doi:10.1111/j.1757-7802.2011.01048.x

Regional macroeconomic assessment of the Pennsylvania Climate Action Plan

Adam Rose, Dan Wei and Noah Dormady

School of Policy, Planning, and Development, University of Southern California, Los Angeles, CA 90089, USA
(Corresponding author e-mail: adamzros@sppd.usc.edu; danwei@usc.edu; dormady@usc.edu)

Received: 27 January 2011 / Accepted: 9 August 2011

Abstract. The Pennsylvania Climate Action Plan (CAP) is the culmination of a formal stakeholder process to specify policies and measures to mitigate emissions of greenhouse gases (GHGs). The implementation of technical and behavioural mitigation options will require changes in the way businesses and government operate, and the way households conduct their daily lives. An important question is whether the sum of all of these microeconomic changes and their interactions will be a stimulus to or a drain on the economy as whole. We apply the Regional Economic Models, Inc. Policy Insight Plus (REMI PI$^+$) model in an innovative manner to analyse the impacts of major GHG mitigation options at the macroeconomic level in Pennsylvania for the policy horizon of 2009–2020. Our results indicate that the net impacts on the state's economy will be significantly positive. We also develop a reduced form econometric model based on the results and subject it to rigorous statistical testing. This is the first time an independent validation of this kind has been applied to the REMI Model in order to verify its simulation results.

JEL classification: R11, R15, Q54, C21

Key words: regional macroeconomic modelling, REMI, model validation, quantile regression, Climate Action Plan

1 Introduction

The Pennsylvania Climate Change Act (Act 70) was signed into law in 2008. A Climate Change Advisory Committee (CCAC) was established immediately after the passage of the bill to facilitate the development of a plan to mitigate greenhouse gasses (GHGs) in co-operation with the Pennsylvania Department of Environment Protection (PA DEP).[1] The ensuing Pennsylvania

[1] Five subcommittees: energy generation, transmission, and distribution; residential and commercial; industry and waste; land use and transportation; and agriculture and forestry, were assigned by CCAC. The tasks of each subcommittee were to identify and provide technical analysis of potential GHG mitigation, sequestration, and offsetting policy actions in its respective sector.

Climate Action Plan (PA DEP 2009) specified a broad set of mitigation options, and, in fact, identified several that result in net cost savings. For example, many electricity demand-side management practices translate into less electricity needed to produce a given outcome, such as running an assembly line or cooling a home, namely, energy efficiency improvements. However, all of the cost estimates of mitigation work plans apply to the site of their application, or what are termed partial equilibrium economic impacts. They do not include broader general equilibrium or macroeconomic impacts. The many types of linkages in the economy and macroeconomic impacts are extensive and cannot be traced by a simple set of calculations. This endeavour requires the use of a sophisticated model that reflects the major structural features of an economy, the workings of its markets, and interactions between them.

The purpose of this paper is to present a methodology for evaluating the macroeconomic impacts of climate policy and to apply it to the evaluation of the Pennsylvania Climate Action Plan (CAP) on the state's economy. We apply, in an innovative manner, the Regional Economic Models, Inc. (REMI) Policy Insight Plus (PI^+) model (REMI 2009), the most widely used state-level macroeconometric modelling software package in the US. The application involves the most extensive analysis of the linkages between individual mitigation options and the workings of a state economy to date. It is based on mitigation data carefully estimated by an extensive stakeholder process. To validate the simulation results we develop a reduced form version of the macroeconomic analysis and test it using multivariate and quantile regression analysis.

Our results indicate that the Pennsylvania CAP will yield positive overall macroeconomic impacts on the state's economy. Greenhouse gas mitigation activities have a wide range of macroeconomic impacts. Whereas some have dampening effects on the economy, others provide significant cost savings through energy efficiency and thereby provide an economic stimulus to households and businesses. Given the range of options available in Pennsylvania, our results show that at the macro level the gains to the economy can exceed the losses. This is especially surprising in a state that contains several major energy sectors and an extensive industrial base. While many analysts have focused on potential losses to these sectors, our analysis has uncovered a strong potential for growth in construction and key manufacturing sectors.

This paper also represents a contribution to the literature by assessing the accuracy of one of the major regional economic analysis and forecasting models in use today. The REMI model has been applied to analyse the total regional economic impacts of climate action plans in more than 10 states and regions of the US, and has been applied to hundreds of other important regional and national policy issues over the course of its history. However, this paper provides the first rigorous multivariate statistical test of its results with respect to the consistency between the model outputs and the direct policy variable changes. REMI and other various regional macroeconomic models have been rigorously evaluated and validated in the literature. To date, our analysis represents a unique addition to this important research. Rickman and Schwer (1993, 1995a, 1995b) conduct extensive evaluations of the REMI model by comparing its multipliers with those of other benchmark multipliers (IMPLAN and RIMS II) to determine the causes of variance in multipliers. Other scholars have conducted error analysis to evaluate REMI model outputs by comparing them with other input-output/econometric integration methods (Rey 1997, 1998). REMI has also been tested for its consistency across regions for equivalent simulations (Cassing and Giarratani 1992). There are also a number of studies in the literature designed to evaluate the predictive accuracy of the REMI model by testing the prediction errors in post-sample period forecasting (Treyz et al. 1991; Cassing and Giarratani 1992). Our analysis moves beyond error analysis to validate, through multivariate econometric analysis, both the explanatory power of the REMI model and consistency of its output with regard to policy variables. This validation method can readily be generalized to many future applications of the REMI Model, as well as other regional macro models.

This paper is divided into 6 sections. Section 2 introduces the REMI Model. Section 3 presents an overview of how we translate the analysis of the CCAC subcommittees' mitigation work plans into REMI simulation policy variables, as well as how the data are further refined and linked to key structural and policy variables in the Model. Section 4 presents the simulation results and the interpretation of results. Section 5 develops a reduced form model that tests the REMI results using multivariate regression. Section 6 provides a summary of the results.

2 REMI model analysis

To conduct a macroeconomic analysis of this scope, including both direct (on-site) effects and various types of indirect (off-site) effects, several modelling approaches are available. These include input-output (I-O), computable general equilibrium (CGE), mathematical programming (MP), and macroeconometric (ME) models. Each of these approaches has its own strengths and weaknesses (see, e.g., Rickman and Schwer 1995b; Rose 1995; Partridge and Rickman 2010). Depending upon the relative importance of various criteria, researchers will choose the approach that provides the best modelling performance, in terms of a balance of various performance criteria, such as accuracy, transparency, manageability and costs. After careful consideration of these criteria, we have selected the REMI PI^{+} Model. The REMI Model is superior to others reviewed in terms of its forecasting strengths,[2] and it is comparable to CGE models in terms of its accuracy and analytical power. Also, it can be made as transparent as any of the other models with careful explanation of the model, its application and its results.

The REMI Model has evolved over the course of 30 years of refinement (see, e.g., Treyz 1993). It is a (packaged) program, but is built with a combination of national and region-specific data. Government agencies in practically every state in the US have used a REMI Model for a variety of purposes, including evaluating the impacts of the change in tax rates, the exit or entry of major businesses in particular or economic programmes in general, and, more recently, the impacts of energy and/or environmental policy actions (see, e.g., Miller et al. 2010).

We simply provide a summary for general readers here. A macroeconometric forecasting model covers the entire economy, typically in a 'top-down' manner, based on macroeconomic aggregate relationships such as consumption and investment. REMI differs somewhat in that it includes some key relationships, such as exports, in a bottom-up approach. In fact, it makes use of the finely-grained sectoring detail of an I-O model, that is, in the version we used it divides the economy into 169 sectors, thereby allowing important differentials between them. This is especially important in a context of analysing the impacts of GHG mitigation actions, where various options were fine-tuned to a given sector or where they directly affect several sectors somewhat differently.

[2] Statistically estimated time series models are best suited to forecasting, but were not among the candidates considered here because our emphasis was on policy analysis. Other widely used policy analysis models include I-O and CGE models. IMPLAN (MIG 2011), the major provider of input-output tables generates static models, which therefore do not have a forecasting capability. Only dynamic CGE models have a projection, but not necessarily a forecasting, ability, and empirical versions at the state level are very rare. In addition, there are very few examples in the literature evaluating the predictive accuracy of the dynamic CGE models. Statistical techniques are extensively used in the equation parameters and response estimations in the REMI model. There are a number of studies in the literature designed to validate the predictive accuracy of the REMI Model (Treyz et al. 1991; Cassing and Giarratani 1992). In these studies, post-sample period forecasts are computed. The predicted values are then compared with the actual values with the prediction error measured by the mean absolute percentage error (MAPE). The evaluations indicated that the REMI model produces very good forecasts over a short period of time beyond the historical data sample. As expected for all forecasting models, prediction accuracy deteriorates as the forecasting period lengthens. Studies also indicate that REMI can predict major changes in the direction of economic activity for larger industries in short-term forecasting (Cassing and Giarratani 1992).

The macroeconomic character of the model is able to analyse the interactions between sectors (ordinary multiplier effects) but with some refinement for price changes not found in I-O models. The REMI PI$^+$ Model also brings into play features of labour and capital markets, as well as trade with other states or countries, including changes in competitiveness.

The econometric feature of the model refers to two considerations. The first is that the model is based on inferential statistical estimation of key parameters based on pooled time series and regional (panel) data across all states of the US (the other candidate models use 'calibration', based on a single year's data).[3] This gives the REMI PI$^+$ model an additional capability of being better able to extrapolate[4] the future course of the economy, a capability the other models lack. The major limitation of the REMI PI$^+$ model versus the others is that it is pre-packaged and not readily adjustable to any unique features of the case in point. The other models, because they are based on less data and a less formal estimation procedure, can more readily accommodate data changes in technology that might be inferred, for example from engineering data. However, our assessment of the REMI PI$^+$ model is that these adjustments were not needed for the purpose at hand. This is because all the selections and specifications of the technological parameters of individual mitigation work plans are undertaken in the microeconomic quantification stage (through the stake-holder and consensus-building process). They are embedded in the estimated costs and savings associated with the implementation of these work plans. Our macroeconomic analysis is built on the results of the microeconomic quantifications.

The use of the REMI PI$^+$ Model involves the generation of a baseline forecast of the economy through 2020. Then simulations are run of the changes brought about through the implementation of the various GHG mitigation options. Again, this includes the direct effects in the sectors in which the options are implemented, and then the combination of multiplier (purely quantitative interactions), general equilibrium (price-quantity interactions), and macroeconomic (aggregate interactions) impacts. The differences between the baseline and the 'counter-factual' simulation represent the total regional economic impacts of these policy options.

3 Input data

3.1 Mitigation options

Through the development of the Pennsylvania Climate Change Action Plan, over 100 GHG mitigation actions covering multiple economic sectors were reviewed by CCAC and PA DEP. Finally, 52 policies and measures, called 'work plans' in the Pennsylvania process, were recommended and approved,[5] among which 42 work plans/measures were analysed in a quantitative manner.[6] Table 1 lists the micro level impacts (GHG reductions and cost-effectiveness)

[3] REMI is the best of the models reviewed in terms of addressing the fact that many impacts take time to materialize and that the size of impacts changes over time as prices and wages adjust. In short, it better incorporates the actual dynamics of the economy.

[4] The model can be used alone for forecasting with some caveats, or used in conjunction with other forecast 'drivers'.

[5] Among the 52 work plans, 28 were approved by CCAC unanimously, 11 with only three or less objections, and 13 with eight or fewer objections or abstentions (PA DEP 2009).

[6] The selection, design, and analysis of the GHG mitigation work plans were performed through an in-depth and consensus-based stakeholder assessment process. This process was fostered by the Center for Climate Strategies, who worked closely with government officials, institutional experts, and members of the stakeholder community. The process combines the traditional facilitated conflict resolution model with expert technical assistance and analysis. A two-level analytical framework is adopted for the development and analysis of mitigation work plans. The first is the 'council' or 'commission' comprised of governor-appointed representatives of groups, interests and parties that have a direct stake in the effects of climate change or efforts to mitigate them. The second level is the multi-sector subcommittees made up of members of the commission plus other individuals with particular expertise in the topic area of the focused economic sectors (see, e.g., Rose et al. 2009).

Table 1. Estimated GHG reductions and costs/savings of the 42 quantified mitigation/sequestration work plans

Work plan no.	Work plan recommendation	GHG reductions (MMtCO2e)			Net present value 2009–2020 (Million $)	Cost- effectiveness ($/tCO2e)
		2020	Percentage of 2020 BAU level	Total 2009–2020		
Ag-3	Management intensive grazing	0.6	0.21	5.5	–387.37	–70.43
Ag-4b	Manure digester implementation support – swine	0.04	0.10	0.23	1.13	4.91
Ag-5a	Regenerative farming practices	0.1	0.02	0.3	17.86	59.53
Ag-5b	Carbon sequestration from continuous no-till	0.4	0.15	2.7	–32.30	–11.96
F-1	Forest protection initiative – easement	0.2	0.06	12.2	70.92	5.81
F-3	Forestland protection and avoided conversion – acquisition	2.1	0.72	22.6	620.43	27.45
F-4	Reforestation, afforestation, regeneration	4.0	1.35	25.9	597.17	23.06
F-7	Urban forestry	3.0	1.01	19.4	1,704.55	87.86
F-8	Wood to electricity	0.3	0.09	1.7	2.95	1.74
F-9a	Biomass thermal energy initiatives – combined heat and power	0.5	0.16	3.0	–159.05	–53.02
F-9b	Biomass thermal energy initiatives – fuels for schools	0.6	0.21	4.0	48.28	12.07
E-3	Stabilized load growth	2.8	0.93	8.2	–254.68	–31.06
E-5	Carbon capture and sequestration in 2014	5.0	1.70	12.6	391.08	31.04
E-6	Improve coal-fired power plant efficiency by 5%	5.4	1.83	55.4	–822.53	–14.85
E-7	Sulfur hexafluoride (SF6) emission reductions from the electric power industry	0.1	0.03	0.7	0.29	0.41
E-9	Promote combined heat and power (CHP)	4.4	1.47	23.2	209.20	9.02
E-10	Nuclear capacity	14.7	4.96	31.0	233.07	7.52
RC-5	Commission buildings	1.5	0.51	9.6	–70.53	–7.35
RC-6	Re-light PA	12.9	4.35	103.2	–4,044.07	–39.19
RC-7	Re-roof PA	1.4	0.49	4.3	1,012.88	235.55
RC-8	Appliance standards	1.9	0.64	12.4	–290.84	–23.45
RC-9	Geothermal heating and cooling	1.4	0.48	8.0	499.75	62.47
RC-10	DSM – natural gas	7.3	2.48	40.5	–357.12	–8.82
RC-11	DSM – heating oil and biofuel for heat	5.7	1.93	35.8	207.57	5.80
RC-13	DSM – water	0.1	0.04	0.8	–1,011.38	–1,264.23

Table 1. *Continued*

Work plan no.	Work plan recommendation	GHG reductions (MMtCO2e)			Net present value 2009–2020 (Million $)	Cost- effectiveness ($/tCO2e)
		2020	Percentage of 2020 BAU level	Total 2009–2020		
Ind-1	Coal mine methane (CMM) recovery	0.6	0.19	6.4	–51.80	–8.09
Ind-2	Industrial NG & electricity best management practices	5.1	1.74	25.3	–972.27	–38.43
Ind-3	Reduce lost and unaccounted for natural gas	0.1	0.05	0.9	–47.57	–52.86
W-1	Landfill methane displacement of fossil fuels	0.1	0.03	0.6	–10.26	–17.10
W-2	Statewide recycling initiative	5.4	1.84	34.4	–258.38	–7.51
W-4	Improved efficiency at wastewater treatment facilities	0.0	0.00	0.0	–3.41	–148.10
W-5	Waste-to-energy digesters	0.1	0.03	0.6	6.97	11.62
W-6	Waste-to-energy municipal solid waste (MSW)	0.2	0.08	1.4	–65.79	–46.99
T-3	Low rolling resistance tyres	0.7	0.23	4.1	–818.34	–199.60
T-5a	Eco-driving 5A PAYD insurance	0.4	0.15	1.8	–665.10	–369.50
T-5b	Eco-driving 5B feebates	0.4	0.14	2.7	–532.83	–197.34
T-5c	Eco-driving 5C driver training	0.6	0.21	4.5	–375.74	–83.50
T-5d	Eco-driving 5E tyre inflation	0.1	0.03	0.6	–90.22	–150.37
T-5e	Eco-driving 5H speed limit reduction	2.0	0.66	23.0	6,790.96	295.26
T-6	Utilizing existing public transportation systems	0.1	0.02	0.6	2,157.51	3,595.85
T-8	Cutting emissions from freight transportation	1.0	0.34	6.7	–956.35	–142.74
T-9	Increasing federal support for efficient transit and freight transport in PA	1.2	0.40	12.9	724.64	56.17
Total		94.7	32.06	570.9	3,019.28	5.29

Notes: Some modifications and updates were made to the original quantifications of some work plans before we undertook the macroeconomic analysis. For example, the original analysis of F-7 Urban forestry included not only energy savings, but also benefits from esthetic, air quality, storm water, etc. into the estimation of the direct savings. In the REMI analysis, we only modeled the energy savings. For another instance, we updated the original quantification of ES-6 'Improve coal-fired power plant efficiency by 5%' by adding the estimation of fuel cost savings yielded by this work plan, which was omitted in the first place.
Source: PA DEP (2009).

of implementing each quantified work plan. In total, they can generate \$8.6 billion net cost savings (net present value in 2007\$)[7] and reduce GHG emissions of 570.9 million tons of carbon dioxide equivalent (MMtCO2e) during the 2009–2020 period. The weighted average cost-effectiveness (using GHG reduction potentials as weights) of the work plans is about \$5.3 per ton of CO2e emissions removed.

3.2 Modelling assumptions

The major data sources of the analysis are the subcommittees' quantification results or their best estimation of the cost/savings of various recommended work plans/policies. However, we supplement these with some additional data and assumptions in the REMI analysis in cases where these costs and some conditions relating to the implementation of the work plans are not specified by the subcommittees or are not known with certainty. These additional assumptions are necessary since, for example, in the micro-quantification only the total amount of capital investment needed for individual work plans are estimated. In the macroeconomic modelling, we need to specify both the source of the investment (private or public) and the economic sectors that would be directly stimulated by the investment. The additional assumptions used in the macroeconomic analysis were made through discussions with the sectoral experts from the subcommittees.

Below is the list of major assumptions we adopted in the analysis:

- Capital investment in power generation is split 60 : 40 between sectors that provide generating equipment and the construction sector for large power plants (such as coal-fired power plants), and 80 : 20 for smaller installations (mainly renewables).
- In all the applicable analyses, we simulated a stimulus from only 50 per cent of the capital investment requirements. This is based on the assumption that 50 per cent of the investment in new equipment will simply displace other investment in the state and that 50 per cent will be additive, stemming from a combination of attracting private investment funds from outside the state and from federal subsidies.
- We assume that any increase in household spending on energy-efficient appliances will reduce the household spending on other commodity categories by the same dollar amount. Similarly, any energy bill savings will enable households to increase their spending on other commodities and services by the same dollar amount.
- For some electricity and residential/commercial (Res/Com) work plans, the energy consumers' participant costs of energy efficiency programmes for the commercial sector and industrial sector are aggregated, respectively. In the REMI analysis, we distributed the total costs for the commercial and industrial sectors among the REMI 169 individual sectors based on the Pennsylvania input-output data provided in the REMI model in relation to the delivery of utility services to individual sectors.
- The original analysis of Electricity 6 (5% efficiency improvement from existing coal-fired plant) only quantified the costs, but not the savings, associated with this work plan. In the REMI analysis, we estimated the savings as avoided fuel cost of coal resulted from the improved efficiency.

[7] There is an extensive literature on market failure in decision regarding energy use, especially why people do not take advantage of cost-saving energy efficiency opportunities. Major reasons include: myopia, inability to process technical information, split incentives (principal-agent issues), and lack of access to capital markets (National Commission on Energy Policy 2004; Sathaye and Murtishaw 2004; Schleich and Gruber 2008).

- For the forestry work plans that include land acquisition, it is assumed that the programme funding comes from the state government budget. It is also assumed that the increased government spending in these forestry programmes will be offset by a decrease in the same amount of government spending on other goods and services.
- For Forestry 7 (Urban forestry), the non-energy benefits, such as aesthetic, storm water, and air quality benefits are not included in the REMI macroeconomic impacts analysis. Also, it is assumed that one-third of the programme funding comes from the state government budget; the other two-thirds will be borne by the commercial sector and residential sector.
- For Transportation 6 (Utilizing existing public transportation systems) and Transportation 9 (Increasing federal support for efficient transit and freight transport in Pennsylvania), potential fuel savings were not counted in the quantification analysis of the work plans. Therefore, the macroeconomic stimulus from energy savings associated with these two work plans are not included in the macro study.
- For Forestry 8 (Wood to electricity), benefits from avoided fossil fuel use were not quantified for this work plan, since wood to electricity was likely to offset very little of the fossil fuel when used for electricity. Therefore, the macroeconomic impacts from the avoided fossil fuel are not included in the REMI analysis.

4 Presentation of the results

The basic results from our REMI model macroeconomic analysis are presented in Tables 2 and 3. These include the macroeconomic impacts from individual Pennsylvania Climate Action Plan mitigation work plans. Table 2 includes the gross state product (GSP) impacts for each work plan for three selected key years, and also provides a net present value (NPV) calculation for the entire period of 2009 to 2020. Analogous results for employment impacts are presented in Table 3.[8]

The NPV total GSP impact for the period 2009–2020 is about $5.05 billion (constant 2007 dollars) with the impacts being negative in 2010 and increasing steadily over the years to an annual high of $2.14 billion in 2020. In that year, the impacts represent an increase of 0.31 per cent in GSP in the state.

Table 2 highlights several important points:

- The macroeconomic impacts of 27 of the 42 work plans are positive, which means implementing these work plans will bring about a positive stimulus to the Pennsylvania economy by increasing GSP and creating more jobs.
- Work plans Res/Com 5 (Commission Buildings) and Industry 2 (Industrial natural gas and electricity best management practices) yield the highest positive impacts on the economy – a total NPV of $4.94 billion; work plan Electricity 9 (Combined heat and power) results in the highest negative impacts to the economy – an NPV of –$3.24 billion.
- Mitigation work plans from the residential and commercial sector and the industrial sector would yield the highest positive impacts on the economy, followed by the work plans from the agriculture sector and waste management sector.

A majority of the work plans generate positive GSP impacts because they are cost-saving. These work plans lower costs throughout all levels of production and increase the purchasing

[8] In contrast to the entries presented in Table 1, a positive number in Table 2 and Table 3 represents a positive stimulus to the state economy (i.e., an increase in GSP or a creation of jobs). A negative number means negative impacts on the state economy (i.e., a decrease in the GSP or a decline in total employment).

Table 2. Gross state product impacts of the Pennsylvania Climate Action Plan

(Billions of fixed 2007$)				
Scenario	2010	2015	2020	Net Present Value
E3	0.00	0.00	0.02	0.01
E5	0.00	–0.03	–0.12	–0.21
E6	0.04	0.10	0.13	0.71
E7	0.00	0.00	0.00	0.00
E9	–0.03	–0.41	–0.94	–3.24
E10	0.00	–0.01	–0.18	–0.14
Subtotal – Electricity	0.00	–0.35	–1.10	–2.88
I1	0.01	0.01	0.01	0.06
I2	0.00	0.25	1.06	2.47
I3	0.00	0.02	0.04	0.12
Subtotal – Industrial	0.01	0.28	1.11	2.66
RC5	0.03	0.31	0.75	2.47
RC6	–0.04	0.28	0.95	1.98
RC7	0.00	–0.04	–0.31	–0.57
RC8	0.00	–0.02	–0.02	–0.10
RC9	0.01	0.07	0.18	0.54
RC10	0.05	0.28	0.35	1.85
RC11	0.13	0.13	0.09	0.98
RC13	0.01	0.05	0.08	0.35
Subtotal – Res/Com	0.17	1.06	2.07	7.50
F1	–0.02	0.00	0.00	–0.07
F3	–0.01	–0.02	–0.03	–0.16
F4	–0.08	–0.10	–0.12	–0.86
F7	0.00	–0.02	–0.06	–0.16
F8	0.00	0.00	0.00	0.00
F9a	0.02	0.12	0.25	0.92
F9b	0.00	0.00	–0.01	–0.03
Subtotal – Forestry	–0.10	–0.02	0.03	–0.37
Ag3	0.00	0.04	0.07	0.27
Ag4b	0.00	0.00	0.00	0.00
Ag5a	0.00	0.00	0.00	–0.01
Ag5b	0.00	0.00	0.00	0.02
Subtotal – Ag	0.00	0.04	0.07	0.27
W1	0.00	0.03	0.06	0.22
W2	0.00	0.02	0.02	0.13
W4	0.00	0.00	0.00	0.00
W5	0.00	0.00	0.00	0.01
W6	0.00	0.00	0.01	0.02
Subtotal – Waste	0.01	0.06	0.09	0.39
T3	0.00	0.06	0.13	0.43
T5a	–0.01	–0.06	–0.34	–0.84
T5b	–0.01	0.00	0.01	0.01
T5c	–0.10	–0.10	–0.09	–0.77
T5d	0.00	0.00	0.01	0.00
T5e	–0.58	–0.11	–0.11	–$1.91
T6	–0.11	–0.12	–0.13	–0.93
T8	0.00	0.07	0.27	0.65
T9	0.10	0.11	0.11	0.84
Subtotal – TLU	–0.72	–0.14	–0.14	–2.52
Summation total	–0.62	0.92	2.14	5.05

Note: A positive number in this table indicates a positive stimulus to the Pennsylvania economy, or an increase in GSP; a negative number indicates a negative stimulus, or a decrease in GSP.

Table 3. Employment impacts of the Pennsylvania Climate Action Plan

(Thousands)			
Scenario	2010	2015	2020
E3	0.0	0.1	0.8
E5	0.0	–0.2	–0.9
E6	0.4	0.9	1.0
E7	0.0	0.0	0.0
E9	–0.3	–3.8	–7.1
E10	0.0	–0.1	–1.7
Subtotal – Electricity	0.1	–3.1	–7.9
I1	0.1	0.1	0.1
I2	0.0	2.8	9.5
I3	0.0	0.2	0.3
Subtotal – Industrial	0.1	3.1	9.9
RC5	0.4	3.9	7.8
RC6	0.6	8.5	13.3
RC7	0.0	–0.2	–1.7
RC8	0.1	0.3	0.4
RC9	0.0	0.2	0.7
RC10	0.7	3.1	3.1
RC11	1.9	1.6	1.0
RC13	0.2	0.7	1.0
Subtotal – Res/Com	3.8	18.0	25.6
F1	–0.3	0.0	0.0
F3	–0.3	–0.3	–0.4
F4	–1.2	–1.4	–1.6
F7	3.0	9.8	15.5
F8	0.0	0.0	0.0
F9a	0.3	1.4	2.4
F9b	0.0	–0.1	–0.1
Subtotal – Forestry	1.4	9.5	15.8
Ag3	0.0	0.5	0.8
Ag4b	0.0	0.0	0.0
Ag5a	0.0	0.0	0.0
Ag5b	0.0	0.0	0.1
Subtotal – Ag	0.0	0.5	0.9
W1	0.0	0.3	0.5
W2	0.1	0.4	0.4
W4	0.0	0.0	0.0
W5	0.0	0.0	0.0
W6	0.0	0.1	0.2
Subtotal – Waste	0.1	0.8	1.2
T3	0.1	0.6	1.2
T5a	–0.2	–1.0	–5.0
T5b	–0.2	0.0	0.2
T5c	–1.7	–1.4	–1.2
T5d	–0.1	0.0	0.1
T5e	–8.4	–4.2	–5.9
T6	0.5	0.3	0.3
T8	0.0	0.7	2.1
T9	1.9	1.8	1.7
Subtotal – TLU	–8.1	–3.2	–6.6
Summation total	–2.5	25.5	38.8

Note: A positive number in this table indicates an increase in employment in Pennsylvania; a negative number indicates a decrease in employment.

power of consumers in Pennsylvania. Overall, these have a stimulating effect on the macro-economy. The savings come from direct reductions in fuel and electricity costs, as resources are used in a more efficient manner. The stimulus effects also come from the increased investment in plant and equipment, the associated multiplier effects with the initial investment, and the payback on initial investment in more efficient technologies. The regional economy is also boosted when more indigenous energy resources are utilized to produce alternative energy to replace fossil fuel energy. In other cases, some work plans result in negative GSP impacts. Even though these policies serve to reduce greenhouse gases, they provide insufficient gains in efficiency to cover the costs associated with their initial investment. In a narrow economic sense, they do not pay for themselves. These also raise the cost of production inputs or consumer goods to which they are related.[9] The negative impacts of some work plans also stem from the fact that the potential future benefits are beyond the study period of this analysis, therefore, those benefits are not counted in the macroeconomic modelling. One example is the F4 Reforestation, afforestation, regeneration work plan. Since the potential future benefit from forestry products (e.g., merchantable timber or bioenergy feedstocks) would most likely be realized well beyond the terminal year (i.e., 2020) of this study, they are not considered in the analysis.

Analogous employment impacts are presented in Table 3. Of the 42 work plans in this analysis, 28 yield positive employment impacts overall. We estimate that in the year 2020 nearly 40,000 jobs (full-time equivalent) are added to the Pennsylvania workforce (or 0.52% increase from the baseline level). This is consistent with findings in the literature that investment in energy efficiency and renewable/alternative energy would result in net gains in jobs, largely because the related economic activities (such as building refurbishment and clean/renewable energy technologies) involve more labour-intensive sectors than the conventional fossil fuel supply sectors (Kammen et al. 2004; Global Insight 2008; Pollin et al. 2009). Because the REMI model presents employment impacts in terms of annual differences from the baseline scenario, these employment impacts are not summed across years, and these results are not cumulative.[10] The simulation results indicate that work plans in the residential and commercial, forestry, and industrial sectors would create more jobs than the mitigation work plans in other sectors.[11]

A comparison between the GSP and employment impacts in percentage terms also indicates a relatively higher gain in the latter. This is because the climate investment tends to stimulate sectors that are relatively more labour-intensive compared with traditional fossil fuel supply

[9] The results for Electricity 9 (cogeneration), for example, can be decomposed into negative and positive stimuli, with the net effects being negative. The negative economic stimuli of this work plan include the increased cost (including annualized capital costs, operating and maintenance costs, and fuel costs) to the commercial and industrial sectors due to the installation of the CHP systems; reduced final demand from the conventional electricity generation (which equals the sum of electricity output from the CHP plus avoided electricity use in boilers/space heaters/water heaters). The positive stimuli include various fuel cost savings (e.g., electricity, natural gas, oil, and other fuel cost savings) to the commercial and industrial sectors from displaced heating fuels for all kinds of CHP systems; increase in final demand to the Construction and Engine, turbine, and power transmission equipment manufacturing sectors; and increase in final demand in Farm (biomass) and Natural gas distribution sectors due to the increased demand of fuels and feedstocks to supply the CHP facilities.

[10] For example, a new business opens its doors in 2009 and creates 100 new jobs. As long as the business is open, that area will have 100 more jobs than it would have had without the business. In other words, it will have 100 more jobs in 2009, 2010, 2011, etc. We cannot say that the total number of jobs created is 100 + 100 + 100 + ... Every year it is the same 100 jobs that persist over time not an additional 100 jobs.

[11] The total GSP and employment impacts presented above represent simple sums of impacts of individual work plans. The REMI model yields slightly higher overall impact results when a simultaneous simulation is performed (in which all the 42 work plans are simulated in one single run). The simultaneous simulation indicates a GSP impact of $3.33 billion and an employment increase of 53 thousand full-time equivalent jobs in Year 2020. The difference in results between the simultaneous simulation and the ordinary sum can be explained by the non-linearity in the REMI Model and synergies in economic actions it captures.

sectors. In addition, a shift from capital to labour is expected when the cost of capital increases stemming from the higher capital costs of clean and renewable energy technologies.[12,13]

The overall results of our analysis are similar to those of some recent regional, national and international studies. Pollin et al. (2009) estimated that the net job creation effect of the American Recovery and Reinvestment Act and American Clean Energy and Security Act can be 1.7 million jobs. In a recent study by Roland-Holst (2009), the impacts of renewable energy deployment and energy efficiency improvements for the California economy, similar to those in the Pennsylvania case, are projected to be a net increase of half a million jobs and an over $100 billion increase in cumulative income by 2050. If we adjust for the relative sizes of the two state economies and the timeline of policy implementation, the results are very similar in percentage terms. Macroeconomic analyses of the climate action plans of Florida and Michigan yield similar positive impacts to the state economies (Rose and Wei 2011; Miller et al. 2010). However, compared with Florida and Michigan, the Pennsylvania Action Plan yields relatively less favourable impacts to the state economy (0.31% increase in GSP in PA vs. 0.66% and 1.1% increases in GSP in Florida and Michigan in the study terminal year, respectively). One major reason is that Pennsylvania uses in-state produced coal to generate large quantities of electricity. Electricity consumption reduction due to various energy efficiency work plans would result in economic activity reductions in the power generating sector, as well as the coal mining sectors in the state. In contrast, nearly 100 per cent of the coal used in the coal-fired electricity generation in Florida and Michigan is imported. This is the major reason why the demand-side energy efficiency options are much less attractive in Pennsylvania than in the other two states. At the international level, Hanson and Laitner (2006) have found energy efficiency improvements and technological change to have positive general equilibrium impacts.

5 Regression analysis

We next perform several multivariate analyses to examine the relationship between the microeconomic analysis results in the Pennsylvania Climate Action Plan and the macroeconomic impacts yielded by the REMI model. This is provided as a validation of the results of the macroeconomic analysis in general and the REMI model in particular.

The dependent variable to be explained by the statistical analyses is the NPV of GSP impacts of individual mitigation work plans. These impacts are the outputs generated by the macroeconomic analysis of REMI, and are shaped by all of the relevant independent variables and their interactions in the macroeconomic modelling (Rose and Dormady 2011). As indicated by the value ‘Y’ in Table 4, the dependent variable has significant variation, and values for individual mitigation options (work plans) in the Pennsylvania CAP range from negative GSP impacts of $3.2 billion, to positive GSP impacts of $2.4 billion. Negative values indicate that the REMI

[12] Nominal wages should increase with overall expansion in the economy. However, the net expansionary effect induced by the 42 PA mitigation work plans we analysed in the study in terms of GSP is less than 0.5 per cent. While the relative capital cost increase caused by the mitigation work plans is about 1 per cent. As capital becomes more costly, the overall substitution effect is from capital to labor.

[13] Analysis on sectoral impacts shows that the impacts of the various mitigation work plans vary significantly by sector of the Pennsylvania economy. One would expect producers of energy efficient equipment to benefit from increased demand for their products, as will most consumer goods and trade sectors because of increased demand stemming from increased purchasing power. The top five positively impacted sectors in terms of the NPV of GSP are, in descending order, Real estate, Transit and ground passenger transportation, Waste collection; waste treatment and disposal and waste management, Offices of health practitioners, and Monetary authorities, and credit intermediation. One would expect electric utilities related to fossil fuels, to witness a decline. In fact, the Electric power generation, transmission, and distribution sector is expected to have the largest negative impact by far – $7.38 billion (NPV). Other negatively affected sectors in descending order of impacts are Petroleum and coal products manufacturing, Natural gas distribution, Coal mining, Water, sewage, and other systems, and Pipeline transportation. However, none of these sectors is expected to have a decline of more than $0.4 billion.

Table 4. Descriptive statistics

Variable	Mean	Standard deviation	Minimum value	Maximum value
*Y**	120.06	996.23	–3237.97	2475.00
*X**	71.89	1381.92	–4044.07	6790.96
ES	0.14	0.35	0	1
RCI	0.26	0.45	0	1
TLU	0.21	0.41	0	1
AFW	0.38	0.41	0	1
CONST	0.28	0.46	0	1
MFG	0.48	0.51	0	1
GS	0.21	0.42	0	1
CR	0.35	0.48	0	1

Note: *All values in millions of 2007 dollars.

Model predicts that the mitigation work plan will incur negative impacts on Pennsylvania GSP, and positive values indicate positive GSP impacts.

The main explanatory variable, indicated by 'X' in Table 4, is the direct net cost of a GHG mitigation work plan. These values are produced from technical working groups (or subcommittees) represented by sector-specific stakeholders in Pennsylvania. A positive value indicates that the technical working group has concluded that the option will result in a direct net cost and a negative value indicates that the direct effect of the option will be cost saving. Table 4 indicates that these direct net costs vary widely between work plans. Although the simple average of direct net costs among work plans is positive (cost incurring), a majority of work plans (55%) have negative direct costs (i.e., cost saving).

It is important to note that there may be wide variability between macroeconomic outputs (Y) and direct net costs (X). For the 42 mitigation work plans included in this multivariate analysis, there is an overall high (negative) correlation between these two sets of values (Rho = –0.52). That is, for the most part, those work plans that are assessed to be cost saving by subcommittees are likely to result in positive GSP impacts from the macroeconomic analysis, while cost-incurring options will typically have the opposite effect on GSP. Also, higher cost-saving work plans are likely to result in higher positive GSP impact, while work plans with larger direct net cost tend to lead to bigger negative GSP impact.

However, this is not always the case. For the exceptions, complicating macroeconomic effects are occurring. For example, the work plan Electricity 9, Combined heat and power (CHP), was assessed to have a slightly positive cost (cost incurring) direct effect of $209 million, but its macroeconomic impact was estimated to have the largest overall negative impact on GSP of $3.2 billion. Residential 6, 'Re-Light Pennsylvania', which is aimed at energy efficiency improvements in residential and commercial buildings, was identified by stakeholders to have some of the most significant GHG reduction potentials. This mitigation work plan was estimated to have a direct negative cost (cost-savings) of over $4 billion, but the results indicated only a smaller positive GSP impact of $1.9 billion, primarily due to reductions in the production of fossil-based electricity it engenders.

Between these two work plans, the variability of outcomes arises from various macroeconomic relationships that are picked up by the REMI model. Macroeconomic effects, which ripple throughout the state economy, take place as price changes, input substitutions, investment requirements, and demand shifts in one sector of the economy affect prices and output in directly and indirectly related sectors of the economy. Combined heat and power systems require significant upfront capital expenditures, which increase the capital cost of the commercial and industrial sectors that install the CHP systems. However, these investments in turn stimulate demand in other production sectors. Likewise, cost savings from energy efficiency improvements increase demand in other sectors, as the upfront capital costs of efficiency improvements are quickly recouped by decreases in consumer expenditures on electricity. Also, a related tradeoff occurs from these efficiency improvements, as they lead to decreased demand from the utilities sector.

The remaining sets of explanatory variables are included mainly for statistical control and also help explain sector-specific impacts. 'ES' indicates that the work plan is from the energy supply sector, 'RCI' from the residential, commercial and industrial sector, 'TLU' from the transportation and land use sector, and 'AFW' from the agriculture, forestry and waste management sector (this is used as the reference sector and excluded from Model 3; instead in Model 3 an intercept term is included). These variables are all binary (dummy) variables.

Four additional explanatory variables are also included in this analysis in binary form. The first two relate to the capital investment associated with the work plan. 'CONST' indicates that the work plan involves a capital investment in construction (e.g. building a new power plant). 'MFG' indicates that the work plan represents a capital investment in equipment or appliances manufacturing. 'GS' indicates that the work plan receives a state government subsidy.[14] And finally, 'CR' indicates that the work plan results in consumer consumption reallocation, such as reducing spending on electricity, gas, and other fuels, and increasing consumption in energy-efficient appliances and other consumption categories. The variable values are presented in Appendix Table A2.

Because of the significant variance in both Y and X, some of the key assumptions of the classic linear regression model are more closely achieved through a minor transformation of the data, specifically a cubic root transformation of both of these terms. This enables us to retain Gaussian parameterization across our dependent variable, lessen any statistically-significant heteroscedastic error variance,[15] retain the full range of estimation across both positive and negative values (which is not possible with logarithmic transformation), and add four interaction terms. The cubic root of direct net costs (X) is placed in a multiplicative interaction term with each of the four aggregate sectors of the climate action plan (ES, RCI, TLU and AFW). This allows us to assess the marginal impact of direct costs associated with each subgroup's GHG mitigation work plans. The functional form of our preferred estimating equation is:

$$\sqrt[3]{Y} = \beta_1 \sqrt[3]{X} * ES + \beta_2 \sqrt[3]{X} * RCI + \beta_3 \sqrt[3]{X} * TLU + \beta_4 \sqrt[3]{X} * AFW + \beta_5 ES + \beta_6 RCI + \beta_7 TLU \\ + \beta_8 AFW + \beta_9 CONST + \beta_{10} MFG + \beta_{11} GS + \beta_{12} CR$$

where:

Y: NPV of the GSP impacts of a work plan
X: NPV of the direct net cost of a work plan
ES: Energy Supply work plan
RCI: Residential, Commercial, Industrial work plan
TLU: Transportation and Land Use work plan
AFW: Agriculture, Forestry, and Waste Management work plan
CONST: Capital investment on building constructions, which has stimulus impacts to the local construction sector
MFG: Capital investment on equipment, which has stimulus impacts to the machinery and equipment manufacturing sectors
GS: Work plan that receives state government subsidy (assuming government spending decreases by the same amount elsewhere)
CR: Work plan that results in consumer consumption reallocation.

[14] A key assumption of our REMI analysis is that state government spending is assumed fixed and exogenous. This means that if a policy option receives a government subsidy, government expenditure is offset elsewhere.
[15] The critical value for a Breusch-Pagan/Cook-Weisberg test of our transformed model (Model 2) is 0.41 (P > 0.52).

Table 5. Regression analysis

	Model 1	Model 2	Model 3				
	OLS	OLS	Q(0.10)	Q(0.25)	Q(0.50)	Q(0.75)	Q(0.90)
$\sqrt[3]{X}$	–0.53***						
	[–4.45]						
$\sqrt[3]{X} \times TLU$		–0.44***	–0.33***	–0.36	–0.60***	–0.24**	–0.35***
		[–3.69]	[–4.73]	[–1.59]	[–4.09]	[–2.61]	[–4.09]
$\sqrt[3]{X} \times ES$		–1.54***	–1.98***	–2.1***	–1.31***	–1.33***	–2.17***
		[–6.00]	[–13.37]	[–4.41]	[–4.16]	[–6.75]	[–11.92]
$\sqrt[3]{X} \times RCI$		–0.58*	–1.08***	–0.95***	–0.33	–0.59***	–0.45***
		[–2.11]	[–12.53]	[–3.40]	[–1.79]	[–5.09]	[–4.23]
$\sqrt[3]{X} \times AFW$		–0.22	–0.17	–0.28	–0.29	–0.21	–0.32*
		[–0.98]	[–1.40]	[–0.70]	[–1.14]	[–1.31]	[–2.11]
ES	–4.35	–5.52*	–7.71***	–9.64**	–3.29	–4.82**	–1.39
	[–1.33]	[–2.23]	[–7.20]	[–2.80]	[–1.45]	[–3.37]	[–1.06]
RCI	3.54	1.61	–2.61*	–3.26	4.62*	4.41**	3.66**
	[1.50]	[0.57]	[–2.39]	[–0.93]	[–1.99]	[3.03]	[2.73]
TLU	1.41	1.32	2.56*	2.05	0.95	3.01*	1.27
	[0.54]	[0.64]	[2.49]	[0.62]	[0.44]	[2.19]	[1.01]
AFW	1.23	0.34					
	[1.02]	[0.30]					
CONST	2.89	5.60*	7.13***	5.57	4.36*	5.33***	5.93***
	[1.32]	[2.53]	[7.21]	[1.75]	[2.08]	[4.04]	[4.87]
MFG	1.47	2.43	–0.52	2.87	1.85	2.07	3.33**
	[0.77]	[1.37]	[–0.63]	[1.10]	[1.07]	[1.90]	[3.32]
GS	–4.74*	–5.01*	–6.14***	–6.08	–2.85	–4.48*	–1.30
	[–2.39]	[–2.41]	[–4.73]	[–1.46]	[–1.03]	[–2.58]	[–0.81]
CR	–1.96	–2.43	–6.81***	–6.58*	–0.80	0.41	–2.37*
	[–1.09]	[–1.46]	[–8.09]	[–2.43]	[–0.45]	[0.37]	[–2.28]
INT			–1.93*	–1.13	–0.08	1.20	2.06*
			[–2.61]	[–0.47]	[–0.05]	[1.21]	[2.25]
R^2	0.62	0.72					
F	21.25***	16.84***					
N	42	42	42	42	42	42	42

Notes: * p < 0.05, ** p < 0.01, *** p < 0.001. T values in brackets. OLS Model t-values based on White's robust standard errors. Model 3 quantile regression output produced using Project-R software. Model 3 standard error calculation method is 'iid'.

Table 5 provides the results of our multivariate statistical analysis. We ran both a reduced form model (Model 1) and an extended model (Model 2), which includes interaction terms to evaluate the individual sectoral impacts of the direct net costs associated with GHG mitigation work plans. Furthermore, our assumption that the regression coefficient for each sector is statistically distinct from the sectors in the aggregate is affirmed. Comparing across these interaction terms, one can see that the energy supply sector has the largest absolute impact on the macroeconomic impacts compared to the other sectors and the aggregate. Cost-saving (cost-incurring) work plans associated with the energy supply sector result in larger positive (negative) GSP impacts because of the nature of electricity supply policy options. These options result in either large costs or cost savings to both the energy sector and related manufacturing and construction sectors, which have large multiplier effects on the Pennsylvania economy.

Overall, Model 2 has strong summary and fitness measures, as indicated by large R-squared and F-statistic values. The model explains over 70 per cent of the variance in the dependent variable. Of note is the exclusion of an intercept term in both ordinary least squares (OLS) models. Exclusion of an intercept term for these models is warranted, because the dependent variable is the rate of change in GSP given policy changes within the state. We assume that, prior to any GHG mitigation/sequestration policies, the state economy is in equilibrium, and there would be no change in the trajectory of GSP overall, except from exogenous and stochastic events beyond the scope of this analysis.[16]

Among sectoral coefficients, the strongest and most statistically significant impacts come from the energy sector itself. Its coefficient indicates that its macroeconomic impacts are nearly 500 per cent larger than other sectors. This sector also has the largest marginal impact of direct costs, and by comparison between Model 1 and Model 2, it is approximately three times larger than the expected direct net cost impact of all sectors combined. The AFW and TLU sectors have the smallest macroeconomic impacts overall, and the direct net cost of TLU sector work plans is highly statistically significant.

The coefficient estimates of the two capital investment variables, investment for construction and investment in machinery and equipment, are both positive, and construction investment is statistically significant. Simulating capital investment change in REMI involves two aspects: the increase of the capital cost of the sectors that take the mitigation actions and the increase of the final demand in the construction and machinery and equipment manufacturing sectors. In general, the former yields negative impacts to the economy, and the latter yields positive impacts. The positive signs of the two capital investment dummy variables indicate that the positive effects are expected to exceed the negative effects in PA.

The estimated coefficient of GS is −5.01. The negative sign indicates that, holding all the other variables fixed, if a mitigation work plan involves state government subsidies, its overall impact on GSP is expected to decrease by −\$125.8 million, or -5.01^3. In REMI, the state government subsidy is simulated in two aspects. The stimulus effects are due to the sectors that receive the government subsidy and the dampening effects are due to the decrease of the same amount of government spending elsewhere. The negative sign of this variable indicates that in PA, it is expected that the stimulus effects of directing government subsidy to the mitigation work plans cannot in general offset the dampening effects associated with the decreased government spending in other areas.

We also chose to take the multivariate analysis one step further by evaluating the data through quantile regression techniques (Koenker and Hallock 2001; Koenker 2005; Rose and Dormady 2011). Quantile regression provides an additional window into the behaviour of the data, as it allows for an analysis of marginal effects of explanatory variables beyond the mean of the dependent variable. Whereas ordinary least squares estimation evaluates all variables for their impact on the dependent variable at the mean of the dependent variable, quantile regression enables us to evaluate those variables at conditional locations along the distribution of the dependent variable. Rather than simply evaluating the impact on the mean of the dependent variable of a one unit change in an independent variable, we can evaluate that one unit change on any quantile of the dependent variable (e.g., median, min, max). Table 5 (Model 3) provides the results of quantile regression analysis at the 10th, 25th, 50th (median regression), 75th and 90th quantiles of GSP impacts. This further step in analysis allows us to see the marginal impact of our explanatory variables differently between those work plans that result in positive GSP impacts and those that result in negative GSP impacts.

[16] Exclusion of the intercept term allows us to easily interpret coefficients because we can include all sectors of the economy, rather than exclude one as the reference category as we do in Model 3. We test for any potential coefficient bias due to intercept suppression, and find it to have very minor impacts that do not outweigh the benefits of easily interpreting the reference category.

The quantile regression results provided in Table 5 were generated using the statistical package known as 'R'. Although the same model in Stata (StataCorp, College Station, TX, USA) generated highly robust standard errors, we provide the R outputs because we believe that the standard error calculation method for R is more accurate.[17] One benefit of quantile regression models is their ability to adjust for over-sampling that may not be picked up by OLS models. However, because we used cubic root transformation of our main dependent and explanatory variables, observations are tight about the mean. As such, the OLS results of our cubic transform model (Model 2) are robust to quantile regression techniques.

Quantile regression plots are provided in Figure A1 in the Appendix. Within Figure A1, there is a separate quantile plot for each explanatory variable, plus the intercept term, plotted at each value of the quantile model. The horizontal line through the center of each figure represents the mean value that would be predicted by OLS regression, and deviations from that line at different quantiles show any over/under sampling between the two modelling techniques. Given this, because of the cubic transformation, which has a larger impact on higher values, nearly all quantile estimates fall within the OLS confidence intervals (the upper and lower horizontal bounds in Figure A1). Again, this indicates that OLS regression (Model 2) is robust to quantile regression techniques and provides statistically similar parameter estimates at nearly all quantile values. Note, the interaction term labels in Figure A1 exclude mathematical symbols, and therefore, for example, 'crxtimes' indicates the cubic root of X multiplied by each respective sector.

Consider the multiplicative interaction term $\sqrt[3]{X} \times RCI$ between the cubic transform of direct net costs (X) and RCI (residential, commercial and industrial work plans). As the costs of RCI work plans increases, the magnitude of the impact of those costs decreases from lower quantiles of the dependent variable to higher ones. As expected, the marginal GSP impact of the cost of RCI work plans reduces by more than half (−1.08 versus –0.45) between those work plans having GSP impacts that are the most detrimental to the state's economy and those that are the most stimulating to the state's economy.

Put another way, there are a wide range of impacts from building efficiency improvements, some of which, despite capital outlays, result in overcoming negative impacts to the state's economy. For interaction terms in Model 3 with coefficients larger than −1, (e.g., –0.45 for $\sqrt[3]{X} \times RCI$), there is less than direct correspondence between a dollar spent on the work plan and a dollar taken out of the state economy. If there were direct correspondence, \$1 spent on a mitigation work plan would result in \$1 reduction in state GSP. However, when that value is larger than −1 (or the absolute value of the coefficient is less than 1), the difference can be explained by the fact that the macroeconomic impact of the direct stimulating effect of that mitigation work plan is stronger than that of the direct dampening effect of the work plan.

This effect is most significant for those variables that show a sign change between lower and higher quantiles. Consider the binary term RCI, compared with the reference sectoral case (AFW). The RCI work plans have overall significant and negative GSP impacts for those policy work plans that result in the most negative GSP impacts, and has overall significant positive GSP impacts for those that result in the most positive GSP impacts. These signs are in the expected direction. Also in the expected direction, are coefficients that are negative at lower quantiles, and less negative at higher quantiles, such as the coefficient for ES. For ES work plans, compared with the reference sectoral case, the dampening effect to the marginal GSP impacts is much greater for those work plans that result in the most negative GSP impacts.

---

[17] In our experience Stata has proven to be a particularly strong statistical software package except for use with some quantile models. In some cases, it has produced excessively large standard errors and dissimilar results between quantile and simultaneous quantile estimates. The analysis conducted here used R's Quantile Regression package Quantreg (Koenker 2010).

Another interesting result of the quantile models is the sharp differences at the lower quantiles between those mitigation work plans that are stimulating to the construction sector, versus those that are stimulating to the manufacturing sector. Although few of the quantiles are significant about MFG, the lower quantiles are negative. On the other hand, the lower quantiles of CONST are positive and highly significant. This indicates that, despite the fact that some work plans may be overall highly dampening to the state's economy, those that provide a stimulus to the construction sector are still likely to result in marginally positive impact to the state's economy.

We do not see this same effect for the manufacturing sector. Capital investments in the construction sector are often highly beneficial to a state or regional economy. One strong piece of evidence supporting this result is this sector's regional purchase coefficient (RPC). Whereas most capital-intensive and manufacturing related sectors RPCs range anywhere from 0.2 to 0.5, the RPC for the construction sector in Pennsylvania is 0.865. This indicates that dollar for dollar, capital investments in the construction sector are more stimulating to the state economy than most other sectors, whose demand is satisfied with greater proportions of imports.

6 Conclusion

This paper summarizes a detailed analysis of the impacts of the Pennsylvania Climate Action Plan on the state's economy. Our results are based on the REMI PI^+ model, a state of the art macroeconometric model, and data derived from in-depth and consensus-based technical stakeholder assessment. These results indicate that the majority of greenhouse gas mitigation or sequestration work plans have positive impacts on the state's economy. The total net results from the 42 individual work plans indicate that in the Year 2020, 38,800 full-time equivalent jobs will be added to the state's economy and the net present value of gross state product will increase by $5.05 billion.

Among these work plans, the largest gains to the state's economy come from commissioning and retro-commissioning buildings and industrial natural gas and electricity best management practices. Combined, these account for about 33 per cent of the total gains. The largest employment gains come from Urban forestry and 'Re-light PA'. Combined, these account for about 45 per cent of the total job creation.

Positive macroeconomic gains stem mainly from the ability of mitigation and sequestration work plans to lower the costs of production. Decreased production costs come principally from energy efficiency improvements, which enable greater production capabilities from fewer or less costly resources. Decreased spending costs on energy have positive impacts on consumer purchasing power, which has positive economy-wide impacts as those efficiency savings ripple throughout the macroeconomy. Positive economic gains also come from stimulus effects of increased investment in plant and equipment.

A further verification of our results is provided through statistical analyses. Multivariate regression analysis is used to confirm the close proximity between the combination of direct and indirect macroeconomic impacts and the direct impact assessments of stakeholders. We provide both a reduced and extended form linear model, as well as a multivariate quantile regression analysis. The results of these analyses indicate that the macroeconomic impacts from the REMI model are highly robust when one controls for investment and consumption characteristics. The results represent a strong validation of the application of the REMI model to the analysis in this paper.

Finally, it should be noted that the estimates of economic benefits from this analysis of the Pennsylvania Climate Action Plan represent a lower bound from a broader perspective. They do not include the avoidance of damage from the climate change that continued baseline GHG emissions would bring forth, reduction in damage from the associated decrease in ordinary co-pollutants, reduction in the use of natural resources, or reduction in traffic congestion, among others.

Acknowledgement

This paper is based on research funded by the Pennsylvania Department of Environmental Protection (DEP) through The Center for Climate Strategies. Many stakeholders and analysts contributed to the process and data utilized in this paper. We wish to offer special thanks to CCS team members Randy Strait, Thomas Peterson, David von Hippel, Hal Nelson, Greg Powell, Alison Bailie, Jennifer Jenkins, Steve Roe, Jim Wilson, Jackson Schreiber, Brad Strode, and Rachel Anderson. Joe Sherrick of DEP provided helpful suggestions during the course of this research, as did several external reviewers of the Pennsylvania Climate Action Plan. We are also appreciative of the comments of the three anonymous referees and the regional editor for this journal. Of course, any remaining errors and omissions are solely those of the authors. Moreover, the views expressed in this article represent those of the authors and not necessarily of any of the institutions with which they are affiliated nor the institutions that funded the research.

References

Cassing S, Giarratani F (1992) An evaluation of the REMI model for the south coast air quality management district. *Environment and Planning A* 24: 1549–1564

Global Insight (2008) *U.S. Metro Economies: Current and Potential Green Jobs in the U.S. Economy*. Prepared for The United States Conference of Mayors and the Mayors Climate Protection Center. URL: http://www.usmayors.org/pressreleases/uploads/greenjobsreport.pdf

Hanson DA, Laitner JA (2006) Technology policy and world greenhouse gas emissions in the AMIGA modelling system. *The Energy Journal* Multi-Greenhouse Gas Mitigation and Climate Policy Special Issue: 355–371.

Kammen D, Kapadia K, Fripp M (2004) Putting Renewables to Work: How many Jobs can the Clean Energy Industry Generate?, Energy Resources Group, Goldman School of Public Policy, University of California, Berkeley. URL: http://rael.berkeley.edu/sites/default/files/very-old-site/renewables.jobs.2006.pdf

Koenker R (2005) *Quantile regression*. Cambridge University Press, New York

Koenker R, Hallock KF (2001) Quantile regression. *Journal of Economic Perspectives* 15: 143–156

Koenker R (2010) Quantreg: Quantile Regression Package for R-Project Software. Available at: URL: http://cran.r-project.org/web/packages/quantreg/index.html

Minnesota IMPLAN Group, Inc. (MIG) (2011) The implan system. URL: http://implan.com/V4/Index.php

Miller S, Wei D, Rose A (2010) The economic impact of the Michigan Climate Change Action Plan on the state's economy. Report to the Michigan Department of Environmental Quality, The Center for Climate Strategies, Washington, DC

National Commission on Energy Policy (2004) Ending the energy stalemate: A bipartisan strategy to meet America's energy challenge. URL: http://www.energycommission.org/

Partridge MD, Rickman DS (2010) CGE modelling for regional economic development analysis. *Regional Studies* 44: 1131–1328

Pennsylvania Department of Environmental Protection (PA DEP) (2009) Pennsylvania Final Climate Change Action Plan. URL: http://www.elibrary.dep.state.pa.us/dsweb/View/Collection-10677.

Pollin R, Heintz J, Garrett-Peltier H (2009) The economic benefits of investing in clean energy. Report by Department of Economics and Political Economy Research Institute (PERI) at the University of Massachusetts-Amherst. URL: http://www.peri.umass.edu/economic_benefits/

Regional Economic Models, Inc. (2009) *REMI PI+ Documentation and User's Guide*. URL: http://www.remi.com/index.php?page=documentation&hl=en_US

Rey SJ (1997) Integrating regional econometric and input-output models: An evaluation of embedding strategies. *Environment and Planning A* 29: 1057–1072

Rey SJ (1998) The performance of alternative integration strategies for combining regional econometric and input-output models. *International Regional Science Review* 21: 1–35
Rickman DS, Schwer RK (1993) A systematic comparison of the REMI and IMPLAN models: The case of Southern Nevada. *Review of Regional Studies* 23: 143–161
Rickman DS, Schwer RK (1995a) Multiplier comparisons of the IMPLAN and REMI models across versions: Illuminating black boxes. *Environment and Planning A* 27: 143–151
Rickman DS, Schwer RK (1995b) A comparison of the multipliers of IMPLAN, REMI, and RIMS II: Benchmarking ready-made models for comparison. *Annals of Regional Science* 29: 363–374
Roland-Holst D (2009) *Energy pathways for the California economy*. Department of Agricultural and Resource Economics, University of California, Berkeley.
Rose A (1995) Input-output economics and computable general equilibrium models. *Structural Change and Economic Dynamics* 6: 295–304
Rose A, Dormady N (2011) A meta-analysis of the economic impacts of climate change policy in the United States. *The Energy Journal* 32: 143–166
Rose A, Wei D (2011) Macroeconomic impacts of the Florida Energy and Climate Change Action Plan. *Climate Policy* forthcoming
Rose A, Wei D, Wennberg J, Peterson T (2009) Climate change policy formation in Michigan: The case for integrated regional policies. *International Regional Science Review* 32: 445–465
Sathaye J, Murtishaw S (2004) *Market failures, consumer preferences, and transaction costs in energy efficiency purchase decisions*. Sacramento, CA, California Energy Commission. URL: http://www.energy.ca.gov/2005publications/CEC-500-2005-020/CEC-500-2005-020.PDF
Schleich J, Gruber E (2008) Beyond case studies: Barriers to energy efficiency in commerce and the services sector. *Energy Economics* 30: 449–464
Treyz G (1993) *Regional economic modeling: A systematic approach to economic forecasting and policy analysis*. Boston, MA, Kluwer
Treyz G, Rickman DS, Shao G (1991) The REMI economic-demographic forecasting and simulation model. *International Regional Science Review* 14: 221–253

Appendix: REMI Model Input Development, Regression Data, and Model 3 Quantile Plot

Before undertaking any economic simulations, the key quantification results for each work plan conducted by the subcommittees are translated to model inputs that can be utilized in the model. This step involves the selection of appropriate policy levers in the REMI model to simulate the policy's changes. The input data include sectoral spending and savings over the full time horizon (2009–2020) of the analysis. In Table A1 we choose one example work plan, demand-side management (DSM) to illustrate how we translate, or map, the subcommittees' results into REMI economic variable inputs.

Using Res/Com-10 DSM (natural gas) as an example, the first two columns of Table A1 show the quantification analysis results of this mitigation work plan according to their applicability to business (commercial and industrial) sectors and the household (residential) sector provided by the Res/Com subcommittee. The last column of Appendix Table A1 presents the corresponding economic variables in the REMI model and their position within the model.

DSM refers to programmes implemented by the utilities aimed at reducing electricity consumptions in the business and household sectors. For both the commercial and household sectors, the selected REMI policy variables to represent energy savings are from the 'compensation, prices, and costs block' and 'output and demand block', respectively. For the former, the energy savings are simulated as the decrease of 'natural gas fuel cost for the commercial sector'. For the latter, the energy savings are simulated as the 'consumer spending' decrease of gas.

The natural gas consumption reduction from this mitigation work plan would result in a decrease in demand from the Gas distribution sector. This is simulated by reducing the 'exogenous final demand' from the Gas distribution sector in REMI. This variable can be found in the 'output and demand block'.

Table A1. Mapping the quantification results of Res/Com-10 Demand-side management (natural gas) into REMI inputs

Quantification results		Policy variable selection in REMI
Natural gas savings of the customers	Commercial sectors	Compensation, prices, and costs block→ natural gas (commercial sectors) fuel cost (amount) of all commercial sectors→decrease
	Households (residential sector)	Output and demand block→consumer spending (amount)→gas→decrease
		Output and demand block →consumption reallocation (amount)→all consumption sectors →increase
Natural gas demand decrease from the NG distribution sector		Output and demand block →exogenous final demand (amount) for Natural gas distribution sector→decrease
NG customer outlay on energy efficiency (EE)	Commercial sectors	Compensation, prices, and costs block →production cost (amount)→increase
	Households (residential sector)	Output and demand block→consumer spending (amount)→Kitchen & other household appliances and Owner-occupied nonfarm dwellings →increase
		Output and demand block →consumption reallocation (amount)→all consumption sectors →decrease
Investment on EE technologies		Output and demand block →exogenous final demand (amount) for Construction sector and Ventilation, heating, air-conditioning, and Commercial refrigeration equipment manufacturing sector→increase

The costs of this work plan are the levelled cost of saved natural gas. For commercial sector, the costs would include improved Heating, Ventilation, and Air-Conditioning equipment, controls and building shell measures, and efficient cooking equipment. The total costs are distributed among the individual commercial sectors based on the reference case natural gas sales to the corresponding sectors. This is simulated in REMI by increasing the value of the 'production cost' variable of individual commercial sectors under the 'compensation, prices, and costs block'. For the residential sector, the costs would involve improvement in space heating efficiency (including adopting insulation measures of the home envelope and investing in more efficient heating and ventilation equipment and systems). These are simulated in REMI by increasing the 'consumer spending' on 'Owner-occupied nonfarm dwellings' and 'Kitchen & other household appliances' (and decrease in all the other consumptions correspondingly). The 'consumer spending' variable can be found in the 'output and demand block' in the REMI model.

Finally, the DSM programme would increase the demand for goods and services from the industries that supply energy-efficiency equipment and appliances and the construction sector. We simulated this in REMI by increasing the 'exogenous final demand' from the ventilation, heating, air-conditioning, and commercial refrigeration equipment manufacturing sector and construction sector.

Table A2. Regression data

Work plans		REMI GSP impacts NPV ($millions)	Direct cost NPV ($millions)	TLU	ES	RCI	AFW	CONST	MFG	GS	CR
Ag-3	Management intensive grazing	267.76	−387.37	0	0	0	1	1	0	0	0
Ag-4	Manure digester implementation support	0.94	1.13	0	0	0	1	0	0	0	0
Ag-5a	Regenerative farming practices initiative – regenerative farming practices	−13.57	17.86	0	0	0	1	0	0	0	0
Ag-5b	Regenerative farming practices initiative – carbon sequestration from continuous no-till	18.03	−32.30	0	0	0	1	0	1	0	0
F-1	Forest protection initiative – easement	−72.10	70.92	0	0	0	1	0	0	1	0
F-3	Forestland protection and avoided conversion – acquisition	−163.42	620.43	0	0	0	1	0	0	1	0
F-4	Reforestation, afforestation, regeneration	−864.85	597.17	0	0	0	1	0	0	1	0
F-7	Urban forestry	−159.30	1704.55	0	0	0	1	0	0	1	1
F-8	Wood to electricity	−3.55	2.95	0	0	0	1	0	0	0	0
F-9a	Biomass thermal energy initiatives – combined heat and power	916.02	−159.05	0	0	0	1	1	1	0	0
F-9b	Biomass thermal energy initiatives – fuels for schools	−29.15	48.28	0	0	0	1	0	1	0	0
W-1	Landfill methane displacement of fossil fuels	224.62	−10.26	0	0	0	1	0	1	0	0
W-2	Statewide recycling initiative	128.77	−258.38	0	0	0	1	0	1	0	1
W-4	Improved efficiency at wastewater treatment facilities	3.68	−3.41	0	0	0	1	0	0	0	0
W-5	Waste-to-energy digesters	7.86	6.97	0	0	0	1	0	1	0	0
W-6	Waste-to-energy municipal solid waste (MSW)	23.31	−65.79	0	0	0	1	0	1	0	0
E-3	Stabilized load growth	9.28	−254.68	0	1	0	0	0	1	0	1
E-5	House Bill 80: Carbon capture and sequestration in 2014	−214.93	391.08	0	1	0	0	1	1	0	0
E-6	Improve coal-fired power plant efficiency by 5 per cent	705.52	−822.53	0	1	0	0	0	0	0	0
E-7	Sulfur hexafluoride (SF6) emission reductions from the electric power industry	−0.47	0.29	0	1	0	0	0	0	0	0
E-9	Promote combined heat and power (CHP)	−3237.97	209.20	0	1	0	0	1	1	0	0
E-10	Nuclear capacity	−142.17	233.07	0	1	0	0	1	1	0	0
RC-5	Commission buildings	2471.50	−70.53	0	0	1	0	1	0	0	0
RC-6	Re-light PA	1978.00	−4044.07	0	0	1	0	1	1	0	1
RC-7	Re-roof PA	−574.65	1012.88	0	0	1	0	1	0	0	0
RC-8	Appliance standards	−102.03	−290.84	0	0	1	0	0	1	0	1
RC-9	Geothermal heating and cooling	538.49	499.75	0	0	1	0	1	1	0	0
RC-10	DSM – natural gas	1853.75	−357.12	0	0	1	0	1	1	0	1
RC-11	DSM – heating oil and biofuel for heat	981.47	207.57	0	0	1	0	1	1	0	1
RC-13	DSM – water	350.37	−1011.38	0	0	1	0	0	0	0	1
Ind-1	Coal mine methane (CMM) recovery	62.86	−51.80	0	0	1	0	0	0	0	0
Ind-2	Industrial natural gas and electricity best management practices	2475.00	−972.27	0	0	1	0	0	1	0	0
Ind-3	Reduce lost and unaccounted for natural gas	124.75	−47.57	0	0	1	0	0	0	0	1
T-3	Low rolling resistance tyres	432.12	−818.34	1	0	0	0	0	1	0	1
T-5a	Eco-driving 5A PAYD insurance	−844.94	−665.10	1	0	0	0	0	0	1	1
T-5b	Eco-driving 5B feebates	9.36	−532.83	1	0	0	0	0	0	1	1
T-5c	Eco-driving 5C driver training	−771.72	−375.74	1	0	0	0	0	0	1	1
T-5d	Eco-driving 5E tyre inflation	1.87	−90.22	1	0	0	0	0	0	1	1
T-5e	Eco-driving 5H speed limit reduction	−1909.66	6790.96	1	0	0	0	0	0	0	1
T-6	Utilizing existing public transportation systems	−931.42	2157.51	1	0	0	0	0	0	1	0
T-8	Cutting emissions from freight transportation	650.35	−956.35	1	0	0	0	0	1	0	0
T-9	Increasing federal support for efficient transit and freight transport in PA	842.76	724.64	1	0	0	0	1	1	0	0

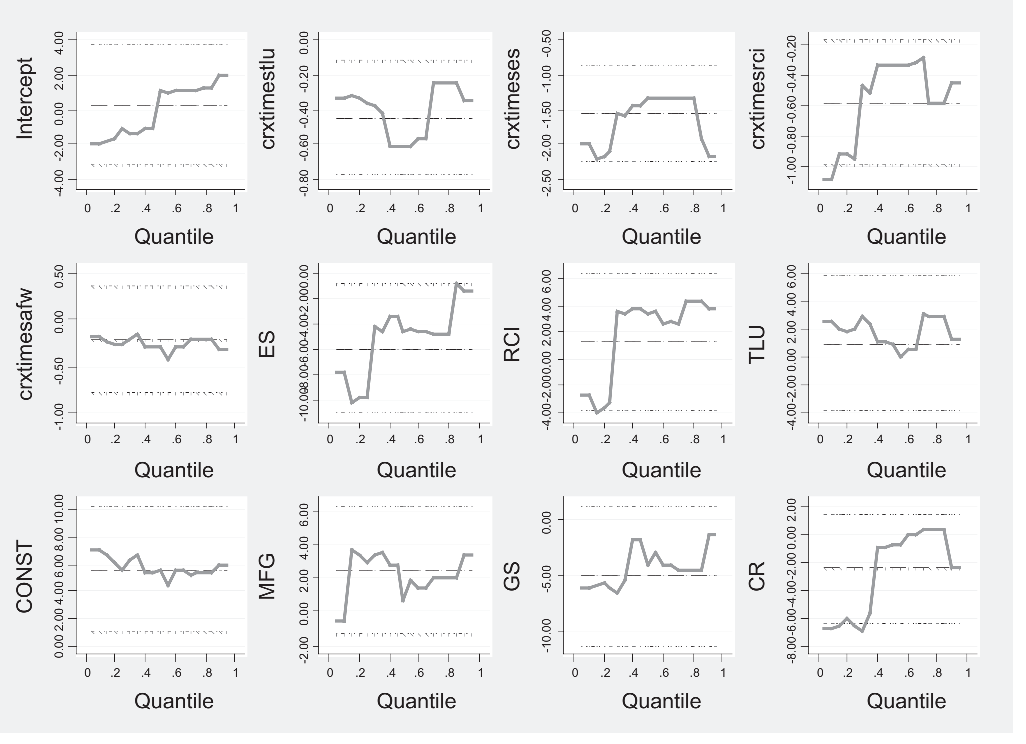

Fig. A1. Model 3: quantile plot