Dynamic General Equilibrium Analysis

At the State Level: Assessing the

Economic Implications of the Kyoto Protocol

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Abstract

This paper addresses a question central to the way climate change policy impacts are discussed in the United States: What are the economic costs for individual states of carbon abatement proposals? We present a dynamic computable general equilibrium model of a single U.S. state facing carbon limits. We consistently incorporate the competitive impacts resulting from carbon abatement in other states and regions. Specifically we assess the impacts on Colorado of the 1997 Kyoto agreement. Our analysis suggests that the competitive impacts which affect a state's terms-of-trade are of crucial importance when assessing the economic cost impacts of the Kyoto agreement for a given state. Also, the overall economic impacts on Colorado are largely dependent on the extent of international trade in emissions permits.

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1 Introduction

A growing body of scientific evidence points to the impact that human activities have on the earth's climate. Most climatologists agree that projected growth in fossil-fuel emissions will result in higher atmospheric CO_2 concentrations and a higher global mean temperature. Scientific research continues on the questions of how large the temperature increase might be, and what consequences higher temperatures might have for human activities and ecosystems. Although specific geographic areas may benefit, there is the potential for detrimental, if not catastrophic, environmental changes in the event of a large temperature increase. In addition, at the individual level, there may be a number of moral and "passive-use" motivations for wanting to curb anthropogenic warming. Regulating carbon emissions is, however, costly in terms of economic growth and prosperity.

International economic models are currently being used to assess both the cost of reaching alternative carbon abatement goals and the potential gains from implementing market-oriented policies to meet a given goal. The structure of the U.S. government, however, dictates that legislators and policymakers focus on their constituents in individual states. The purpose of this paper is to demonstrate the potential for modeling the impacts at the state level of an international agreement to reduce carbon emissions and to present a set of results for one state – Colorado.

We present results for the Colorado economy under alternative assumptions about the state's exposure to the external price impacts from other states and countries induced by the Kyoto agreement. In addition, we offer a range of impacts that are consistent with the Kyoto agreement but make different assumptions about international trade in carbon permits. In each case we model an efficient implementation of abatement within the state (marginal abatement costs are equalized across all sources via a system of tradable permits). We do not, however, consider the possibility that permit revenues might be utilized to offset other distortionary taxes (permits are allocated lump-sum to households). These are important issues that could change our quantitative estimates of the costs of achieving Kyoto. Our goal however is to demonstrate the system and draw attention to the qualitative importance of external price impacts on the state.

In December 1997 an agreement was drafted in Kyoto, Japan, that would limit greenhouse gas emissions from the United States to 93% of 1990 levels by the period 2008-2012. Under the terms of the protocol, other industrial countries also agreed to emissions limits – some higher and some lower than the United States – but developing countries remained free to continue to increase their emissions without limit.

Carbon dioxide produced from the combustion of fossil fuels is the most important greenhouse gas. Emissions of CO_2 would need to be cut by over 32% from current IEA projections to meet the 2010 target, and up to 42% by 2030. Accomplishing these reductions will entail significant increases in energy costs. We estimate that a uniform carbon permit price (or, equivalently, a carbon tax) across the U.S. of $231 per tonne is required to meet the 2010 target.[1] This price drops dramatically, to $72 per tonne, under the assumption of an efficient system of international permit trading among signatories to the agreement. Developing countries have not made any commitments to limit their emissions, and some developed countries (the Former Soviet Union and Eastern Europe) have substantially lower commitments relative to their projected 2010 emissions. A global strategy that arrives at the same level of emissions but equalizes marginal abatement costs will substantially lower the overall costs of attaining the goal. We have estimated that the price of a carbon permit under global trade would be as low as $36 per tonne in 2010.[2]

Climate change policy is global in its scope, and affects the U.S. economy through limits on energy use and through changes in the terms-of-trade with other countries. As with other cases of environmental policy, U.S. policymakers have shown a great deal of interest in the economic consequences for individual states. Because energy consumption patterns and the industrial base vary significantly in different states, there are likely to be important differences in economic impacts across states. The major challenge for us has been to develop a computationally tractable model that provides state-level detail while also incorporating the major external market adjustments that global and national carbon abatement entails.

This paper describes a state model that relies on a hierarchical structure of linked models to determine the external trade implications of a policy shock. At the highest level a multi-regional trade model of the world establishes international trade patterns for the U.S. A U.S. multi-regional model is then utilized to establish interstate trade patterns. Finally, the state-level model ties together changes in global trade markets, impacts on trade within the U.S., and emissions policy to arrive at a set of consistent results for an individual state economy. The model estimates economic impacts at the state level consistently for all 50 states, but for exposition we focus the analysis in this paper on one state – Colorado.

Our analysis suggests that the competitive impacts which affect a state's terms-of-trade are of crucial importance when assessing the economic cost impacts of the Kyoto agreement for a given state. This key insight brings into question the results published in an earlier state-level study of carbon abatement by Li and Rose (1995). The transmission of impacts from other regions within the U.S. is of most importance, because states have the closest trading relationships with other states. The social accounts used in this study indicate that in 1993 $2.9 trillion of commodities were traded across state boarders, where as the volume of international trade was only $1.3 trillion.[3] Furthermore, some of the important energy commodities (coal, electricity, and natural gas) have very limited

[1] For comparison our estimate is lower then that of the U.S. Department of Energy, Energy Information Administration (1998). They estimated an average carbon price between 2008 and 2010 of over $350 per tonne to meet the Kyoto cap of 7% below 1990 emissions.

[2] A report released by the Council of Economic Advisers, CEA, (July, 1998) presents a lower rate of $23 per tonne under international carbon trade and costless improvements in energy efficiency (above those assumed in the Energy Information Administration, projections). Unfortunately, the CEA does not present the base case of no international carbon permit trade and standard efficiency improvements. See Montgomery (1998) for a critical assessment of the CEA's analysis.

[3] Trade volumes are calculated from the social accounts developed by The Minnesota IMPLAN Group, Inc. The volume of trade is defined as U.S. imports plus U.S. exports.

presence in international markets. The volume of electricity trade in 1993 was $71.5 billion in interstate markets and only $0.8 billion internationally. We show that ignoring the mitigating competitive effect of rising prices in interstate markets (as Li and Rose do) exaggerates supply contractions and underestimates the consumption and welfare costs for the state.

In addition, we show the importance of international price impacts for specific commodities. Crude oil is traded more widely on international markets: $47 billion of international trade versus $33 billion of interstate trade. The international model predicts a significant drop in the price of crude oil under the Kyoto agreement because industrialized countries reduce demand. Domestic producers of crude oil, facing lower wholesale prices, reduce output. Furthermore, international price impacts are important for energy intensive industries because the increase in production by developing countries limits the domestic industry's ability to pass control costs through to consumers.

Section 2 of this study outlines the basic methodology that we employ and identifies key issues specific to analyzing state-level impacts. The specific model structure is presented in Section 3, and key features of the baseline equilibrium are provided in Section 4. Section 5 presents results of the carbon-stabilization scenarios. We offer concluding remarks in Section 6.

2 Methodology

There are three key features of a dynamic Computable General Equilibrium (CGE) model that make it an appropriate tool to analyze carbon abatement policies.[4] First, CGE models have a relatively transparent theoretic structure that captures the entire economy. A consistent global perspective offers advantages compared to partial equilibrium models, which often miss important inter-market relationships and ignore macroeconomic impacts. Second, general equilibrium models are able to analyze large, discrete, policy changes such as the Kyoto commitment to reduce emissions by 32% from baseline estimates. Econometric based models make questionable inferences when shocks are outside the range of historic variation.

The third advantage that CGE models have in the context of carbon policy is that they are calibrated to actual input-output data, ensuring that the relative size and importance of markets are taken into account when tracing impacts through the economy. The focus is on those parts of the economy where the important adjustments take place. Purely theoretic arguments, which are not founded on data, can sometimes become centered on inconsequential and even perverse impacts. The scaling of markets and sectors in a CGE model founded on data often reveals that these impacts are dominated by other (maybe less intellectually interesting) effects.[5]

[4] CGE studies of the impacts of climate policy include Bernstein, Montgomery, Rutherford, and Yang (1999), Harrison and Rutherford (1998), Jorgenson and Wilcoxen (1993), McKibbin, Ross, Shackleton and Wilcoxen, (1999), Manne and Richels (1997), and Bovenberg and Goulder (1996).

[5] See Bovenberg and Goulder (1996), or Boehringer, Pahlke, and Rutherford (1997) for a critical assessment of the possibility of a double-dividend in a calibrated CGE model.

Data characterizing the interrelationships of commodities within the economy are of primary importance in determining costs from carbon abatement policies. Many of the impacts of reducing carbon emissions indirectly increase the cost of production and consumption. For example, regulation on the quantity of allowable emissions from electric utilities results in higher electricity prices. Furthermore, higher electricity prices raise production costs, especially in sectors that use electricity-intensive processes. The Minnesota IMPLAN Group, Inc. (MIG) has developed a Social Accounting Matrix (SAM) that fully tracks the intensities of commodity use in each of the 50 states' production and consumption sectors. The IMPLAN data was augmented by two additional data sources. First, state level energy production and electricity fuel input data from the U.S. Department of Energy, Energy Information Administration (EIA) was used to get a more accurate representation of the states' energy profile. Second, data from the U.S. Department of Commerce (1996), *Commodity Flow Survey*, was used to estimate a state by state bilateral trade matrix.

The SAM used in our model represents a snapshot of the Colorado economy in 1993 along a dynamic growth path. Agents are assumed to be forward-looking and invest to support a growing stock of capital. Interest and growth rates are assumed to determine the balanced dynamic equilibrium, which is consistent with the standard Ramsey growth model (See Lau, Pahlke, and Rutherford [1997] for an overview the Ramsey model and its operation as a computable general equilibrium).

We complete the calibration of the dynamic equilibrium by incorporating in the model growth forecasts made by the Bureau of Economic Analysis (BEA) and EIA.[6] Unlike the steady-state models of economic growth, these projections are flexible and incorporate consensus shifts in the mix of industries and energy efficiency within an individual state and across states. For calibration, these sector-specific output projections are used as constraints on the multi-sector Ramsey model to reveal the factor productivity shifts necessary to meet the projected equilibrium.[7] This new equilibrium, with these productivity shifts, is used as the baseline for policy analysis. We refer to this baseline equilibrium as the business-as-usual (BAU) scenario.

Relative to the BAU, the Kyoto scenario incorporates two impacts on the Colorado economy: an efficiently administered limit on carbon emissions and the changes in Colorado's trade position vis-à-vis other affected economies (including other states and other countries). We use additional information from other models to determine the relative sizes of these exogenous trade shocks. We feel that incorporating these terms-of-trade impacts is a significant contribution. Li and Rose (1995) employ a CGE model to assess the impacts of carbon limits on an individual state, but do not consider movements in external markets. Thus, their results reflect a unilateral reduction in emissions by the state – not the impacts of an international agreement to reduce emissions. The dynamic structure of our model and our incorporation of output and

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[6] U.S. Department of Commerce, Economics and Statistics Administration, Bureau of Economic Analysis, *Regional Economic Information System* (REIS), June 1996. The BEA projections for the energy sectors in each state in total were at odds with the projections made by the EIA for the U.S. as a whole. Because we feel that the EIA projections are more accurate and also because these data are the foundation for the emission profile over the horizon, we scaled the BEA state projections so that when totaled they were equal to the EIA projections for the U.S.

[7] The model does evolve to a steady state once the productivity shifts become stationary.

emissions projections to 2010 and beyond (when the emissions reductions are to be imposed) are additional advantages that our framework offers over the approach taken by Li and Rose.

To incorporate external market impacts, we have built a hierarchical structure of models in which relevant information is passed down from more complete geographic models to more detailed models of a specific region (see Figure 1). Computational limitations preclude a CGE model that provides details for 50 individual states while fully encompassing the world economy. We can, however, decompose the problem into separate models that are consistently linked such that external impacts are incorporated into a detailed state-level model.[8] At the highest level, we use the Multi-Sector Multi-Region Trade (MS-MRT) model of the world to examine the impacts of international carbon emissions agreements under alternative international carbon-trading regimes. MS-MRT incorporates eight regional trade blocks and nine commodities, and it fully tracks the physical flows of energy and their embodied carbon (see Bernstein, Montgomery, Rutherford, and Yang, [1999]; or Harrison and Rutherford [1998] for documentation and results from the MS-MRT model). Because the United States is one of the trade blocks, MS-MRT predicts carbon permit prices and changes in the prices of U.S. imports and exports. Given this information, an open-economy model of the U.S. alone can be run independently of the other regions.

Figure 1 about here

At the national level, the U.S. is divided into five regions and ten industries. This multi-region national (MRN) model is built from an aggregation of 51 separate, balanced IMPLAN SAMs (one for each state and the District of Columbia). As with the state model, the MRN is calibrated to a dynamic equilibrium, which considers the BEA or EIA sector-specific projections. MRN and the state model carry the same production structure, but MRN fully models the multilateral interstate trade equilibrium. The carbon-limit scenarios imposed on MRN include international price impacts from MS-MRT and the price of carbon if international carbon trade is examined. MRN provides an array of regional U.S. results, including interregional price changes and the price of nationally traded carbon permits.

With the interregional and international trade price impacts established, we proceed to look at a state (Colorado in this case) in isolation. One caveat does arise, however, and that is the approximation error created because the state is not a precise replicant of its region. If a model were constructed in which Colorado was its own region, we would arrive at slightly different results from those presented below. Our intention, however, is to illustrate a framework that is flexible and can be used to analyze any state (given that we can not compute a 50-region model of the U.S.). We are willing to sacrifice the precision of computing the exact trade prices for this flexibility.

The scenarios analyzed in this paper are defined in Table 1. Our choice of scenarios is dictated by our primary goal of showing the importance of external market impacts in a state-level model, and our secondary goal of offering a range of impacts for

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[8] The technique of decomposing a conceptually large multi-region model into individually computed SOEs that pass trade prices between one another was employed by Mansur and Whalley (1982) to iterate to a multi-region equilibrium. The key intuition is that external shocks on an open economy are fully transmitted through the terms-of-trade faced by that economy.

Colorado consistent with varying degrees of international carbon permit trade. Scenarios 1 through 3 compare alternative assumptions about external markets, and scenarios 3 through 5 vary the degree of international carbon trade. In all scenarios an efficient administration of the carbon limit is assumed within Colorado, and all rents generated from permit sales are lump-sum distributed to the representative agent.

The first scenario listed is a unilateral commitment by Colorado to cut its emissions to 93% of its 1990 emissions from 2010 into the future. The second scenario includes the national impacts of carbon abatement on domestic commodity markets and carbon permits (but ignores any international market impacts). To maintain consistency, Colorado is endowed with permits equivalent to 93% of its 1990 emissions from 2010 on, in all of the scenarios. In scenarios 2 through 5, however, there is an external buyer willing to pay the predetermined (trade) price for permits. Permit revenues that accrue to the representative agent are always equal to the endowment (or cap) of 15.8 million tonnes of carbon times the price per tonne, and emissions within Colorado reflect the opportunity cost of selling the permit in the external market.

In Scenario 3 we fully incorporate all of the relevant markets for Colorado. The United States limits emissions to 93% of 1990 levels, determining the domestic carbon price, while other Annex B countries meet their limits specified under the Kyoto protocol. Terms-of-trade adjust to the new equilibrium. Developing countries respond to the price changes by concentrating production in energy-intensive sectors. Within the U.S., regional differences induce a reallocation of production and consumption across states.

Scenarios 4 and 5 extend the analysis to allow international carbon permit trade. In these cases the impacts on economic activity in Colorado are smaller, reflecting the purchase of relatively inexpensive permits to maintain emissions somewhat higher than 93% of 1990 emissions. Even the intermediate case of carbon trade between Annex B countries (Scenario 4) seems optimistic in terms of carbon trade given the current infighting among the signatories to the Kyoto agreement. Scenario 5 is offered as a reference case in which the costs of achieving the emissions reduction outlined in the Kyoto agreement are minimized (often referred to as "where" flexibility).[9]

[9] This is not to say that the costs of meeting some level of CO_2 concentration, which is the relevant factor in climate change, are minimized. See Mann and Richels (1997) for a discussion of both "where" and "when" flexibility in achieving concentration goals.

Table 1

Colorado Carbon Abatement Scenarios

Scenario	Description	Terms-of-Trade Impacts: National	Terms-of-Trade Impacts: International	Carbon Trade: National	Carbon Trade: International	2010 Carbon Price ($/Tonne)	2010 Emissions by Colo. (MMT)	2010 Permit Revenues for Colo. ($Billions)*
1. **UNILATERAL**	Unilateral Stabilization by Colorado (7% below 1990 levels)	**No**	**No**	**No**	**No**	**$197 (endogenous)**	**15.8**	**3.1**
2. **DOMESTIC**	Kyoto Stabilization with only domestic price impacts	**Yes**	**No**	**Yes**	**No**	**$231**	**16.3 (endogenous)**	**3.6**
3. **KYOTO_NT**	Kyoto with No Trade in CO_2 Permits Internationally	**Yes**	**Yes**	**Yes**	**No**	**$231**	**16.5 (endogenous)**	**3.6**
4. **KYOTO_AB**	Kyoto Scenario -- International Carbon Trade between Annex B Countries	**Yes**	**Yes**	**Yes**	**Partial**	**$72**	**19.2 (endogenous)**	**1.1**
5. **KYOTO_GL**	Kyoto Emission Reductions Under Full Global Carbon Trade**	**Yes**	**Yes**	**Yes**	**Full**	**$37**	**20.2 (endogenous)**	**0.6**

* We hold the carbon endowment fixed at 7% below 1990 levels, and revenues reflect the value of this endowment (including the sales of carbon in the national or international markets). The fixed endowment maintains consistency across scenarios. It should be noted, however, that this is just one of any number of state level revenue allocation schemes.

** Total global emissions targets are not specified under the current Kyoto agreement. We impose a total cap equal to the total emissions computed for the Kyoto scenario with no international carbon trade. This reflects an increase in emissions by developing countries or 'leakage' given the commitments made by Annex B countries that put their carbon-intensive industries at a competitive disadvantage. The global trade scenario thus reaches the same overall emissions reduction as Kyoto but equalizes marginal abatement costs across all countries.

3 Model Structure

General Structure

The basic structure of our model represents the economy as an intertemporal extension of the standard Arrow–Debreu equilibrium. The household sector maximizes utility subject to endowments of primary factors and available production technologies that transform factors and intermediates into commodities. Production sectors are assumed to be competitive, exhibiting constant returns to scale (except the natural resource extracting sectors). In general, Constant Elasticity of Substitution (CES) functions are used to represent technologies and preferences. A list of the CES parameter assumptions can be found in the Appendix. Dynamically an evolving capital stock is supported by foregone consumption of current output. The model is formulated as a mixed-complementarity-problem using GAMS/MPSGE software (Rutherford [1995], [1998] and Lau, Pahlke, and Rutherford [1997]).

Household Utility (U) is defined by a Constant Elasticity of Substitution (CES) infinite sum of discounted per effective capita transitory utility: [10]

$$U = \left(\sum_{t=0}^{\infty} \left(\frac{1+g}{1+\Delta} \right)^{t} u_t^{\rho} \right)^{1/\rho};$$

where Δ is the effective discount rate, ρ indicates the intertemporal elasticity of substitution ($\sigma = 1/(1-\rho)$), and g is the rate of economic growth. Aggregate temporal utility (or full consumption summed across all individuals) in a given time period is the CES composite of consumption (C_t) and effective leisure units:[11]

$$U_t = (\alpha C_t^{\omega} + (1-\alpha)(\overline{L_t} - L_t)^{\omega})^{\frac{1}{\omega}}.$$

$\overline{L_t}$ is the exogenous endowment of effective labor at time *t*, L_t is effective labor supplied for production, and ω indicates the elasticity of substitution between consumption and leisure. This is scaled by the economic growth factor to convert it into per effective capita units:

$$u_t = \frac{U_t}{(1+g)^t}.$$

[10] For convenience we define the model in terms of per "effective" labor units rather than per capita. Where an effective unit of labor includes a Harrod neutral technical progress factor ($(1+\gamma)^t$). This reconciles the difference between population growth and economic growth. At the steady-state, per capita consumption grows at a rate equal to the rate of technical progress, but there is no growth in the per effective consumption and present value prices fall at the effective discount rate. The effective discount rate (Δ) is not the pure rate of time preference. The pure rate of time preference is given by: $\Delta^* = (1+\Delta)(1+\gamma)^{-1/\sigma} - 1$. This is a discrete time analogue of the model presented by Barro and Sala-I-Martin (Chapter 2, 1995).

[11] Given Harrod neutrality we simply measure labor in effective units and drop the productivity growth parameter: $(\overline{L}_t - L_t) = (\overline{L}_t^* - L_t^*)(1+\gamma)^t$, where $\overline{L}_t^*$ is the actual labor endowment, which grows at the population growth rate.

Over the computed finite horizon (which ends at terminal time period *T*) the representative agent optimally allocates spending between consumption and leisure in each time period. The consumer problem is as follows:

$$\text{Max:} \quad U = \left(\sum_{t=0}^{T} \left(\frac{1+g}{1+\Delta} \right)^{t} \left(\frac{[\alpha C_t^{\omega} + (1-\alpha)(\overline{L_t} - L_t)^{\omega}]^{\frac{1}{\omega}}}{(1+g)^{t}} \right)^{\rho} \right)^{1/\rho}$$

subject to the intertemporal budget constraint:

$$\sum_t C_t p_t = \sum_t w_t L_t + pk_0 K_0 - pk_T K_T .$$

The budget constraint equates the present value of consumption to the present value of income earned in the labor market and the value of the initial capital stock less the value of post-terminal capital.[12]

The representative agent optimally distributes wealth over the horizon by choosing how much output in a given period to consume and how much to forgo for investment. The current period output is defined as the macroeconomic composite commodity (X_t):

$$C_t + I_t = X_t = f(x_t) .$$

X_t is a nested CES composite of commodity inputs to non-government institutions.[13] x_t is the vector of commodities and $f(.)$ is the aggregating nested CES function. The individual commodities in x_t come from the production of firms or commodity imports. For this study the following commodities and corresponding production sectors were included:

- Services (SRV)
- Manufacturing (MAN)
- Agriculture (AGR)
- Coal (COL)
- Crude Oil & Gas Extraction (CRU)
- Electric Utilities (ELE)
- Energy Intensive Sectors (EIS)
- Motor Vehicles (M_V)
- Natural Gas (GAS)
- Refined Petroleum (OIL).

These commodities cover the energy sectors relevant in assessing carbon policy, and the Motor Vehicles sector is broken out as well because of its contribution to personal transportation.

[12] Consistent with a formulation of equilibrium unemployment, the wage is net of the premium paid to workers matched to a job. This is the correct rate at which to measure the labor-leisure tradeoff (w_t equals the marginal benefit of leisure). L_t represents the total effective labor units devoted to the labor market – gross of unemployment.

[13] Included are household and enterprise purchases, but not production intermediates.

Two primary factors are supplied by the household sector: labor, which grows exogenously, and capital. The capital stock depreciates geometrically but can be augmented in each period through an investment activity. First-period capital is fixed and investment is restricted to be non-negative. Capital evolves as follows:

$$K_{t+1} = (1-\delta) K_t + I_t,$$

$$K_0 = \overline{K}, \text{ and}$$

$$I_t \geq 0.$$

Our method for approximating the infinite time horizon begins from the observation that an optimal solution over the infinite horizon may be decomposed into two distinct optimization problems, the one defined above over the period $t = 0$ to $t = T$ and a second over the interval $t = T+1$ to $t = \infty$. The two subproblems are linked through the capital stock in the period $t = T+1$. The challenge is to specify the value for $\overline{K}_{T+1}$. It might seem natural to impose the long-run, steady-state level, but in that case the model horizon should be sufficiently long to eliminate terminal effects. Instead, we include the level of post-terminal capital as a variable and add a constraint on the growth rate of investment in the terminal period:

$$\frac{I_T}{I_{T-1}} = \frac{C_T}{C_{T-1}}.$$

This constraint imposes balanced growth in the terminal period but does not require that the model achieve steady-state growth. The advantage of this is that we do not need to determine a specific target capital stock nor a terminal period growth rate.[14] This is shown to be a reliable and accurate technique for approximating the infinite horizon solution (see Lau, Palhke, and Rutherford [1997]).

Adjustment Dynamics

Under typical assumptions about intertemporal elasticities of substitution, the above formulation of a Ramsey optimal growth model results in a rapid convergence to the steady state. Traditionally, modelers have slowed adjustments through ad hoc absorptive capacity or liquidity constraints, or quadratic adjustment costs. As an alternative, we incorporate adjustment costs based on an explicit specification of available technologies or preferences. Currently we model adjustment costs through a partial putty-clay production structure and equilibrium unemployment.

Unemployment results when some portion of labor supplied by the representative agent is not matched to a job. The model incorporates a reduced-form representation of equilibrium unemployment based on a job-matching technology (see Balistreri [2000]). Specifically, a technology that exhibits participation externalities transforms supplied labor into labor that is realized in production. The labor market equilibrium is one in which the value of labor supplied is greater than the wage bill paid by firms. This difference is devoted to the matching process (or alternatively lost to unemployment). The appealing property of the formulation is that it captures some stylized facts about

[14] The model is formulated as a system of inequality equations and complementary slackness conditions consistent with the underlying optimization problem (Rutherford [1995]). The terminal constraint can be added directly to this system. It is non-integrable, however, and does not translate into the underlying optimization problem.

labor markets – the cost to an individual of participating in the workforce falls as the ratio of the vacancy rate to the unemployment rate increases. Thus, the model captures many features of the business cycle without incorporating theoretically questionable behavioral assumptions or ad hoc market constraints.

The second method for incorporating adjustment costs is a partial putty-clay production structure. Capital that is in-place at the start of the horizon is sector-specific and has fixed input coefficients. Any production that utilizes the original capital must use other factors in a set of fixed proportions. New capital that replaces depreciated capital or augments the stock to support growth is malleable; that is, it can be designed to use inputs in a combination that satisfies a general nested CES production function. This formulation is both appropriate and realistic. One relevant example for this study is the degree to which fuel use might be reduced per unit of personal transportation service (Vehicle Mile Traveled [VMT]). New cars might have any range of efficiencies that are dictated by the amount of capital embodied in design and equipment. In contrast, vehicles that are already produced and operating at the start of the horizon have a fixed efficiency, and fuel use reductions are only realized through a decrease in utilization. Whether for personal transportation or production, the capital investment (or lack of investment) necessary to substantially change the overall input mix is large in the short run. This contributes substantially to adjustment costs and results in plausible adjustment dynamics in the model.

In addition to labor and capital, there are primary resource factors specific to the extraction of crude oil and natural gas (CRU), and coal (COL). In these sectors there is no putty-clay formulation, but all other inputs are used in fixed proportion to one another and then substituted against the specific resource input. This operationalizes the decreasing returns associated with natural resource extraction. Given the inelastically supplied resource, an elasticity of substitution between it and the other inputs is used to calibrate responses to an exogenously specified time-varying elasticity of supply along the baseline.

Production and Preference Nesting

A nested CES structure is employed for production in the non-resource extraction sectors that utilize new vintage capital. The CES process combines material (intermediate) inputs of non-energy commodities with a capital-labor-energy composite. The structure of the production nesting is presented in Figure 2, where *j* indexes one of the eight non-extraction sectors. Elasticity settings are presented in the Appendix. At the bottom level of the energy nest, coal and gas have substitution opportunities (defined by the parameter ECG). Then there is an opportunity to substitute between the coal-gas composite and oil. Finally, composite sector-specific energy is the combination of electricity and the fossil-fuel composite. Capital and labor can be substituted against energy. Material inputs enter production in fixed proportions.[15] The production nesting is intended to reflect the fuel substitution that might result from carbon abatement.[16]

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[15] Materials include SRV, MAN, AGR, EIS, CRU, and for completeness any inputs from M_V. CRU does not enter the energy nest because it is assumed that it must be refined and distributed through the OIL or GAS sector before it can be used as a fuel.

[16] In addition to the "putty" and the "clay" processes for generating electricity a benchmark non-fossil process is included. This allows for a more accurate representation of physical heat rates (BTUs of fuel

Figure 2 about here

For household consumption a different nesting is employed to represent consumer tradeoffs and utility. Figure 3 shows the nesting structure for the consumption composite. At the bottom level consumers can choose between different energy inputs (excluding gasoline). Energy is then combined with a Cobb-Douglas aggregate of other goods and services consumed by households. At the top level the composite of energy and other consumption is combined with personal transportation or VMT.

Figure 3 about here

Trade Structure

The basic Ramsey model is further extended to an open economy with interstate and international trade. We employ an intertemporal balance-of-payments constraint that dictated no change in net indebtedness over the horizon. Capital markets are otherwise unrestricted. Trade is specified such that all goods (except for Crude Oil) are differentiated by their origin; this is the popular Armington formulation (Armington [1969]).[17] An Armington aggregate good, which is either consumed or used as an intermediate in production, is the CES composite of imports of the good from outside the U.S., imports from five U.S. regional markets, and finally goods produced locally (within the state). Similarly, a constant elasticity of transformation was defined between output destined for home consumption and output destined for one of the other six possible markets.

The logic of decomposing the trade equilibrium into endogenous import demand and export supply functions with exogenous prices is illustrated in Figure 4.[18] Modeling a single geographic region in isolation has computational advantages, but it must be done in a way that carries important external impacts over to the region of interest. Consider an arbitrary home country, which is a large-open-economy with its own export supply function S_0, and facing an export demand function from the rest of the world D_0. It is inconvenient from a modeling and computational perspective that only half of the market is determined by conditions in the home country (we concentrate our discussion on the export market for one Armington good, but the same will hold true for all import and export markets). The export supply function represents the marginal cost of the home country's exports, but the export demand function represents the marginal benefits to the foreign country of the home country's exports. This function cannot be specified without explicitly modeling the foreign country as a trade partner. Most single-country models make the small-open-economy assumption that export demand is perfectly elastic (D_{SOE0} in the figure).

Figure 4 about here

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input to KWH of output) associated with current and future generation. In the benchmark equilibrium, the implied heat rates from the fossil processes are 9200 and 8000 for the years 2010 and 2020 respectively. In aggregate, if we include the non-fossil process, heat rates are 7000 and 6600 for 2010 and 2020 respectively. The non-fossil process evolves according to EIA projections (for current Hydro, Nuke, and Renewable). Capital in this process depreciates and must be covered by maintenance investments. New non-fossil processes which increase the capital to fuel ratio (decrease the heat rate) in aggregate electric generation occur in the putty process.

[17] We assume that crude oil is a homogeneous world good (i.e., the Armington elasticity is infinite).

[18] Again we refer the reader to Mansur and Whalley (1982) for an application of a similar decomposition technique.

In the context of climate policy, the problem with the SOE assumption is deeper than its disregard of the elasticity of export demand (and import supply): a particular scenario is likely to shift not only the home country's supply curve but also the external economy's demand curve. This is illustrated in Figure 4 by the new equilibrium at point B. An OECD-wide policy of limiting carbon emissions may shift marginal cost to S_1, and foreigners, with less income because of their own carbon abatement, might reduce demand to D_1. As an approximation, the SOE assumption of the demand curve D_{SOE0} would result in an equilibrium at point C, which misses both the shift in export demand and the movement along the export supply curve. If we know the new equilibrium price (P_1), however, then a new SOE export demand curve, D_{SOE1}, could be imposed simultaneously with the domestic carbon tax to arrive at the correct equilibrium at point B.

In MRN we model the U.S. in isolation but use the additional information that international prices must coincide with the results from the MRT model. In turn, the Colorado economy is modeled as an SOE but trade prices from MRT and the five regional markets in MRN dictate the position of the perfectly elastic export demand and import supply functions.

Personal Transportation Sector

The importance of gasoline in the U.S. economy dictates a unique structure for modeling the impacts of carbon abatement on personal transportation. Analogous to the capital stock that supports production, a motor vehicle earns rents for its owner as it is combined with gasoline and other support commodities to produce VMT. We consider auto purchases as an investment activity that augments a stock of autos. This is a unique view of the social accounting matrix (SAM) and requires a unique set of adjustments, for although the SAM fully tracks the purchases of autos and gasoline, it does not capture the joint product that they produce – personal transportation. Similar to the calibration of the social accounts to a dynamic equilibrium, assumptions about rates of return and depreciation, the level of investment, and a given benchmark equilibrium trajectory imply a value of capital stock.

First, we need a specification of the personal transportation technology. Figure 5 represents the VMT nesting structure for new vintage vehicles.[19] The primary input tradeoff in Figure 5 is that between the capital embodied in an auto and gasoline. At an aggregate level, the agent faced with higher fuel prices can substitute into new, more effective (efficient) autos. In order to account for this correctly there must be a separate tracking of the number of vehicles and the capital embodied in those vehicles. This approach, while skirting many of the issues related to technologies available to auto makers versus those that are realized in the market, does capture the key aggregate elements of the economy's reaction to policies that affect personal transportation, and is quite appropriate in a representative agent model. At the top level of the nest other insurance and repair services enter VMT in fixed proportions.

Figure 5 about here

[19] Again we employ a partial putty-clay structure for the VMT sector. The initial stock of autos must use fuel in fixed proportions to capital.

Policy Instruments:

To incorporate carbon emissions in the model, a constructed emissions permit is tracked for each of the three fuel inputs (OIL, GAS, and COL). In the BAU equilibrium these permits are not scarce (their price is zero), and the quantity of permits demanded equals the projected baseline emissions. The carbon permit is required at the fuel's point of purchase according to the carbon content of the purchase. Limiting the number of permits available imposes an emissions constraint, and the permit price reflects the marginal cost of abatement. This method of incorporating emissions, via permits, is convenient in terms of providing a number of policy instruments that involve emissions trading or specific wedges between abatement costs across geographic regions or sectors.

4 Business-As-Usual Baseline Equilibrium

As a baseline for comparison of the carbon abatement scenario, we present the Business-As-Usual (BAU) equilibrium. The calibrated dynamic equilibrium is based on the SAM provided by MIG, Inc., and the BEA and EIA forecasts of sectoral growth.[20] We are willing to adopt the BEA (or any other consensus) forecasts as a means of drawing attention to the policy comparison and away from any one model's predictive ability.

Table 2

Baseline Output by Sector ($Billions and Share of Total)

	2000	2005	2010	2015	2020	2025	2030
SRV	149.3	169.3	192.7	216.5	240.0	266.5	298.4
Services	70.5%	70.4%	70.5%	70.7%	70.8%	70.9%	71.1%
MAN	26.9	30.6	34.5	38.5	42.4	46.7	52.1
Manufacturing	12.7%	12.7%	12.6%	12.6%	12.5%	12.4%	12.4%
EIS	20.4	23.8	27.5	31.3	35.1	39.3	44.1
Energy Intensive Sectors	9.6%	9.9%	10.1%	10.2%	10.3%	10.4%	10.5%
AGR	8.1	9.5	10.9	12.2	13.5	14.9	16.6
Agriculture	3.8%	3.9%	4.0%	4.0%	4.0%	4.0%	3.9%
M_V	0.5	0.5	0.5	0.6	0.6	0.7	0.7
Motor Vehicles	0.2%	0.2%	0.2%	0.2%	0.2%	0.2%	0.2%
GAS	0.6	0.7	0.8	0.8	0.9	0.9	1.0
Natural Gas Distribution	0.3%	0.3%	0.3%	0.3%	0.3%	0.3%	0.2%
COL	0.9	1.0	1.1	1.2	1.2	1.3	1.3
Coal	0.4%	0.4%	0.4%	0.4%	0.4%	0.3%	0.3%
CRU	1.9	1.7	1.6	1.5	1.4	1.3	1.2
Crude and Natrual Gas Extraction	0.9%	0.7%	0.6%	0.5%	0.4%	0.3%	0.3%
ELE	2.1	2.3	2.5	2.7	2.8	3.0	3.2
Electricity	1.0%	1.0%	0.9%	0.9%	0.8%	0.8%	0.8%
OIL	0.9	1.0	1.0	1.1	1.1	1.1	1.2
Refined Oil	0.4%	0.4%	0.4%	0.4%	0.3%	0.3%	0.3%
Total	211.7	240.4	273.2	306.4	339.1	375.8	419.7

[20] The BEA growth rates are augmented by 0.7% to be consistent with the EIA data. The overall weighted-average growth rate for the U.S. economy computed from the state-level, sector-specific output projections published by the BEA is extremely conservative relative to the projections that are the basis for the energy data. The Department of Energy growth rates for macroeconomic indicators are at just over 2% for the U.S., whereas the BEA projected output growth of only 1.4%. Colorado is projected to grow faster than the nation, at an average rate of 2.3% (including the 0.7% augmentation) over the horizon to 2030.

Table 2 presents the gross output by sector in the Colorado baseline. The service sector dominates the other aggregate sectors contributing to over 70% of gross output. Agriculture and the energy extracting sectors are also relatively important to Colorado. The general pattern is a growth in the service sector's share of total output and a substantial decline in energy and resource extraction's contribution. All of the sectors grow in absolute except crude and natural gas extraction.

As a measure of overall activity, Table 3 presents macroeconomic indicators. Gross State Product is measured as total factor income (Gross Domestic Product). Consistent with national income accounting, Consumption is measured as net of personal transportation services but gross of auto purchases.

Table 3

Baseline Macroeconomic Indicators ($Billions)

	2000	2005	2010	2015	2020	2025	2030
Gross State Product	121.1	140.1	158.1	177.5	197.1	218.6	244.2
Consumption	65.1	75.4	85.4	96.0	106.8	118.8	131.1
Investment	30.4	34.2	38.9	43.2	46.6	50.8	56.5
Capital Stock	369.1	427.3	490.5	559.4	630.6	699.2	771.9

Baseline emissions for Colorado and the United States as a whole are presented in Table 4. Baseline emissions are determined endogenously in the model given assumptions about carbon content by fuel and implied efficiency improvements over time. For consistency, the baseline for the U.S. model closely matches the baseline from the international model, and is consistent with EIA's aggregate projections. Carbon content and efficiency improvements are transferred directly from the national model to the state model.

Table 4

Baseline Emissions

		2000	2005	2010	2015	2020	2025	2030
Colorado	Emissions(MMT)	21.3	20.9	21.2	21.5	21.9	22.6	23.5
	Cap as a % of Emissions	N/A	N/A	74%	73%	72%	70%	67%
US	Emissions(MMT)	1,633	1,749	1,868	1,954	2,024	2,096	2,171
	Cap as a % of Emissions	N/A	N/A	67.09%	64%	62%	60%	58%

It is interesting to note that, unlike the nation as a whole, emissions in Colorado for 2005 are actually slightly below those for 2000. This reflects a decrease in fuels consumed in Colorado as an endogenous reaction to the baseline projections. Contributing to this pattern are exogenous efficiency improvements, a slow down in the growth of services from 2000 to 2005 in Colorado, and a rapid increase in the price of refined petroleum.

5 Results

The overall impacts over the five scenarios are presented in Table 5. The welfare losses associated with the emissions limits are measured in Equivalent Variation (EV) for the infinite lived representative agent.[21] For reporting impacts on GSP, consumption, and investment the price of consumption in Colorado is used as the temporal numeraire.

Relative to a unilateral commitment by Colorado scenario 2 includes the national commodity price changes consistent with U.S. carbon abatement. Welfare impacts in scenario 2 are significantly higher as Colorado cannot rely on inexpensive imports and income from energy exports. These price increases are also important in determining Colorado's trade position on carbon permits. Colorado has an apparent comparative advantage in carbon permits because its unilateral price is below the U.S. trade price, but Colorado is actually a net importer of permits in the equilibrium. This is because prices of imported intermediates rise and the national market for Colorado's fuel exports shrink. The comparative advantage in carbon is eliminated when we consider the national price changes induced by abatement in other states.

Table 5

Overall Impacts by Scenario

		Permit Price ($/tonne, 2010)	Welfare	Gross Product (2010)	Investment (2010)	Consumption (2010)	CO_2 Permit Exports (MMT, 2010)
1)	UNILATERAL	$197	-0.2%	-1.0%	-8.7%	-0.9%	N/A
2)	DOMESTIC	$231	-0.9%	-1.4%	-3.8%	-1.1%	-0.5
3)	KYOTO_NT	$231	-0.9%	-1.1%	-3.1%	-1.0%	-0.7
4)	KYOTO_AB	$ 72	-0.5%	-0.5%	-0.8%	-0.4%	-3.4
5)	KYOTO_GL	$ 37	-0.2%	-0.3%	-0.2%	-0.2%	-4.4

Consumption and Gross Product show larger impacts in scenario 2, but investment is supported as capital flight is mitigated by the domestic price impacts. In scenarios 1 stable external prices reflect an attractive return on holding claims to production outside Colorado, and capital flows out until the domestic return is equal to the return from holding external exchange. In scenario 2, all of the domestic markets face abatement costs, and therefore offer no haven for Colorado's captial. Limits on capital flight are further reinforced in scenario 3, when foreign price changes are included.

Figure 6 shows the dynamic trajectories for the macroeconomic indicators in scenarios 1 through 3. Looking at investment, capital flight is clearly shown for scenarios 1, and this also has important ramifications for consumption. Although consumption is supported in scenarios 1, because imports are relatively inexpensive, there is a bias away from consuming in 2010 to support the portfolio shift away from home assets. That is capital outflows are financed by trade surpluses.

Figure 6 about here

In trying to quantify the impacts on Colorado it is clear that external price impacts are significant, and the SOE assumption exaggerates investment reactions while underestimating the consumption impacts. Furthermore, welfare impacts are five fold higher when Colorado cannot simply move capital to another state to avoid the costs of

[21] An approximation must be used because the model is only computed for a finite horizon. For a presentation of this approximation, see Harrison and Rutherford (1998).

abatement. In the last panel of Figure 6 we can see that these important differences are maintained despite very similar emissions reductions across the scenarios.

Consistent with what we might expect, correctly specifying interstate trade is much more important then international markets. Colorado will have much closer trade relationships to other state then with other nations. The large difference between scenarios 1 and 2, and the relatively small difference between 2 and 3 highlights our contention that state level modeling warrants an important consideration of state trade effects.

Unfortunately, the tradition is to ignore or downplay trade impacts within a country. In fact, small geographic regions within a country are most closely tied to neighboring regions within the country. Ironically, in regional modeling, it might be more important to specify a reasonable model of trade within a country then across countries. Clearly, in the context of an international and national policy to reduce carbon emissions, state-level models must consider the implied national price impacts.

Table 6

Percentage Change in Output by Sector (2010 and 2030)

		(1) UNILATERAL	(2) DOMESTIC	(3) KYOTO_NT
SRV	**2010**	-2.7%	-1.1%	-0.8%
Services	**2030**	-1.8%	-1.9%	-1.6%
MAN	**2010**	0.9%	0.3%	-0.2%
Manufacturing	**2030**	-3.1%	-3.6%	-3.2%
EIS	**2010**	-3.5%	-3.4%	0.1%
Energy Intensive Sectors	**2030**	-7.9%	-4.9%	-1.6%
AGR	**2010**	-1.0%	-1.4%	-1.3%
Agriculture	**2030**	-6.8%	-2.0%	-2.1%
M_V	**2010**	-13.5%	-12.6%	-12.5%
Motor Vehicles	**2030**	-6.3%	-7.3%	-6.6%
GAS	**2010**	-36.7%	-34.6%	-31.0%
Natural Gas Distribution	**2030**	-44.6%	-40.1%	-36.5%
COL	**2010**	-10.3%	4.7%	-8.2%
Coal	**2030**	-12.7%	6.4%	-11.4%
CRU	**2010**	0.9%	8.8%	-6.5%
Crude and Natrual Gas Extraction	**2030**	0.8%	9.7%	-9.0%
ELE	**2010**	-19.0%	-18.7%	-18.2%
Electricity	**2030**	-21.5%	-16.0%	-15.5%
OIL	**2010**	-30.9%	-36.0%	-27.8%
Refined Oil	**2030**	-42.7%	-43.2%	-34.6%

The importance of trade effects is further emphasized when we look at detailed sectoral results. In Table 6, scenario 1 shows very large impacts on electricity generation (-21.5% in 2030) because utilities within Colorado face high abatement costs and consumers are able to purchase electricity on the U.S. regional markets at the BAU prices. In scenario 2 however, electricity generation is only down by 16% because, although utilities in Colorado face higher marginal abatement costs, national prices for electricity are much higher as other U.S. utilities also face emissions reductions. Other sectors (EIS, AGR, COL and GAS) also have a similar pattern as national price increases in scenario 2 mitigate the competitive disadvantage placed on Colorado industry.

The Crude and Natural Gas Extraction sector also shows significantly different impacts across the scenarios. We treat crude as a homogeneous world trade commodity so to arrive at consistent impacts we must include the world price impacts (scenario 3). Scenarios 1 and 2 produce incorrect qualitative responses because Colorado finds the stable external price of crude an attractive export market. In scenario 3 the decline in the demand for crude on the world market (as each of the Annex B countries limit their emissions) depresses the price of crude and consequently Colorado reduces output.

Figure 7 compares the impacts on macroeconomic indicators and emissions from different degrees of international carbon permit trade. In each case the full set of commodity trade impacts are included. The model produces predictable results as less restricted international permit trade reduces the cost of abatement. It is interesting to note that under Annex B trade (scenario 4) welfare costs are reduced by over a third, and the marginal abatement cost is reduced by over two thirds. Considering that Annex B trade meets the same emissions cap, there is considerable impetus to exploit the gains from trade. Unfortunately, current negotiations seem to be centered on what restrictions should be placed on international permit trade rather then how to establish the institutions to facilitate trade.

Figure 7 about here

Figure 8 shows the gross product impacts in 2010 for each of the 50 states under the Annex B carbon trade scenario. To make interstate comparisons of impacts we adopt a common temporal numeraire from the U.S. model (the price of consumption in the eastern region). For the interstate comparison the change in Colorado's GSP is –0.67% in 2010 which is slightly larger then the change reported in Table 5. This simply reflects a difference in the numeraire. Colorado is ranked 25th hardest hit of the 50 states. States that fare worse then Colorado include the coal supplying states such as Wyoming, West Virginia, Kentucky, and Illinois. Whereas, service oriented states such as California, Florida, and New York suffer smaller losses relative to Colorado.

Figure 8 about here

6 Conclusion

The state-level computable general equilibrium model presented here was shown to be quite sensitive to external market impacts when analyzing a policy with both internal and external constraints on carbon emissions. The small-open-economy assumption is often imposed when external markets are viewed as large enough that policy changes made by a country do not affect its terms-of-trade. It might be tempting to think that the SOE assumption only concerns the relative size of the country (or state in this case) being modeled. In fact, the SOE assumption also restricts the types of experiments that can be modeled. Policies that are not explicitly unilateral cannot be modeled correctly without extending the SOE to incorporate terms-of-trade effects.

It might be true that a limit on emissions in Colorado will not greatly affect the prices of most commodities in the world or even in the U.S., but the converse cannot be true. A global agreement to significantly reduce carbon emissions will have significant impacts on the commodity prices faced by individuals in Colorado. This is true regardless of Colorado's emissions policy.

As a demonstration of our state-level model, we present results for Colorado under three possible implementations of international carbon permit trade under the 1997 Kyoto protocol. Although improbable in light of current negotiations, full international trade in carbon permits can significantly reduce abatement costs and welfare impacts on Colorado.

The overall results highlight the importance of an analysis acknowledging that states may be in fundamentally different positions compared to the nation as a whole. Issues that remain largely unexplored in the literature have dramatic implications. Specifically, how atypical is the state's energy profile (and, as a related issue, what are the state's projected emissions)? In addition, the allocation of permit ownership across states can have significant income effects. Under our allocation based on historical emissions, Colorado receives $3.6 billion worth of carbon permits in 2010 (for the Kyoto scenario with no international permit trade). This represents a significant 2.3% of projected 2010 GSP. Should a permit mechanism be implemented, some allocation of these substantial rents will result. The allocation will likely dictate the sharing of burden across states, industries, and individuals.

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Appendix:

Key Response Parameters

	Consumer Responses	
σ	Intertemporal Elasticity of Substitution	0.50
ω	CES between leisure and consumption	0.87
c_vmt	CES between VMT and Other Consumption	0.60
esub	CES between Energy and Non-energy composite commodities consumed by households	0.50
cons	CES between non-energy commodities consumed by households	1.00
etyp	CES between energy commodities consumed by households	0.50
tech_vmt	CES between auto capital and gasoline	0.30
	Industry Responses (non-resource extraction)	
matsub	CES between KLE composite and materials	0.00
KL_E	CES between Capital-Labor Composite and Energy Composite (Not Electricity)	0.95
	CES between Capital-Labor Composite and Energy Composite (Electricity)	0.20
K_L	CES between Capital and Labor	1.00
ELE_NELE	CES between Electric and Non-electric energy (Not Electricity)	0.20
	CES between Electric and Non-electric energy (Electricity)	0.00
OIL_CG	CES between Refined Oil and the Coal-Gas Composite	0.10
ECG	CES between Coal and Natural Gas	2.00
	Industry Responses (Resource Extraction)	
μSR_COL	Short run elasticity of coal supply	0.40
μLR_COL	Long run elasticity of coal supply (7% convergence rate)	1.90
μSR_CRU	Short run elasticity of crude oil and gas extraction supply	1.00
μLR_CRU	Long run elastictiy of crude oil and gas extraction supply (7% convergence rate)	1.00
	Trade Responses	
ARM_SUB	CES between domestic composite and foreign imports	4.00
DARM	CES between domestic source goods (home good and US regional imports)	8.00
TARM	CET between goods produced for home market, regional exports, and foreign exports	2.00

Figures:

Figure 1: Hierarchical Structure for the State-Level Model

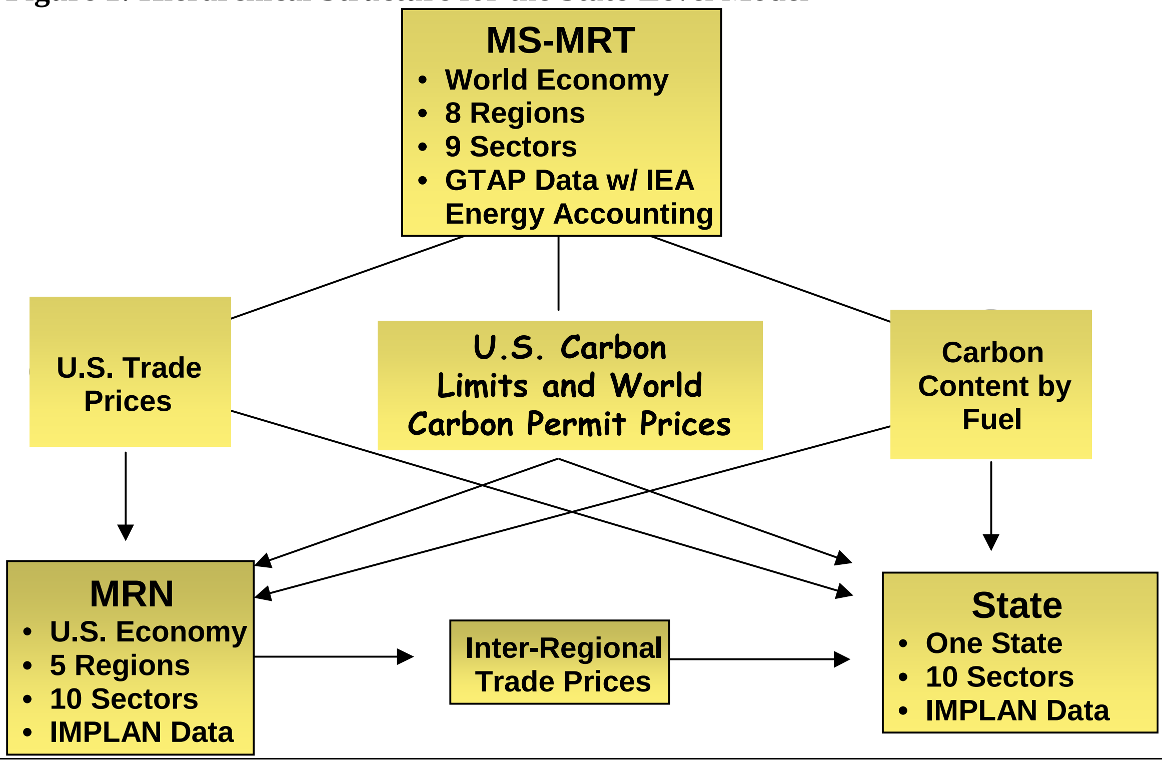

Figure 2: Nesting Structure for Non-primary Resource Sectors

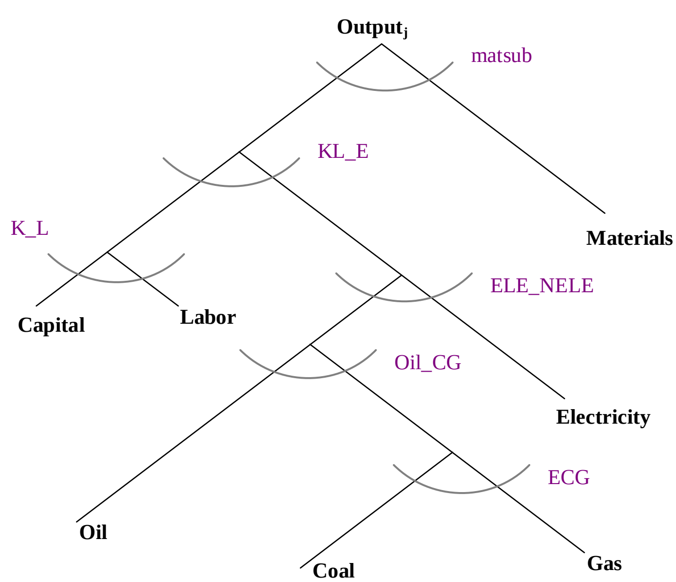

Figure 3: Household Consumption Nesting

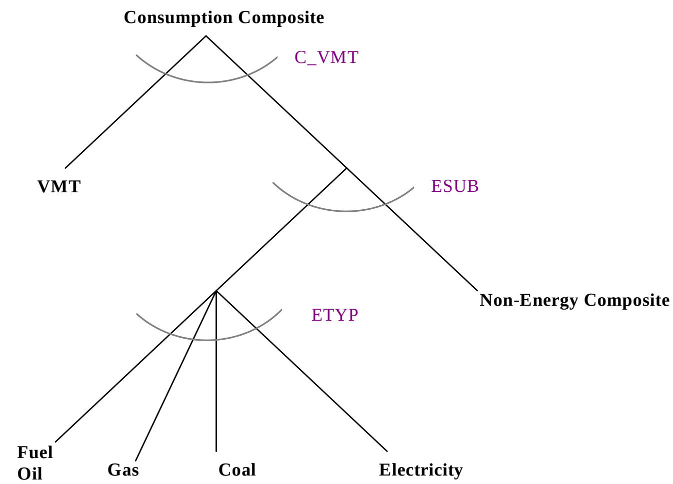

Figure 4: Decomposition of Trade Effects

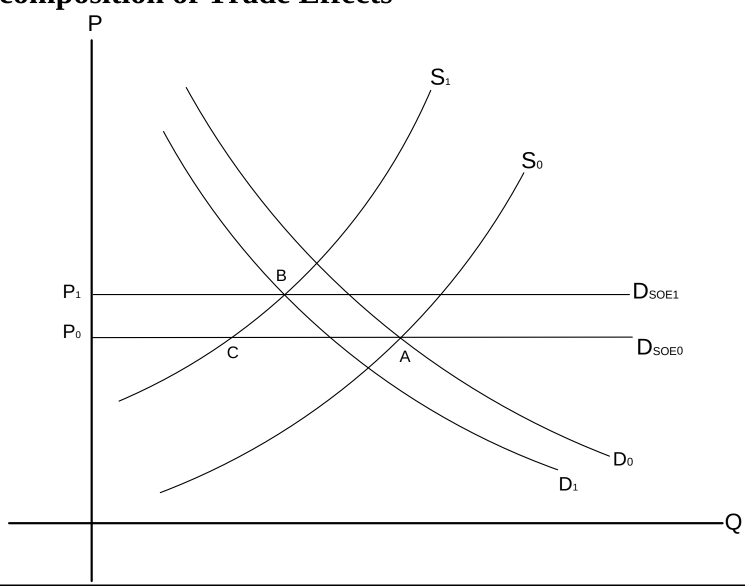

Figure 5: Personal Transportation Nesting

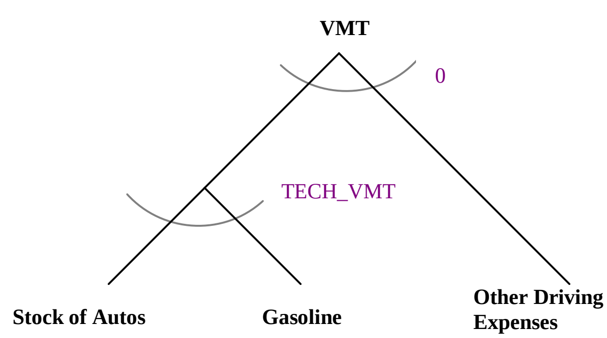

Figure 6: The Impacts of External Commodity Price Changes on Colorado under Kyoto Abatement

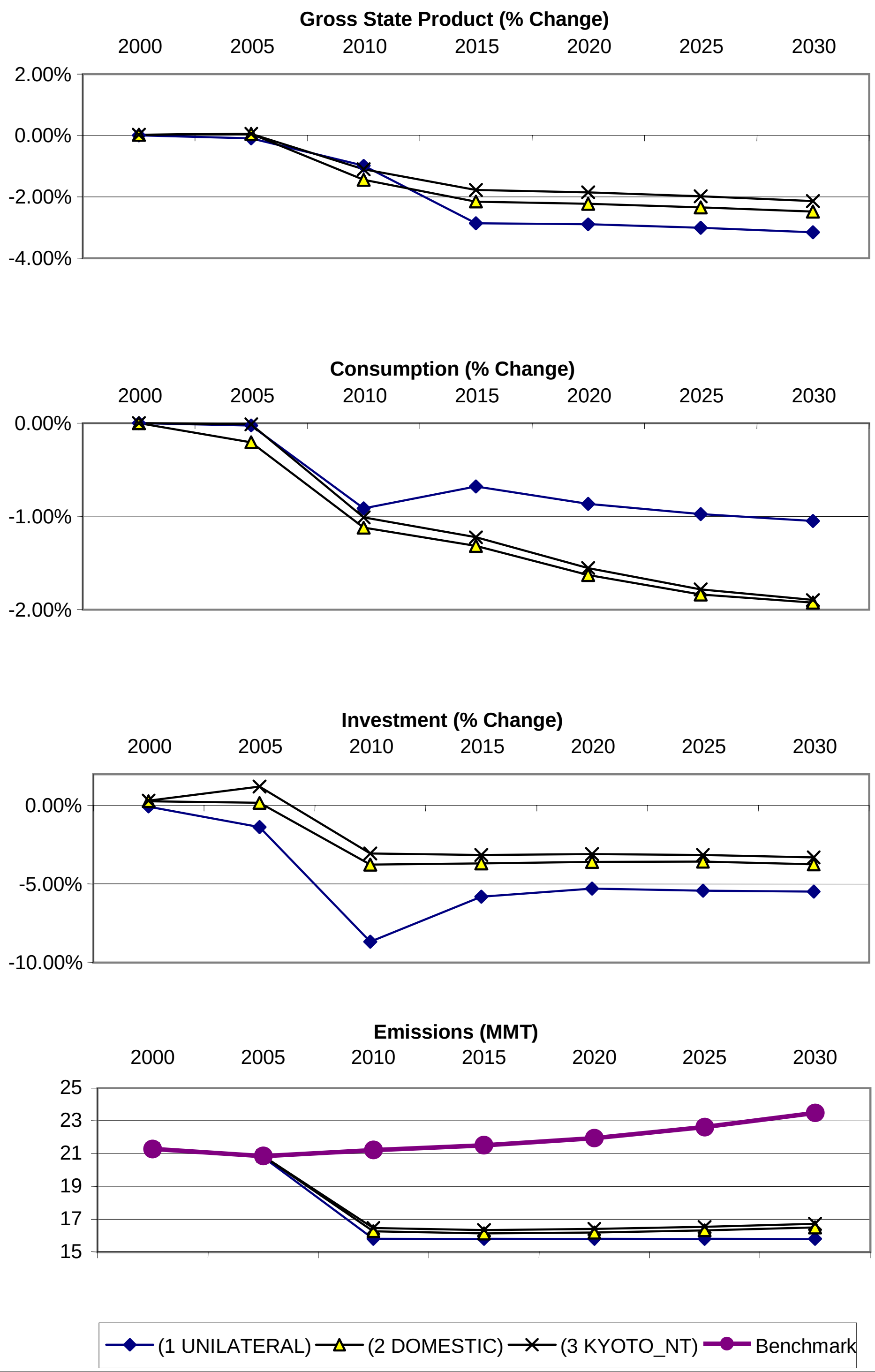

Figure 7: The Impacts on Colorado of International Carbon Permit Trade

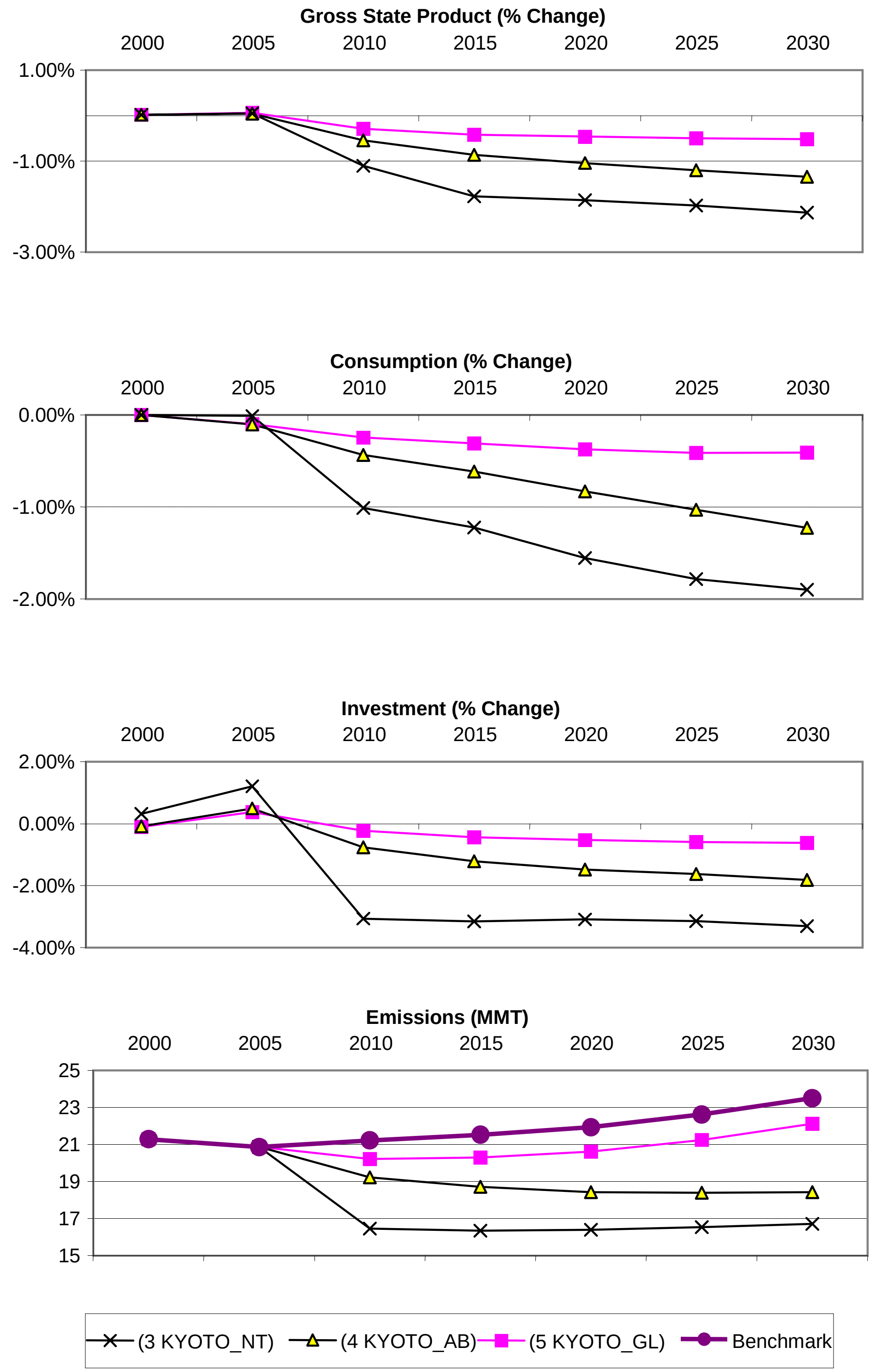

Figure 8: Change in 2010 Gross State Product for 50 States under Kyoto Abatement with International Carbon Permit Trade Among Annex B Countries