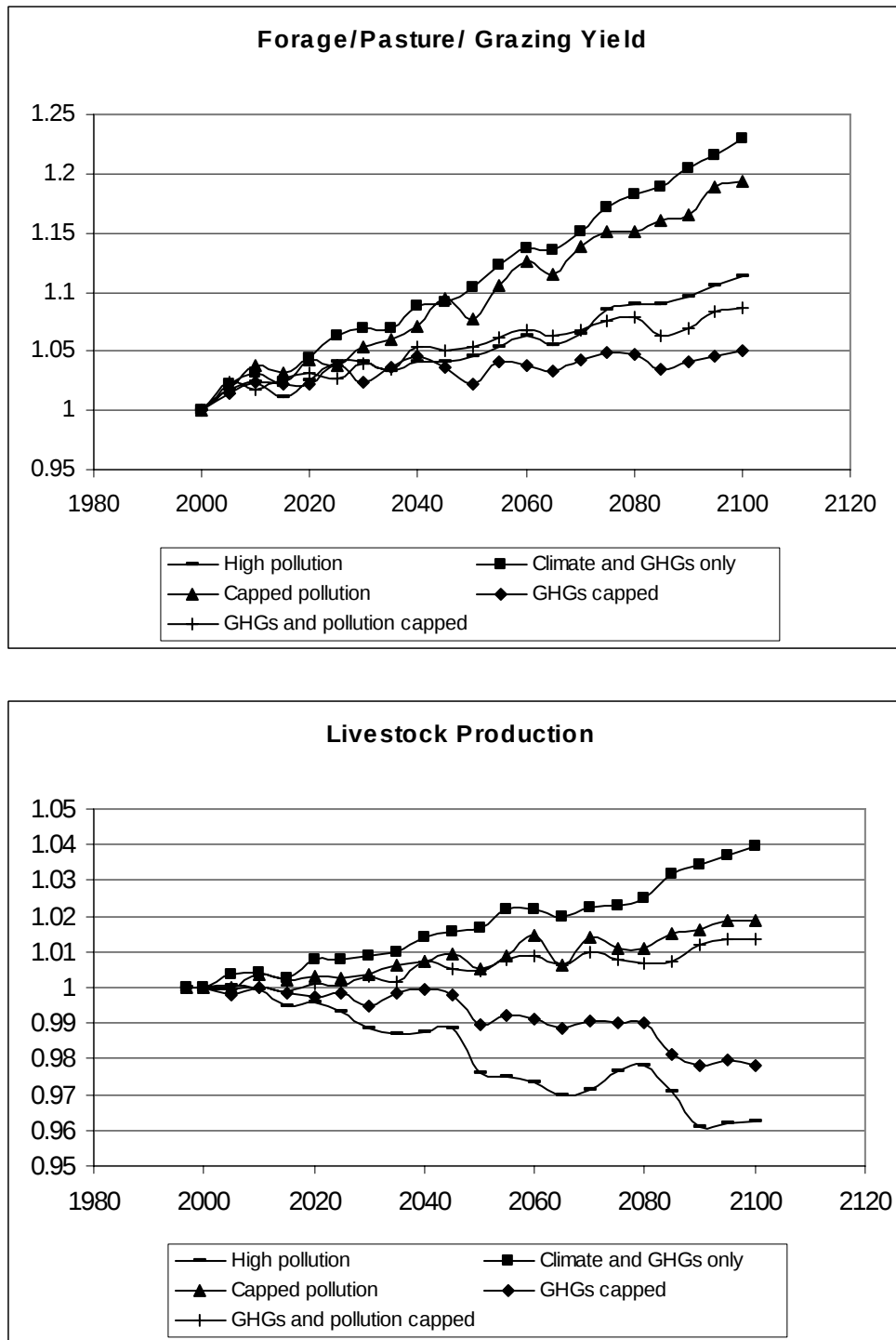


Figure 12. Index for Forestry Yield and Production

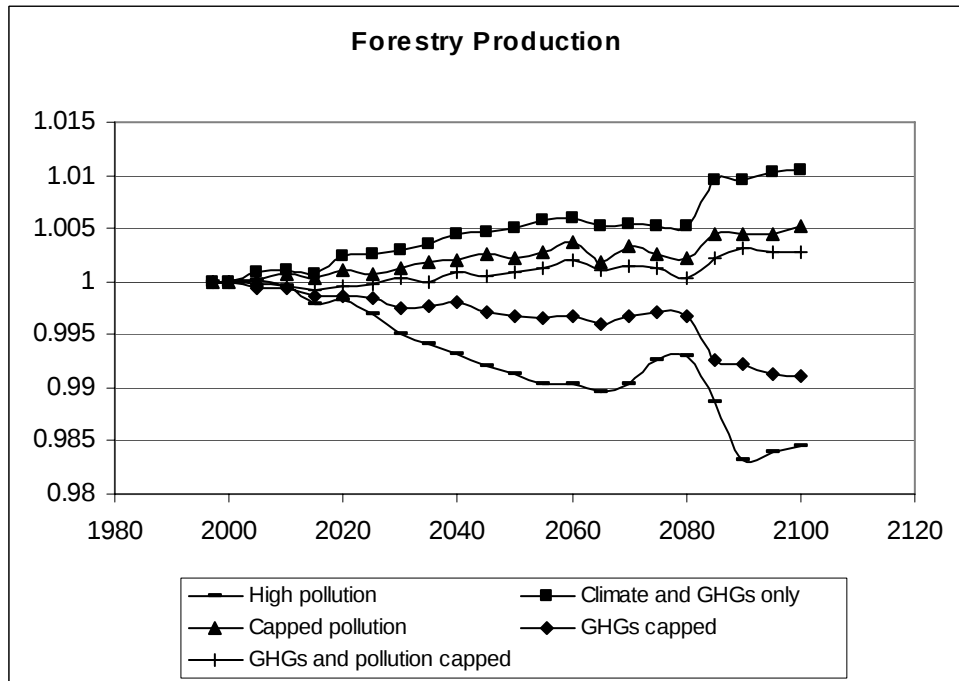
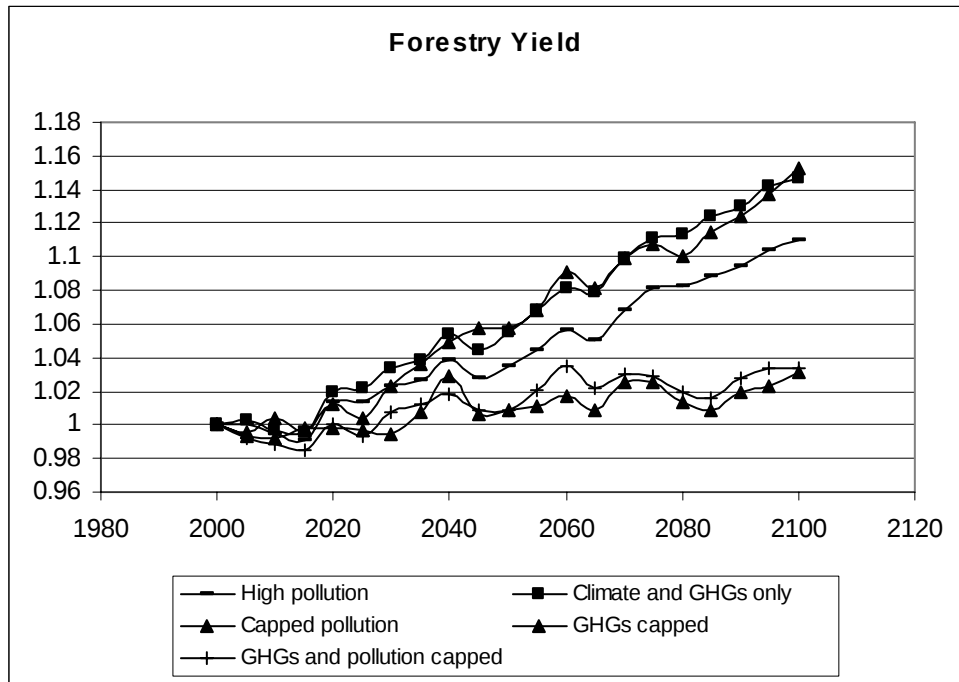


Figure 13. Change in Global Food Consumption and Total Global Macroeconomic Consumption as a share of Agriculture Production

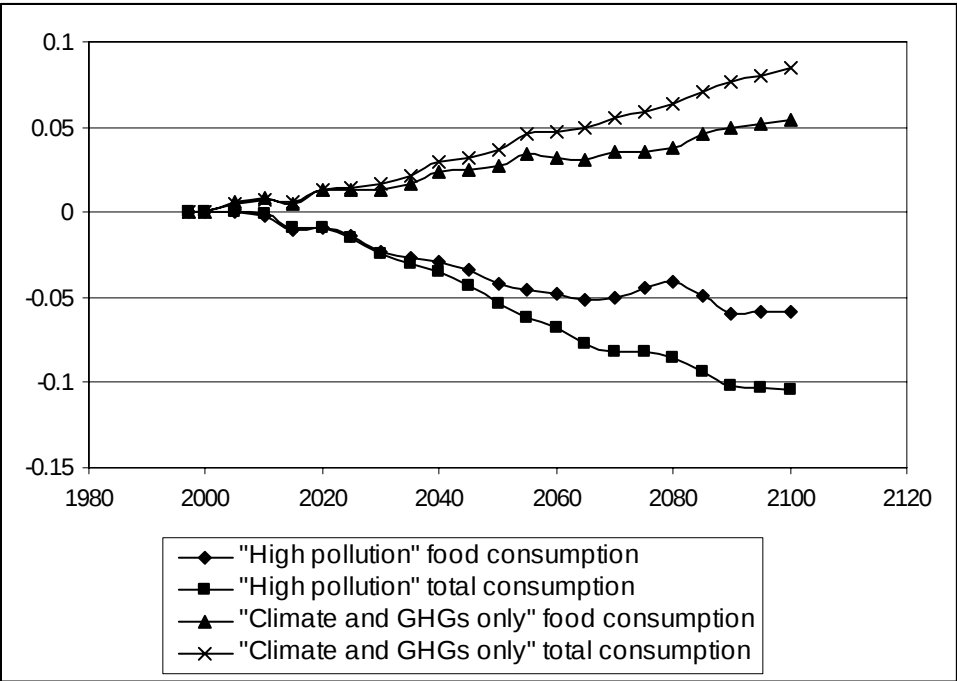


Figure 14. Percent Change in Macroeconomic Consumption, Selected Regions: *High Pollution Scenario* (top panel); *Climate and GHGs only Scenario* (bottom panel).

