Carbon Policy Office

CONSULTANT REPORT

Oregon's Cap-and-Trade Program (HB2020): An Economic Assessment

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ABBREVIATIONS:
BLS – U.S. Bureau of Labor Statistics
CGE – Computable General Equilibrium
C&T – Cap-and-Trade
CPO – Carbon Policy Office
CI - Carbon Intensity
DEQ – Department of Environmental Quality
EITE – Emissions Intensive, Trade Exposed
GHG – Greenhouse gases
MMTC02e – Million metric tonnes of CO2 equivialents
NERC – Northwest Economic Research Center
PGE – Portland General Electric
RPS – Renewable Portfolio Standard
ZEV - Zero Emissions Vehicle

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Oregon's HB2020 Cap-and-Trade Policy:

An Economic Assessment

Prepared for the Oregon Carbon Policy Office
by
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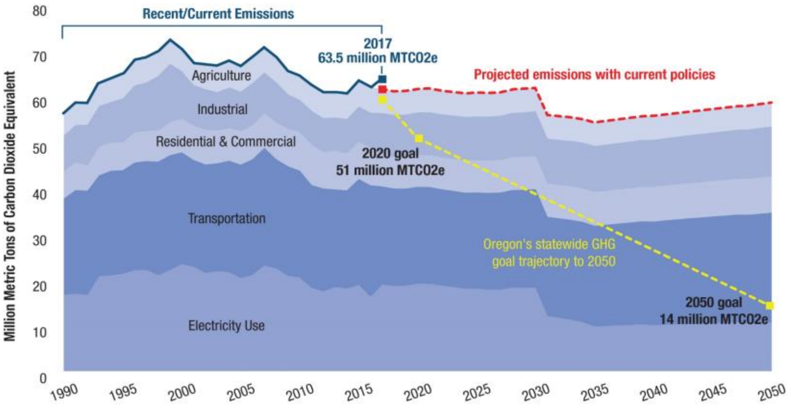
1 INTRODUCTION

Oregon's proposed cap-and-trade Policy (HB2020) has established ambitious public commitments to energy efficiency, pollution mitigation, and long-term environmental security. Under the right conditions, these policies have potential to both limit resource waste and climate risk and promote development of the next generation of clean and energy efficient technologies. However, substantive mitigation policy must recognize some direct and indirect costs. Moreover, the distributional impacts of cap-and-trade policies are largely dependent on the design and conditions related to implementation (Rausch et al 2011).

Figure 1.1: Oregon's GHG Emissions Targets



The established milestone for GHG reductions in Oregon's proposed policy, 80% below 1990 levels by 2050, is ambitious and would require Oregon to reduce emissions even faster than it has since 2000 (Figure 1.1). In this report, we examine alternative cap-and-trade policy scenarios that could achieve the 2050 goal, assessing their economic impacts and implications for economic growth. Generally, we find that while there are adjustment costs, the overall benefits to the economy outweigh the costs.

Our approach, which integrates the latest available technology information with a long term economic forecasting model, reveals that innovations in the transportation, electric power, and other sectors can facilitate GHG reductions in ways that confer economic savings on households and enterprises across the state. These savings, made possible by rapid innovation and a pervasive restructuring of the light vehicle fleet and electric power system and other sector innovations can offer a pathway to Oregon’s emission goals that promotes higher economic growth and employment than continuing the status quo. While we cannot predict the details of individual behavior and enterprise decision making, our results clearly reveal the potential of technology adoption and diffusion to reconcile the state’s ambitious climate goals with economic growth objectives. More importantly to individual Oregonians, adoption of already available and forthcoming technologies can offset most of the adjustment costs of decarbonizing the state economy. Indeed, economic savings from energy efficiency and renewable energy can be a potent catalyst for inclusive economic growth.

In terms of the pathway to 2050, we also show that more aggressive technology adoption would permit the state to fulfill the ambitious intermediate (2035) emissions targets in HB 2020. While the 2050 goals would be met under all the scenarios we consider, a more aggressive approach to medium term GHG reduction would reduce total state emissions significantly. On the one hand, steeper targets would increase the cost of compliance. At the same time, more aggressive intermediate GHG targets would improve Oregon’s air quality faster and offer more opportunities for innovation, energy savings, and technology leadership. Balancing these tradeoffs will determine the most appropriate path forward.

2 BACKGROUND

As part of their own policy research and implementation activities, Oregon’s Carbon Policy Office commissioned Berkeley Energy and Resources (BEAR) to undertake the present study. This study uses a long-term dynamic Computable General Equilibrium (CGE) model, combined with the latest economic and technology data, to evaluate alternative cap-and-trade policy mixes from now to 2050. Updating contributions made by other public and private research, we explicitly model existing Oregon climate policies, as well as some alternatives being discussed for intermediate GHG targets and pathways. We examine the interaction between combined policies while accounting for diverse institutions and behaviors, and explore whether these policies would be complementary and improve policy effectiveness. We also demonstrate the importance of recognizing uncertainty and creating mechanisms to accommodate this during a significant structural adjustment process because, as most experts already acknowledge, a truly low carbon economy would be very different from today's Oregon.

The distinguishing feature of a general equilibrium model, applied or theoretical, is its closed form specification of all specified activities in the economic system under study. This can be contrasted with more traditional partial equilibrium analysis, where linkages to other domestic markets and agents are deliberately excluded from consideration. A large and growing body of evidence suggests that indirect effects (e.g., upstream and downstream production linkages) arising from policy changes are not only substantial, but may in some cases even outweigh direct effects. Only a model that consistently specifies economy-wide interactions can fully assess the implications of economic policies or business strategies.

The BEAR model used for this anlysis is an advanced policy simulation tools that traces detailed patterns of demand, supply, and resource allocation across a state, regional, or national economy, estimating economic outcomes annually over decades (usually to 2050 or 2060). It is a state-of-the-art economic forecasting tool, based on a system of equations from economic theory, calibrated to detailed economic data that simulate price directed interactions between firms and households in commodity and factor markets. The model is carried forward with numerical simulation to produce annual results, detailing pathways of adjustment over a given policy time horizon. A core feature of our model is a fully specified cap-and-trade (C&T) mechanism, including flexible annual emission constraints, coverage, and added instruments representing policy options such as offsets, alternative allowance and revenue allocation strategies, adjustment/transition assistance, etc.

The BEAR Oregon model is calibrated to detailed sectoral data from the Bureau of Economic Analysis, Bureau of Labor Statistics, using supporting spatial data from the US Census, IMPLAN, and official state sources. Baseline dynamics have been calibrated to the Oregon Office of Economic Analysis economic and demographic forecasts.

2.1 Overview of Previous Research

The existing literature concerning the economic impacts of a cap-and-trade (or carbon tax) program in Oregon finds mixed results. Ambiguous results are common throughout the climate policy literature and are by no means unique to Oregon. That is because whether the effects are estimated to be positive or negative depends both on the specific policy in question and also on the assumptions used in modeling. For example, studies often find negative benefits if they fail to account for co-benefits (such as the effects to health from the improvement in air quality) or don't account for mitigation of increased energy prices via revenue recycling effects. Conversely, studies typically find positive effects when they account for investment in local jobs and energy-saving measures.

Generally, these trends are reflected in the previous work in Oregon, which have found either positive or negative economic shocks depending on key assumptions. Although results are conflicting, the overall economic impacts of either a cap-and-trade or carbon tax policy in Oregon would be small relative to the state economy. For example, in the most extreme cases the overall effect to the Oregon economy is on the order of approximately 1% of gross state product. With the Oregon economy historically growing by 2.7% annually[1], this means even the most aggressive climate policies would still result in overall net positive economic growth.

2.1.1 NERC

To date there have been three studies of interest. The first study, released in December 2014 from Portland State University's Northwest Economic Research Center (NERC), considers the economic impacts of a carbon tax. This report was produced in response to the 2013 Oregon Legislature Regular Session, where SB306 (2013) was passed directing the state to conduct a study of the economic impacts of implementing a clean air tax or fee in Oregon. Thus, this report is largely

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[1] According to the US Bureau of Economic Analysis, Oregon real GDP averaged 2.7% growth over the 20 year period 1996-2016.

a precursor to further efforts to consider the impact of cap-and-trade policy. Although both cap-and-trade and carbon tax establish a price on GHG emissions price carbon, there are crucial policy differences. A cap-and-trade policy sets an emissions reductions target and allows the price of carbon to adjust based on market demands. Conversely, a carbon tax sets the price of carbon but does not require specific emissions reductions.

The NERC report is comprised of two primary forecasts that span from 2012 - 2034. The first, emissions and revenue modeling, forecasts expected GHG emissions based on varying economic scenarios. The emissions and revenue modeling are an important first step to determine the appropriate size carbon tax to ensure policies are consistent with Oregon's climate goals.[2] The primary objective of an emissions model is to determine the impact of the carbon-tax on emissions levels relative to the baseline "business-as-usual" scenario. Additionally, this forecast also produces estimates on the revenues generated from carbon-taxes, which are later used as inputs into the economic model. The second forecast is the economic model, which considers the economic impact of various carbon taxes and revenue usage scenarios. NERC uses a six-region REMI model to analyze the effects of various carbon taxes and revenue usage scenarios across the state.

Starting first with the emissions forecast, NERC finds that the amount of emissions reductions depends on the size of the carbon tax rate. Table 2.1 below shows the relationship between various carbon tax rates and expected emission reductions in the year 2034. NERC's results suggest that carbon tax of $60/tCO2e or greater would likely be sufficient to meeting Oregon's 2020 goal of a 10% reduction in emissions below 1990 levels. However, even at the highest tax rate ($150/tCO2e), the longer-term goal of a 75% reduction by 2050 will not be achievable by 2034 without additional climate policies.

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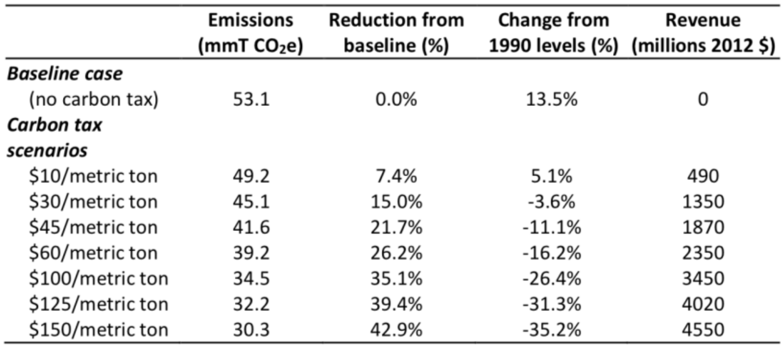
[2] These goals were set by the Governor's Advisory Group on Global Warming in 2004 and call for a 10% reduction below 1990 GHG levels by 2020 moving to a 75% reduction below 1990 GHG levels by 2050. The Oregon Legislature put the goals into law in 2007 with HB3543.

Table 2.1: Projected Average GHG Emissions (2034)



	Emissions (mmT CO_2e)	Reduction from baseline (%)	Change from 1990 levels (%)	Revenue (millions 2012 $)
Baseline case				
(no carbon tax)	53.1	0.0%	13.5%	0
Carbon tax scenarios				
$10/metric ton	49.2	7.4%	5.1%	490
$30/metric ton	45.1	15.0%	-3.6%	1350
$45/metric ton	41.6	21.7%	-11.1%	1870
$60/metric ton	39.2	26.2%	-16.2%	2350
$100/metric ton	34.5	35.1%	-26.4%	3450
$125/metric ton	32.2	39.4%	-31.3%	4020
$150/metric ton	30.3	42.9%	-35.2%	4550

Turning to the economic impacts, the size of the effect depends both on the price of carbon as well was revenue sharing assumptions. NERC considers 5 different revenue scenarios, which are as follows:

- **Scenario A – No Repatriation:** No repatriation of any revenues. Revenues would be allocated to one of three Oregon Reserve Funds: the Oregon Rainy Day Fund, the Education Stability Fund, the Small Legislative Ending Balance Fund.

- **Scenario B – Revenue Neutral:** True revenue neutral is complicated by the Oregon Constitution which requires revenues from transportation fuels to used only on transportation projects. Thus, NERC assumes that carbon tax revenues from transportation fuels could be used to offset existing fuel taxes. The additional revenue would be returned to households through either personal or corporate income tax cuts.

- **Scenario C – Revenue Neutral (Excluding Transportation Revenue):** Similar to scenario B, except transportation revenues are spent in the Highway Trust Fund. Spending from this fund results in a positive economic impact through road maintenance and construction activity as well as improved transit connections. Therefore, this scenario is revenue positive overall. Leftover revenue is used for cutting income taxes or direct income support.

- **Scenario D – Public Investment and Support:** A refinement of scenario C except includes other scenarios where carbon tax revenues are dedicated towards investment in other state goals. These include, low income/worker assistance and direct assistance to industries unduly impacted by the carbon tax.

- **Scenario E – Alternative Transportation-Related Carbon Tax Revenue Disbursement:** Uses a different allocation than the Highway Trust Fund would dictate. For example, this scenario considers distributing funds to regions based on unweighted VMT, which favors urban over rural transportation projects. It also considers the list of eligible projects in the Highway Trust Fund were expanded to other transport categories such as light rail or bike lines.

The main results of the economic analysis are found below in Table 2.2. Overall, NERC finds ambiguous results depending on the price of carbon and revenue scenario. The most dramatic impacts are found in Scenario A, which is a theoretical exercise where Oregon does not repatriate any of the revenues. Scenario C is overall the most likely, as transportation revenue would be used as indicated by the Highway Trust Fund and leftover revenue is earmarked for personal or corporate tax cuts. Excluding Scenario A, these results suggest output would fall roughly 0.3 – 0.5% depending on the price of carbon, while employment would decrease by 5,000 - 10,000 or increase by 5,000 – 7,000. Considering the size of Oregon's overall economy these effects are quite minimal.

Table 2.2: Annual Impacts of Various Carbon Prices and Revenue Scenarios (NERC)

			Maximum Level of Carbon Tax (per mTCO$_2$e)				
			$10	$30	$60	$100	$150
Emissions Impact			–7%	–15%	–26%	–35%	–43%
Tax Revenue[3]			$490M	$1,350M	$2,350M	$3,450M	$4,550M
Revenue Usage Scenarios	A	Employment	[redacted]	-15K to 25K	-27K	-37K	[redacted]
		Output	[redacted]	-0.6% to -0.4%	-1.1%	-1.35%	[redacted]
	B	Employment	-1.1K	-4K	-8K	-9K	-14.5K
		Output	-0.05%	-0.2%	-0.5%	-0.5%	-0.7%
	C	Employment	0	+4K	+7K	+5.5K	+2K
		Output	-0.02%	-0.05%	-0.3%	-0.3%	-0.7%
	D	Employment	[redacted]	+5K	-13K to -9K	[redacted]	[redacted]
		Output	[redacted]	-0.3%	-0.5%	[redacted]	[redacted]
	E	Employment	[redacted]	0	-5K	[redacted]	[redacted]
		Output	[redacted]	-0.3%	-0.5%	[redacted]	[redacted]

2.1.2 DEQ

The next relevant study was produced by the Oregon Department of Environmental Quality (DEQ). Much like the NERC report, this research was created in response to the 2016 Oregon Legislature Session, where SB 5701 (2016) calls for the DEQ to "study a market-based approach to controlling GHG emissions by providing economic incentives for achieving emissions reductions." Thus, this report has a wide-scope and begins with an overview of cap-and-trade programs and the considerations for Oregon, before moving into the economic impacts of such a program.

To conduct their analysis, DEQ retained the services of Energy and Environmental Economics (E3). Similar to the NERC report, E3 also used a two-step modeling process, first beginning with projections of economic and energy demand growth. This first model provides the baseline "business-as-usual" GHG emission scenario from which the necessary amount of emission reductions can be determined. Once the cap on emissions is established, E3 then considers the economic impacts of this policy relying on an IMPLAN input-output model of the Oregon economy.

Starting first with the emissions forecast, E3 modeled three scenarios from the period 2015 – 2050, with a focus on 2035, the midpoint between Oregon's 2020 and 2050 goals. The scenarios are as follows:

1. **Baseline Scenario:** represents Oregon GHGs in the absence of the recent extension of the Renewable Portfolio Standard (RPS) and suspension of importation of electricity generated from coal by 2035.

2. **Reference Policy Scenario:** represents Oregon GHGs with updated electricity policies signed into law in 2016 including a 50% RPS by 2040 and suspension of coal-fired electric imports.

3. **Aggressive Policy Scenario:** represents Oregon GHGs if the state pursued additional policies to reduce GHGs outside of a carbon market, focusing on incremental energy efficiency and increased zero emission vehicles.

Under these scenarios, E3 forecasts the level of emissions reductions both from complementary policies as well as the cap-and-trade policy. Complementary policies alone are expected to reduce some 8 to 15 million tCO2e for either the reference or aggressive policy scenarios respectively. This leaves a gap of 16 to 9 million tCO2e that will need to be reduced by cap-and-trade by 2035.

With emissions forecasts in place, E3 is able to model the economic impacts of the emission caps under several different scenarios. Their analysis tests four variables, under two outcomes, which in combination produces 16 scenarios:

1. **Policy Scenario:** Reference and Aggressive Policy
2. **Carbon Allowance Prices:** Low ($35/tCO2e) and High ($89/tCO2e)
3. **Loss Factor:** Low (15%) and High (30%)
4. **Allowance Allocation:** 100% Free Allocation to Emitters and 100% Auction with Revenue Recycling to consumers

The main results of E3's economic impacts are found below in Tables 2.3 and 2.4. Given the modeling assumptions, these results likely contain the range of expected impacts as the scenarios serve as bookends rather than expected policies. Thus, the purpose of these results is to inform the range in order to inform policy, rather than advocate for a specific policy. Much like the NERC report, the overall impacts to Oregon economy are projected to be low, from a reduction in state GDP of 0.08% to an increase of 0.19%. Similarly, estimates on the impacts to jobs are also small, ranging from a decrease of 1,500 to an increase of 6,500.

Table 2.3: Net Benefits to the Total Oregon Economy by Scenario (2035)

		$32/tCO2e		$89/tCO2e	
		15% Loss Factor	30% Loss Factor	15% Loss Factor	30% Loss Factor
Reference Policies	Free Allocation	+$173	($14)	+$481	($40)
		+0.07%	-0.01%	+0.19%	-0.02%
	Auctioned Permits	+$102	($73)	+$282	($203)
		+0.04%	-0.03%	+0.11%	-0.08%
Aggressive Policies	Free Allocation	+$160	+$5	+$445	+$13
		+0.06%	+0.00%	+0.17%	+0.00%
	Auctioned Permits	+$89	($54)	+$246	($151)
		+0.03%	-0.02%	+0.10%	-0.06%

* - All costs in millions, percentages relative to 2014 Oregon economy ($259 Billion)

Table 2.4: Direct Changes to Employment by Scenario (2035)

		$32/tCO2e		$89/tCO2e	
		15% Loss Factor	30% Loss Factor	15% Loss Factor	30% Loss Factor
Reference Policies	Free Allocation	+492	(555)	+1,368	(1,543)
		+0.02%	-0.03%	+0.07%	-0.07%
	Auctioned Permits	+2,277	+915	+6,332	+2,545
		+0.11%	+0.04%	+0.31%	+0.12%
Aggressive Policies	Free Allocation	+580	(289)	+1,614	(803)
		+0.03%	-0.01%	+0.08%	-0.04%
	Auctioned Permits	+2,365	+1,181	+6,578	+3,285
		+0.11%	+0.06%	+0.32%	+0.16%

2.1.3 FTI

The final report hails from the private consulting firm, FTI, who was retained by the business advocacy group Associated Oregon Industries (AOI). This report considers the economic impacts of SB 1574 (2016), which caps GHG emissions at 75% below 1990 levels by 2050 and applies to entities with annual emissions greater than 25,000 tCO2e. The FTI report is similar to the DEQ report in scope but uses a dynamic rather than static model and provides a greater level of spatial disaggregation. Thus, although many of the supporting assumptions and inputs are similar, the findings from the reports diverge.

Like the NERC and DEQ report, FTI uses emission forecasts based as an input to their economic model. However, unlike the other reports, FTI uses a combination of emissions forecasts from models of the electricity sector (PLEXOS) and gaseous and liquid sectors (CTAM). Compared to the DEQ report, FTI finds that forecasted GHG emissions across scenarios are lower. This may be explained by the more robust modeling of emissions, or that FTI uses a more recent Annual Energy Outlook (AEO) estimates.[3]

Turning to the economic impacts, FTI uses an 8-region REMI model and finds that cap-and-trade program suggested from SB1574 (2016) would reduce state GDP by almost $1.3 billion (or -0.4% of state GDP) relative to the baseline scenario by 2035. This scenario assumes a carbon price of $85/tCO2e, which is similar to the upper bound price ($89/tCO2e) used by DEQ. Thus, the 2035 findings present the most “apples-to-apples” comparison between reports. Although this effect is larger than what is found in the DEQ report, it is in line with the findings from the NERC report.

FTI notes that their larger negative effect is likely justified by price effects (i.e. the influence of higher energy prices on consumers and business). The FTI analysis is also spatially disaggregated which reveals an interesting divergence between rural and urban areas. Specifically, rural areas such as coastal and eastern Oregon perform better on average, which is somewhat counterintuitive. The FTI report highlights four reasons for this rural/urban divide. First, rural Oregon is not a producer of fossil energy, and thus lower demand will not impact extraction in rural areas. Second, free allowances for emissions-intensive, trade-exposed (EITE) industries have a larger impact in rural areas. Third, the investor owned utilities are

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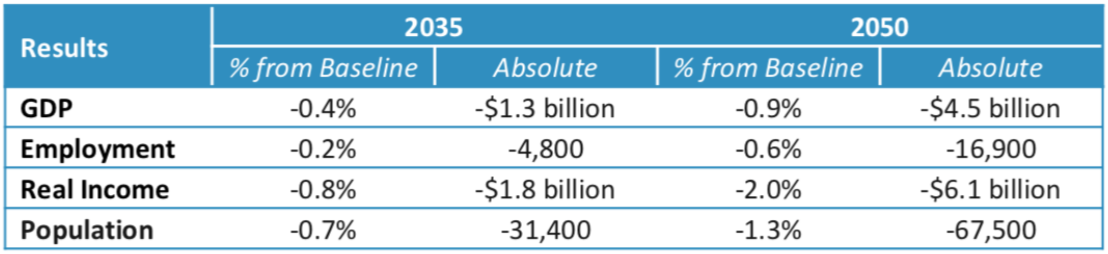
[3] FTI uses the 2017 AEO forecast, which has lower fuel consumption and emissions in the Pacific Region compared to the 2016 AEO forecast used in the DEQ report.

largely concentrated in urban areas and will have higher rate impacts. Fourth, rate impacts will lead to greater reductions in urban areas via induced spending where there is a higher proportion of spending in the service sector. In regard to employment, impacts are similar to those found for output, with urban areas faring worse than rural. Overall, FTI estimates a reduction of approximately 4,800 jobs in 2035 from the cap-and-trade policy.

FTI also forecasts to 2050 assuming a carbon price of $450/tCO2e. As neither the DEQ or NERC reports forecast this far it is impossible to make comparisons between reports. Using a high long-term GHG allowance price results in more drastic reductions in GDP and employment with output falling by $4.5 billion and employment by 16,900. Although these numbers are larger than the estimates from 2035, they still suggest overall growth in the Oregon economy would remain positive. The primary results are listed below in Table 2.5.

Table 2.5: Economic Impacts of Oregon Cap-and-Trade



Results	2035		2050	
	% from Baseline	*Absolute*	*% from Baseline*	*Absolute*
GDP	-0.4%	-$1.3 billion	-0.9%	-$4.5 billion
Employment	-0.2%	-4,800	-0.6%	-16,900
Real Income	-0.8%	-$1.8 billion	-2.0%	-$6.1 billion
Population	-0.7%	-31,400	-1.3%	-67,500

3 POLICY SCENARIOS FOR CLIMATE ACTION

To assess prospects for cap-and-trade and other determined Oregon climate initiatives over the next three decades, the BEAR model was implemented with a variety of scenarios that reflect policy options being actively considered (Table 3.1).

Table 3.1: Cap-and-Trade Scenarios Evaluated in the Present Study

	Scenario	Description
1	**Reference**	A "Current Practice" or Reference Scenario with only existing policies in force over the scenario period. Key existing policies include the Renewable Portfolio Standard, “Coal-to-Clean”, and Clean Fuels program.
2	**Linear**	The basic mechanism: Placing an annual cap (Figure 1.1), reducing covered GHG emissions by a constant quantity (1.5MMT) annually from 2021 to 2050 when the 80% reduction below 1990 levels is achieved. Covered entities are required to obtain permits through auction for the emissions they contribute to the cap, except for allowances distributed at no direct cost (see Section 3.2 below). Revenues are allocated to state funds, with permit proceeds for emission from transport fuels dedicated to the State Highway Trust Fund. Assumes no linkage to the WCI.
3	**Interim Target**	Interim Target cap-and-trade: Same as the Linear scenario, but reducing covered GHG emissions by a constant yearly quantity across two intervals, -2MT annually over 2021-2035 and -1MT annually over 2036-2050.
4	**Core**	The Core Scenario for this assessment, reflecting the main features proposed in HB2020: This follows the Interim Target emission reduction scenario, but allows covered entities to claim 8% of their emissions against certifiable offsets.
6	**WCI-Low**	Core scenario, with a permit price at the California Auction Reserve Price (ARP) low level, also known as the floor price. We assume in all three WCI scenarios that Oregon is a price taker in the regional market, trading together at the assumed border price of permits, and retains all permit revenue within state coffers. Costless permit allocations follow the core scenario, as do offset rules.
7	**WCI-Med**	Core scenario, with a permit price following the California Energy Commission Mid-level pathway (Figure 5.1).
8	**WCI-High**	Core scenario, with a permit price following the WCI Ceiling.

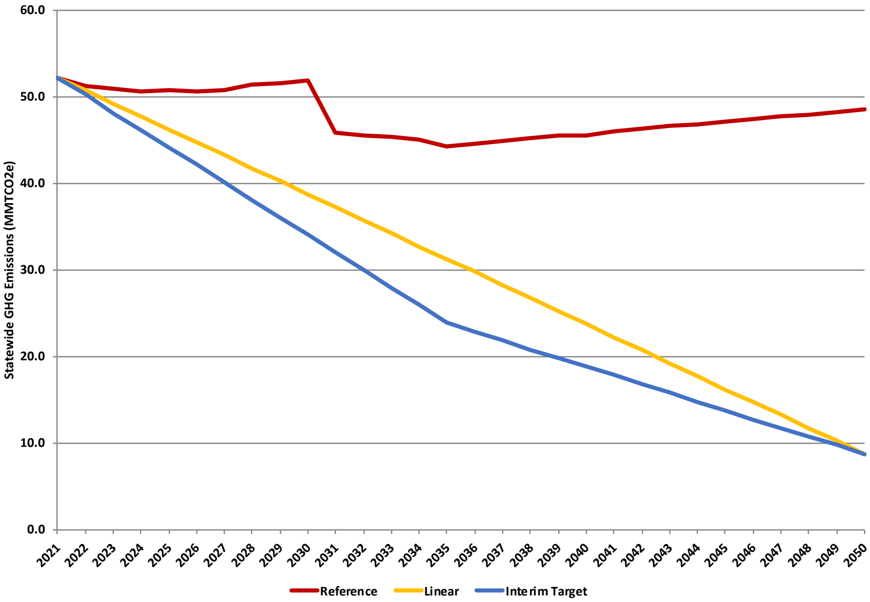
In addition to the Reference case, incorporating existing and committed policies (e.g. 50% RPS by 2040, Clean Fuels Program, Coal to Clean), we looked at several primary cap-and-trade design features: Alternative mitigation pathways, allowances to recognize adjustment needs, offsets, permit revenue allocation schemes, and participation in regional emissions markets. Each of these cap-and-trade design features would benefit in its own right from more detailed microeconomic assessment, but the present study focusses on macroeconomic impacts for the Oregon economy.

3.1 Cap-and-Trade Pathways

Although the policy has a brief history, Oregon's proposed cap-and-trade program (HB2020) is built upon solid experience nationally and globally, providing market based incentives for mitigation and innovation at relatively modest cost across a diverse economies. Should it become law, the statewide carbon cap will be the primary indicator of the state's mitigation objectives, leading Oregon to an 80% GHG reduction below 1990 levels by 2050. While the 2050 destination is an ambitious focal point, the pathway there is of course more relevant to today's stakeholders and decision makers. As the following figure suggests, that pathway chosen can also make a big difference to the primary determinants of local air quality and global warming, the stock of CO_2 and criteria co-pollutants in the atmosphere.

The two mitigation pathways we evaluate hit the same 2050 GHG target, but one reduces pollution more aggressively along the way. A more conservative Linear scenario (Linear) reduces the emissions cap in constant quantity steps (-1.5 $MMTCO_2e$), while the Interim Target pathway (Interim Target) prescribes constant pollution reductions over two intervals, -2 $MMTCO_2e$ annually from 2021 to 2035 and -1 $MMTCO_2e$ annually thereafter. If we follow the Interim Target rather than the Linear pathway, Oregon will contribute about 15% less to local and global atmospheric pollution. The question we ask is, can these environmental benefits be achieved at reasonable cost, and what would be the differences between them in macroeconomic terms?

Figure 3.1: Oregon Emissions Pathways



The scenarios we evaluate include several other policy "design" characteristics to accompany the basic cap-and-trade mechanism. In addition to setting a limit on total emissions of entities covered by the program, we include complementary measures designed to improve compliance and mitigate adjustment costs.

Generally speaking, complementary policies fall into three categories. The first are policies targeting individual agent's behavior, e.g. sector-specific incentives for compliance like the decoupling policies developed in collaboration with utilities in other states. A second category addresses situations where prices alone cannot achieve the intended mitigation, such as miles per gallon (mpg) and other efficiency standards. Finally, a broader set of complementary policies, such as the proposed offset, creates system flexibility that can push down allowance prices and help preserve the competitiveness of Oregon goods and services in the national economy. It is not difficult to develop a laundry list of such measures, but careful research is needed to determine their real potential and appropriate implementation. In the present study, most complementary policies are included in the Reference case. Exceptions are concessionary allocation of pollution permits and offset allowances, which are design characteristics of cap-and-trade itself.

3.2 Permit Allocation in all Cap-and-Trade Scenarios

In recognition of adjustment needs in the electric power sector, proposed cap-and-trade legislation allows for allocation of emission permits to utilities at no direct cost. Allocation through 2030 will be based on 100% of their forecast emissions for all electricity serving Oregon ratepayers from sources inside and outside (imported) the state. Thus, the anticipated compliance obligations of these companies for serving Oregon load would be covered via this direct allocation. It would not be consigned, but could be used for compliance, thus averting rate impacts. After 2030, this allocation would be reduced gradually and in a prescribed manner consistent with decline of the overall emissions cap across the Oregon economy.

Natural gas utilities would receive direct allocations of allowances in an amount necessary to account for emissions associated with their low-income residential load.

Emissions intensive, trade exposed (EITE) industries would receive direct allocations of emissions permits, beginning at their initial level of emissions, which is aligned with their product output. Each year thereafter, allocations are adjusted based on their product output, while also declining at the rate of the overall allowance budget.

3.3 Emission Offsets

It is well known that many opportunities for mitigation exist outside the direct activities of covered entities, including measures to reduce ambient emissions by sequestration (e.g. afforestation). In cases where these reductions may be more cost effective than emission reductions by a covered entity, recognition of verifiable and additional offsets can be more economically efficient for enterprises and society. While offsets may not solve problems of local emission concentration, they still achieve the important objective of reducing overall GHG emissions and offer some adjustment assistance to covered entities. For these reasons, Oregon proposes to allow up to 8% of compliance to be offset in this manner. In our scenarios, we make the conservative assumption that covered entities use their full offset allowance in each year and pay a price for indirect mitigation that is equal to that year’s permit price. To the extent that they could find less expensive mitigation, the aggregate economic benefits of the program would be greater. Thus we assume offsets to be cost neutral to covered entities, but they reduce their individual allowance demand by this amount.

4 ASSESSMENT RESULTS

Our assessment of the five types of cap-and-trade policy scenarios set forth above (Table 3.1), evaluated over the period 2016-2050, yields five main findings, summarized in the following table.

Table 4.1: Main Findings

1. Oregon can meet its 2050 climate goals in ways that achieve higher aggregate economic growth and employment. More aggressive GHG mitigation pathway, reducing 2035 emissions 45% below 1990 levels, will confer greater benefits on the state economy, adding about 1% to GDP and about 11,000 new jobs. Sustaining these reductions to 80% below 1990 by 2050 would increase GDP over 2.5% and add about 23,000 new jobs.
2. Energy efficiency and renewable electrification offer broad-based savings to enterprises and households, which can be a potent catalyst for more inclusive economic growth and job creation.
3. To do this will require a fundamental restructuring of the state's energy system, including electrification of at least the light vehicle fleet, deep decarbonization of the electrical sector, and dramatically reduced direct use of natural gas in heating and industrial applications.
4. Recognizing sector needs for short and medium term flexibility, adjustment costs for this economic transition can be substantially reduced. Limited directly allocated emissions permit allowances are an important part of this strategy.
5. Economic benefits of improved air quality, in terms of averted medical costs and premature mortality, are substantial, contributing about 1/3 to overall economic growth.

When the BEAR model was applied to the alternative policy scenarios, aggregate economic impacts indicate that the state can achieve its medium and long term climate goals while promoting economic growth (Table 4.2). Put differently, the aggregate net economic benefits are positive under all climate action scenarios considered. As will be apparent in the discussion below, the primary drivers of these growth dividends are efficiency gains, multiplier effects from economy wide energy savings, and public health benefits. In the medium and long term, these savings outweigh the costs of new technology adoption, and those net savings are passed on by households and enterprises to the rest of the state economy, stimulating indirect income and job creation. Because aggregate gains are based on the scope of distributed efficiency measures, the benefits compound over time and with the degree of emissions reduction, conferring the largest dividends by 2050.

Table 4.2: Macroeconomic Impacts of Cap-and-Trade

2030 Results

	Ref (levels)	Linear	Interim Target	**Core**
GDP ($B)	$366.0	1.08%	0.93%	1.08%
Consumption	$184.5	1.07%	0.91%	1.07%
Jobs (%)	-	0.50%	0.44%	0.50%
Wages	-	0.22%	0.20%	0.22%
FTE ('000)	3,360	17	15	17
GHG (%)	-	-29%	-46%	-46%
GHG ($MMTCO_2e$)	44.2	31.2	23.9	23.9

2050 Results

	Ref (levels)	Linear	Interim Target	**Core**
GDP ($B)	$526.2	2.55%	2.19%	2.55%
Consumption	$266.3	2.40%	2.02%	2.40%
Jobs	-	1.08%	0.93%	1.08%
Wages	-	0.46%	0.42%	0.46%
FTE ('000)	4,393	48	41	48
GHG (%)	-	-82%	-82%	-82%
GHG ($MMTCO_2e$)	48.5	8.7	8.7	8.7

Notes: All entries except in Reference column represent changes from the Reference scenario in the year indicated, in percentage or the units given in parantheses. Gross Domestic Product (GDP, value added) and real household Consumption are measured in constant (2016) dollars. Employment chages are measured in thousands of Full Time Equivalent (FTE) annual jobs. GHG measures annual Oregon covered emission changes (% from Reference) and levels ($MMTCO_2e$) for the given year and scenario.

4.1 Spatial Impacts

The BEAR model produces personal income and job impact estimates measured as total real (2016 dollar) household incomes and Full Time Equivalent (FTE) jobs. At the statewide level, Figure 4.1 breaks down income effects by Bureau of Labor Statistics tax brackets. Salient features of these results include the fact that the lowest income groups benefit significantly. This is because energy costs are a larger percent of their incomes. After this, real income gains are driven by two forces, energy efficiency savings (increasing with household income) and job creation/wage appreciation driven by the stimulus of expenditure shifting.

These impacts can then be downscaled from the state to the census tract or county using occupational and sector employment information in the census. We use 5-year American Community Survey estimates (2012-2016) of the share of households with residents employed in each sector and each occupation. We assume that wages within sectors and occupations are uniform across the state, and that Oregon is one labor market. These labor mobility and competitiveness assumptions may not apply precisely in all cases, but the results we obtain are qualitatively robust.

Direct employment is distinguished from indirect and induced employment using employment intensities for the sectors directly impacted by the cap-and-trade decarbonization scenarios. These direct effects are then netted out to determine the indirect and induced employment impacts of the decarbonization scenario. The following figures illustrate the spatial impacts of our Core scenario on income and jobs, estimated at the county and census tract level.[4]

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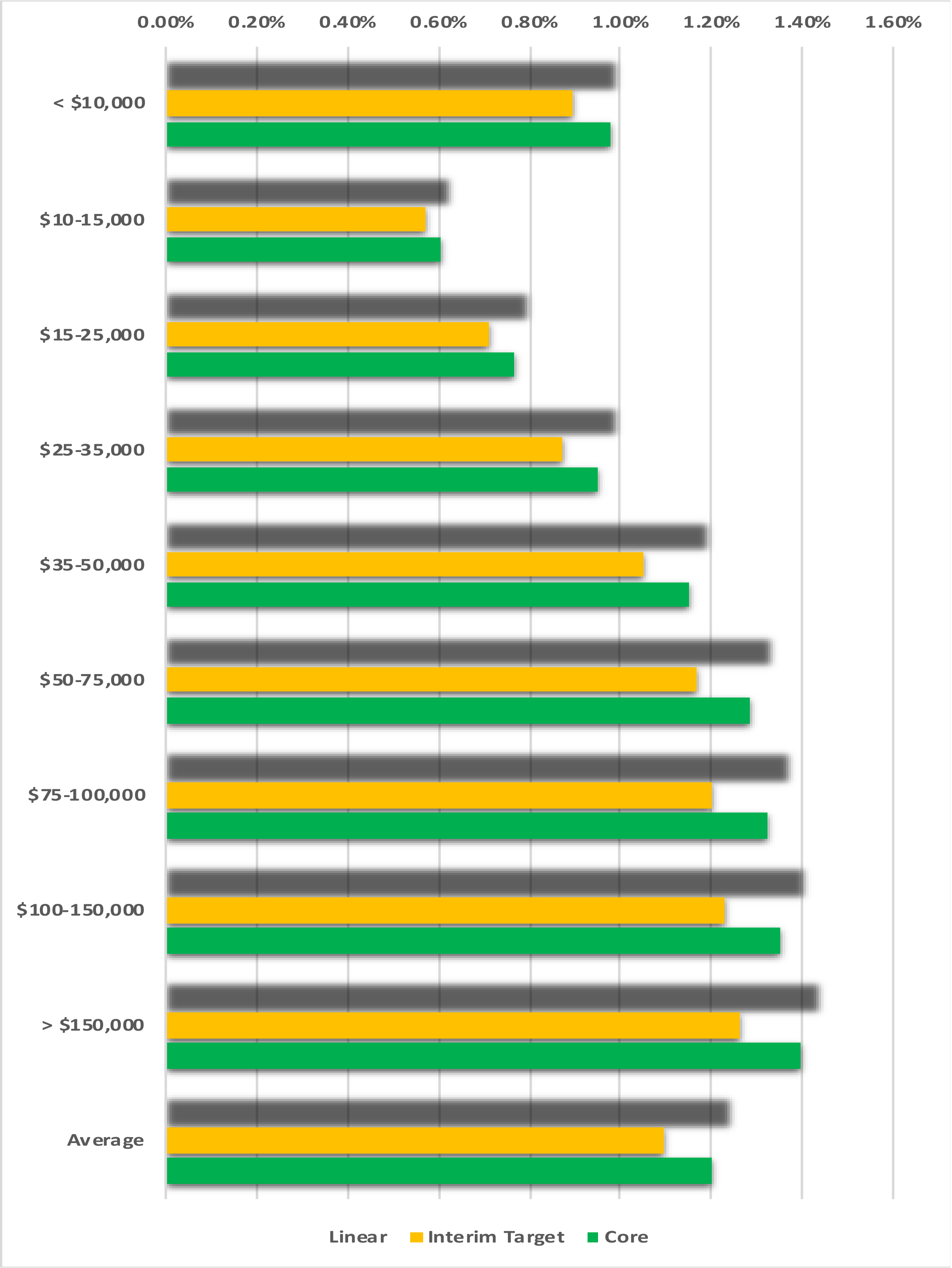
[4] It should be noted that we do not have enough information to predict the exact location of new jobs so we assume that future jobs are created in the locations where current jobs exist. Therefore, we are assuming that future jobs, within a given sector and occupation, are uniformly spatially distributed across the locations of current workers. Relying on this assumption, allows us to allocate total job changes at the state level evenly to households within that sector and occupation. For example, we are assuming that construction jobs in 2030 are in the same locations that they are now so all new 2030 construction jobs are assigned to each census tract proportionally to the number of current construction workers. If new construction jobs are generated in places that do not currently have construction jobs those jobs would be captured in our macro estimates but would not be assigned to the correct census tracts.

**Figure 4.1: Household Income Effects by Income Level
(BLS tax brackets, percent change from Reference in 2050)**



For incomes, level changes are largely proportional to average incomes, so we are effectively seeing the initial income distribution in Figure 4.2, i.e. higher absolute gains in higher income counties. More interesting is Figure 4.3, where we see that percentage gains in income are much more widely distributed across the state. The same holds for job creation, revealing one fundamental aspect of our findings – energy savings and multipliers from expenditure diversion create much more inclusive income and job growth. More dramatically, we see in Figures 4.4 and 4.7 that income and job creation among the lower quintile of Oregon households is concentrated in rural areas. This is a testament to the economic benefit of adopting energy efficient technology. As already noted, these households are relatively more energy dependent as a percent of their income, so they benefit more from the adoption of cost saving technologies by utilities, vehicle owners, and manufacturers.

Figure 4.2: Median Household Income Level Change by County

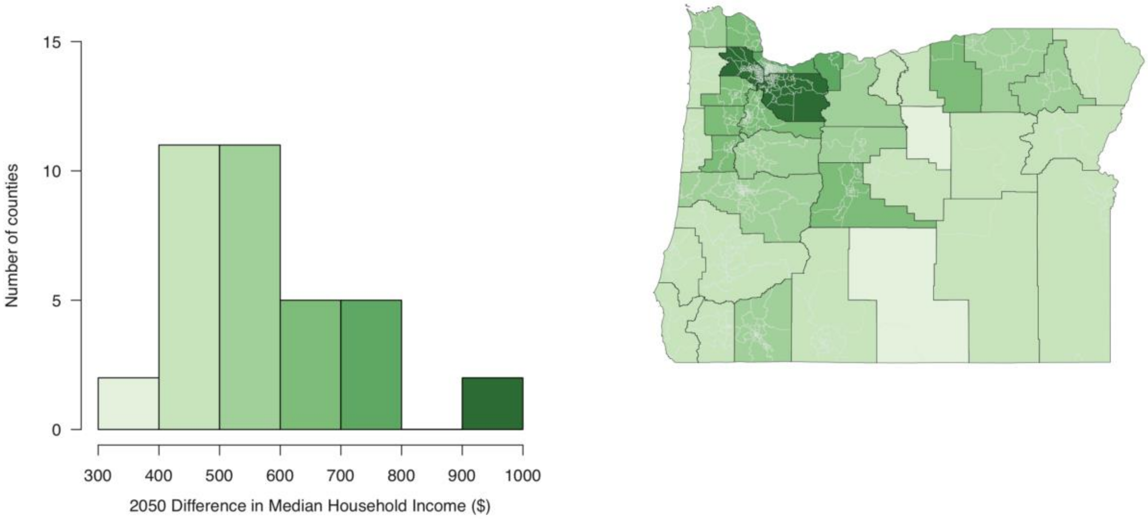


Figure 4.3: Median Household Income Percent Change by County

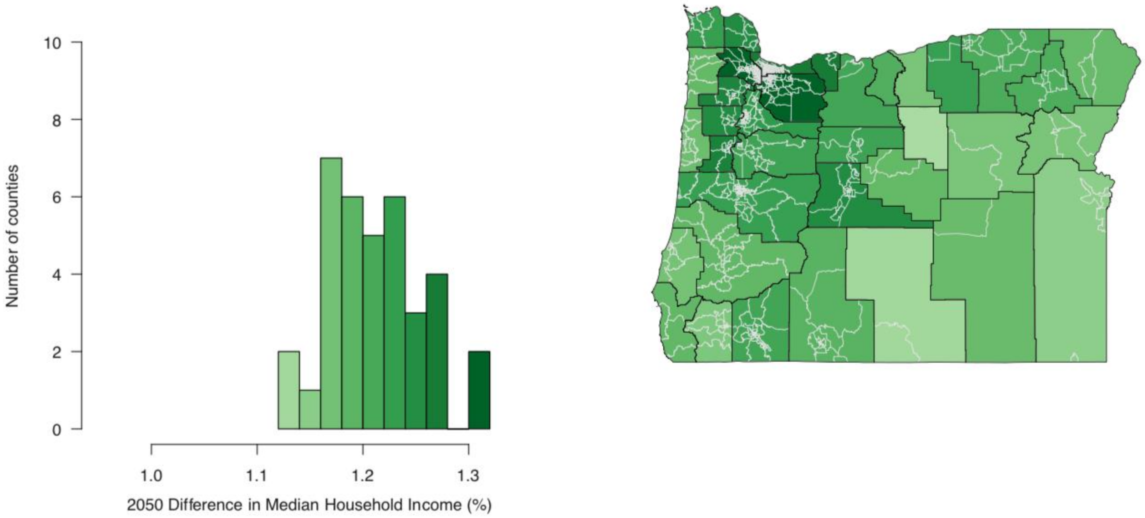


Figure 4.4: Median Low Income (quintile) Income Percent Change

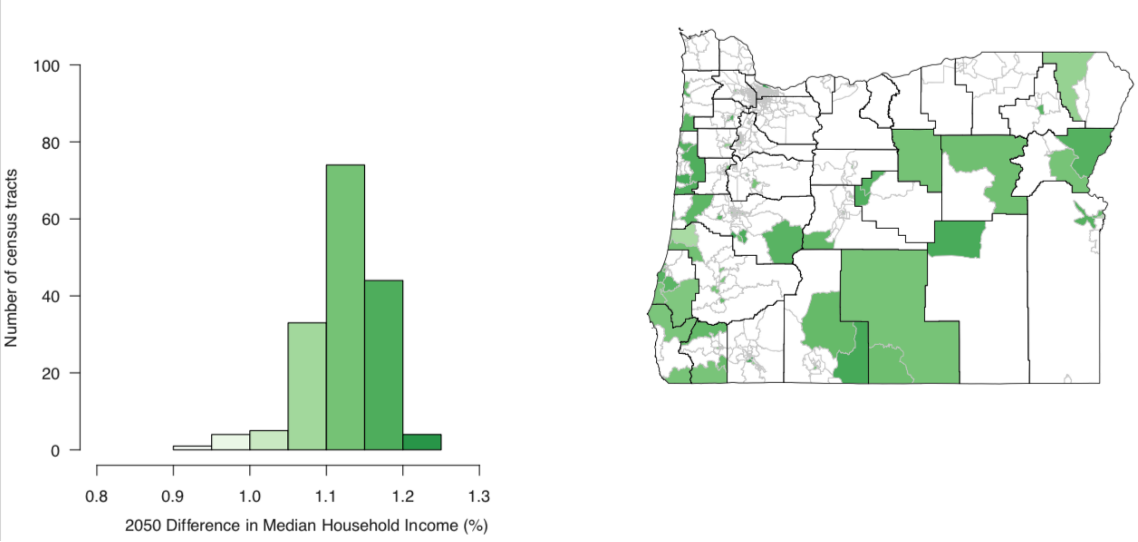


Figure 4.5: Net Job Creation by County (FTE change)

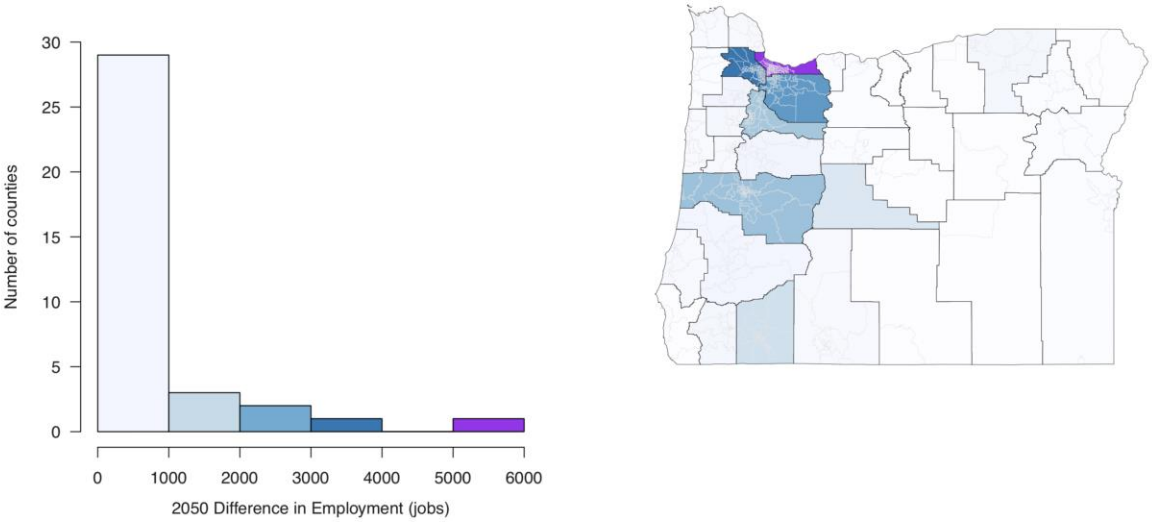


Figure 4.6: Net Job Creation by County (percent change)

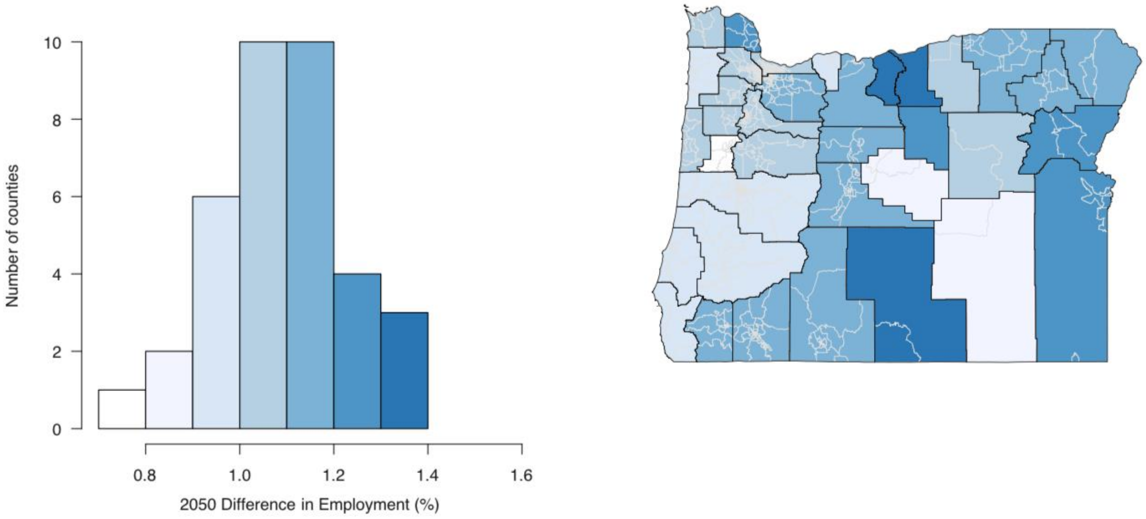
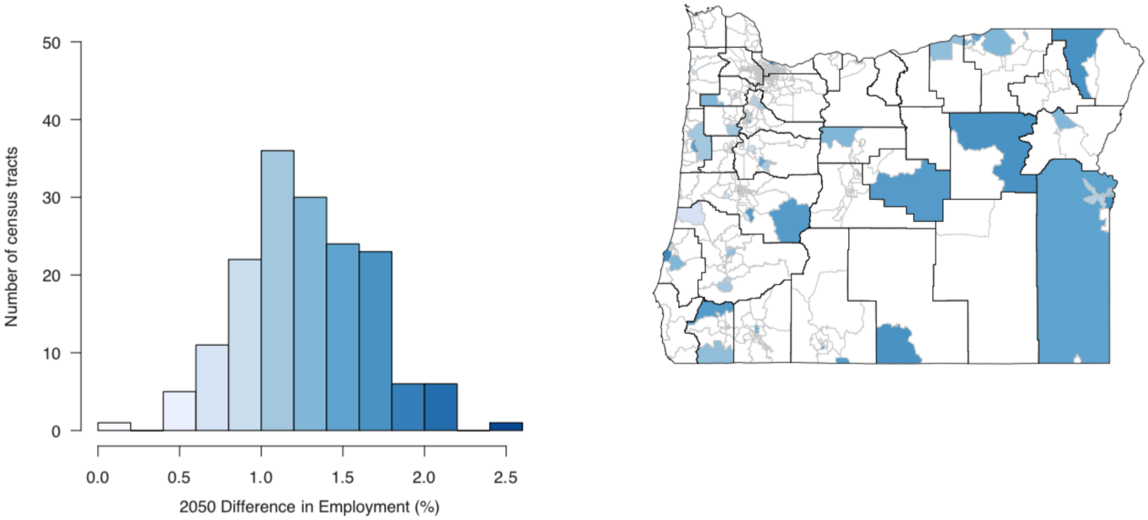


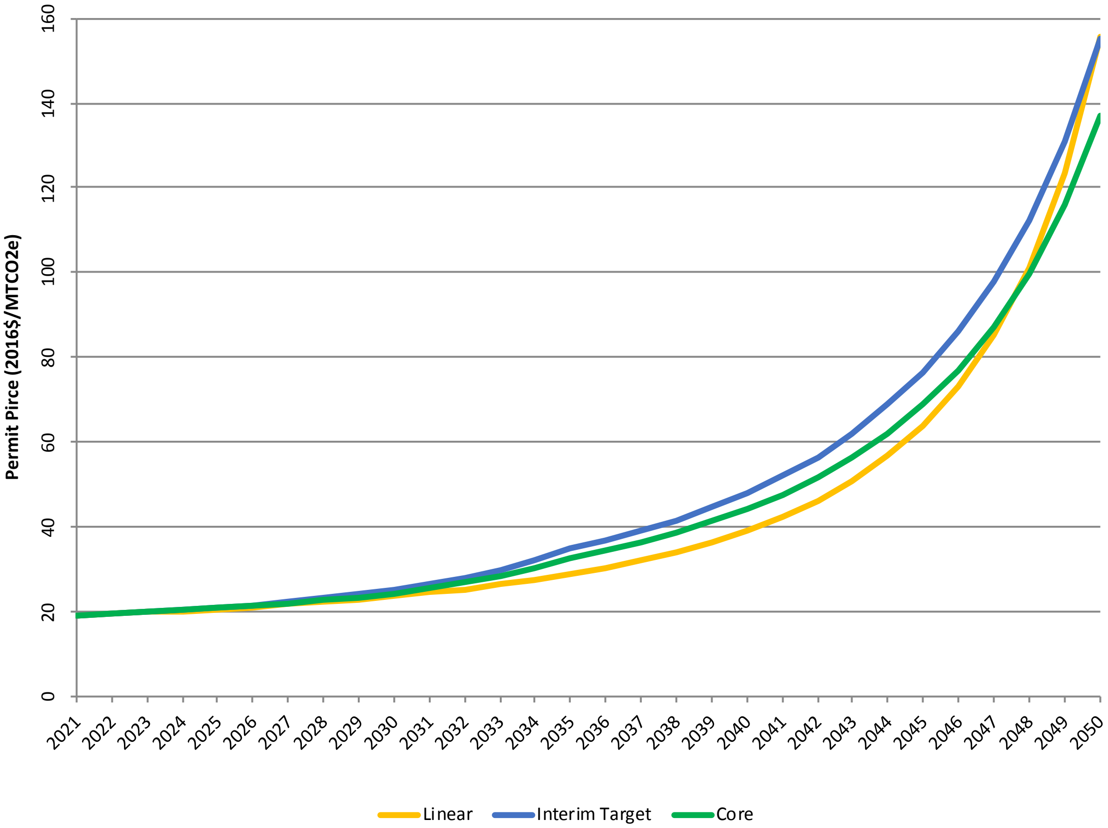
Figure 4.7: Net Low Income (quintile) Job Creation (percent change)



4.2 Permit Prices

Another important feature of our results is explicit projection of permit prices that would result from cap-and-trade operating under the scenarios considered. Figure 4.8 illustrates these estimates in 2016 dollars per $MTCO_2e$, and several salient features are immediately apparent. Firstly, permit prices are generally relatively low, reflecting experience in other markets and suggesting that direct (permit) and indirect (investment) compliance costs are manageable even under the more ambitious Interim Target mitigation pathway. In all scenarios reported in Figure 4.8, the Oregon market is not linked with the WCI.

Figure 4.8: Estimated Permit Prices Rise Slowly Until Nearly 2040



There is understandable concern among stakeholders about the effect of cap-and-trade on end user energy prices. Our permit price estimates reflect the fact that decarbonization will be driven by adoption of cost saving technologies, not higher fuel prices, in the electric power and transportation sectors. As we explain below, these two primary sources of GHG emissions already offer technology choices that can save energy and return those savings to ratepayers and vehicle owners. In both sectors, diffusion of these technologies will keep prices relatively stable. For example, we do not envision gasoline prices rising by more than 15-25 cents per gallon during this period.[5] During the second half of the process, pressure from permit prices may increase because of the challenge posed by natural gas heating in the building stock, but this should provide strong impetus to the innovation community.

Secondly, it is clear that a more flexible approach to recognizing mitigation can be cost effective for Oregon. Note that we have assumed for the sake of this scenario that offset mitigation credits are relatively costly, i.e. equal to the price of in-state emission permits obtained at auction. In reality, there are likely to be abundant sources of in-state, domestic, and regional (WCI), and even international mitigation that are cheaper than GHG reductions in Oregon.[6] Even in the (unlikely) event that offsets credits are the same price as HB2020 auction permits, access to offsets would eventually reduce direct compliance costs by about 12 percent for the Core policy scenario.

The reason auction prices are lower, even though external credits are priced at parity to them, is because the credit allowances effectively loosen the cap by diverting permit demand, increasing availability for those who buy in-state permits. Of course it should be emphasized that the same GHG mitigation is achieved globally, and we have chosen to eliminate credit allowances by 2050, meaning Oregon meets its ultimate mitigation goal within the state. Third, note that permit prices are relatively stable for the first 15 years, even with the ambitious Interim Targets of the Core scenario rise sharply for the more ambitious pathway because they share the same 2050 target.

Permit prices under the cap-and-trade scenario are likely to be considerably lower thanks to the existence of complementary regulatory policies such as the RPS and the Clean Fuels Program. Conversely, economic impacts towards the end of the forecast period are likely to be sensitive to the effectiveness of existing complementary policies. For example, if policies such as the RPS and the Zero Emissions Vehicle mandate are more effective than anticipated, the reported economic effects are likely to represent a conservative estimate of the true

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[5] Actual market price estimation should be done with detailed econometric evidence, not macro models.

[6] For example, the International Commercial Airline Association (representing 90% of global passenger capacity) has announced that the plan to securitized 100% if their GHG emissions by 2025. Their own auditors estimated that the cost of this (from existing offset sources) would equal just 1% of revenue.

economic impacts of the cap-and-trade program. If the existing regulatory programs are less effective than expected, it is likely the results reported here will underestimate the economy-wide costs of the proposed cap-and-trade program. Furthermore, this analysis extends beyond the time period of certain existing regulatory policies, although we have assumed that these policies continue out to 2050. This creates some uncertainty around how much the cap-and-trade program itself will be responsible for reducing emissions, as opposed to complementary policies.

According to our estimates, Oregon in the aggregate will be able to achieve relatively cost-effective mitigation, limiting demand for permits to levels that generate low prices in the early years, rising in later years significantly, but still only to median expectations. That being said, not all economic actors will benefit equally. Some entities may experience difficulties associated with paying higher carbon prices. It should also be emphasized that, like all forecasts, these estimates can be taken with higher confidence in the early years. This is important, as our data reflect costs and benefits of adopting existing or on-the-shelf technologies, extrapolated at historically established rates of innovation and efficiency improvement (more on this below). Thus, our estimates indicate that diffusion of available technology can cost-effectively meet the state’s emission objectives for the next one or two decades, but marginal pollution abatement costs will rise significantly (but affordably) in the later years. This pattern reflects uncertainty about the potential for further innovation.

The composition of energy cost impacts has two primary dimensions. The first divides the energy supply between its main end-user sources, electric power, natural gas, transport fuels. In the case of electric power, our results show the potential for renewable substitution to lower utility costs and enable reductions for Oregon ratepayers. Our macro model assumes that utilities invest in the most cost-effective non-coal sources of power and pass their cost savings on to ratepayers. For electric power users his means long-term savings from combined renewable deployment and more efficient use technologies.[7]

Natural gas users are quite diverse and span the entire enterprise and household communities. Apart from the electric power sector, whose primary decarbonization pathway is renewable energy deployment, the major categories of end use are industrial processes and heating of residential and commercial buildings. Industrial gas transition will be a case-by-case experience, one that can be facilitated by both technology adoption and flexible permit allocation to bridge financing

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[7] In their own cost projection compliance documents, Oregon utilities are already reporting expected cost savings from renewable deployment.

requirements. These sectors should be closely watched to promote efficient solutions to the adoption challenges they face. In the context of heating, electrification solutions exist but will take time because of slow turnover of the capital stock and the need for relatively long-term financing. Again, supporting policies can be considered in this case, but in the absence of significant innovation we estimate that this late stage decarbonization will increase permit prices through the last 10-15 years of the period considered (Figure 4.8).

For transport fuels, the picture is different. Conventional fuels like gasoline will experience increasing marginal costs from cap-and-trade permit prices, but the main determinant will be global oil markets, over which Oregon has no control. In this context the decarbonization incentives of the permit system can promote energy security and limit fluctuations in transportation costs. Permit-induced increases are estimated to be much smaller than historical oil price volatility, in the range of 15-25 cents more per gallon in the early years, but declining in importance with reduced dependence on conventional fuels. Having said this, vehicle owner's vulnerability to these price increases depending on many factors. Although some households spend more on transport fuel than others, the statewide average is a low single-digit percentage of total consumption. This reasoning assumes, however, that vehicle technology remains constant. We argue the opposite below, that Oregonians already have important opportunities from new vehicle technologies, holding the potential for substantial savings at today's fuel prices. If the next thirty years sees them respond to these incentives, conventional fuel prices will have negligible impact on their future. Instead, as in the past, technological change will be improving their economic prospects and their quality of life.

The second dimension of energy impacts relates to intensity of energy use. Households can be diverse in this respect, but industries vary much more in their energy intensity per unit of output and (especially) in the intensity of particular uses by source of energy. The category of emissions intensive and trade exposed (EITE) sectors exemplifies this, identifying sectors with high compliance costs as a percentage of total cost and dependence on export activities which could be undermined by higher compliance costs.

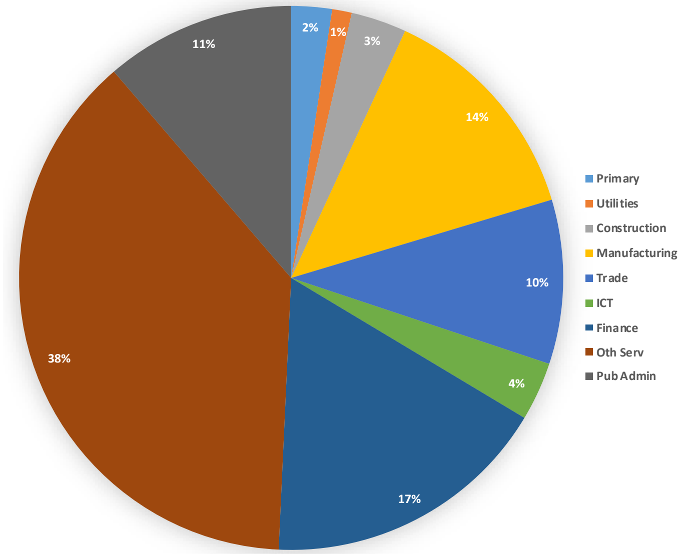
While EITE enterprises are of course essential to their owners, employees, and local communities, they comprise a modest share of the state's GDP (Figure 4.9). This suggests that we should look for complementary policies that can take account of their adjustment needs without sacrificing the overall economic and environmental benefits of cap-and-trade. This reasoning is a primary justification for HB2020's permit allocation rules to EITE sectors.

In summary, the estimated permit price pathways indicate a relatively smooth transition is ahead for the first one or two decades of cap-and-trade, and we hope innovation can simply extend this by reducing the cost of use technologies even further. We have not assumed this will happen, but historical evidence certainly supports optimism in this regard. To see how dramatic the difference can be between expected and actual adjustment costs, it is worth recalling the first years of California's cap-and-trade system. In the legislative runup to AB32, many stakeholders claimed permit prices would exceed $100-150 at opening, and one study by a respected consultancy estimated prices over $400 per MT. The real evidence is now available (Figure 4.9) and, after initial market "disagreement" (volatility) in the first year, the price has settled into the low teens. Surely it won't stay at such a low level indefinitely, but this experience is testimony to the important of testing market hypotheses.

Figure 4.9: California's Recent Permit Price History

5-day moving average price and volume of California Carbon Allowance Futures over time from ICE End of Day Reports. Daily trading volume units are 1000 allowance futures. Download data.

Figure 4.10: Composition of Oregon Gross State Product by Activity (2016 percentages)



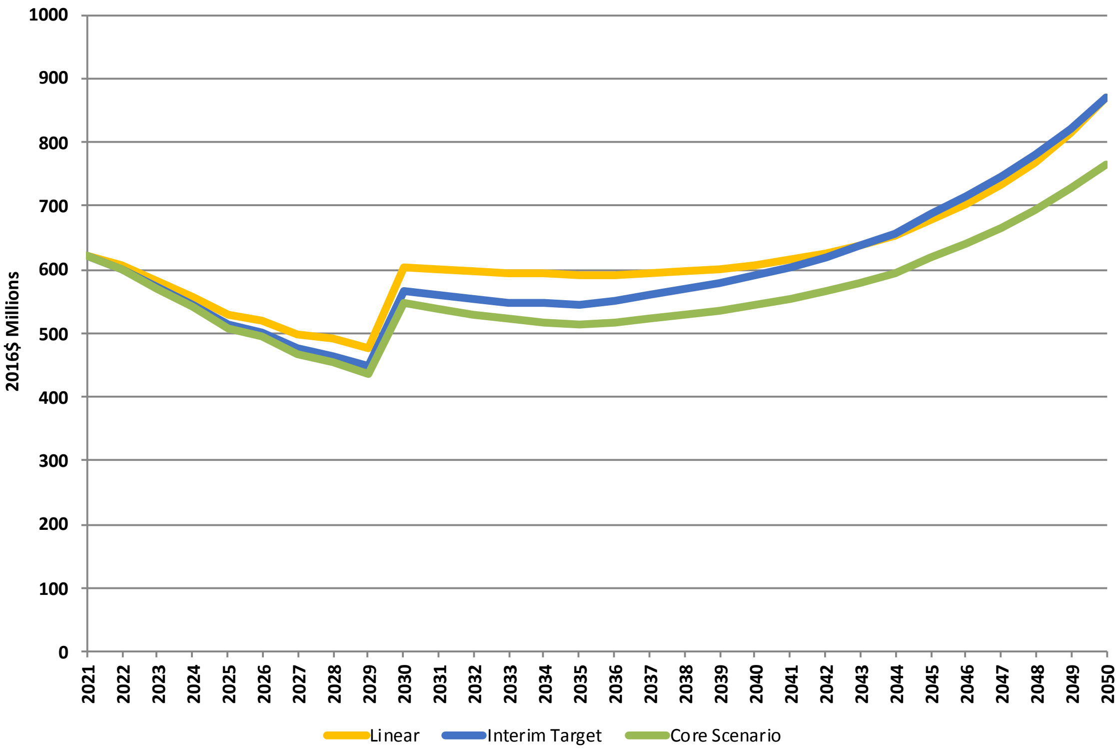
Source: US Bureau of Economic Statistics

4.3 Permit Revenues

Figures 4.11 and 4.12 show, for our three main cap-and-trade scenarios, expected total auction revenue and allocation of that revenue. Figure 4.11 reveals three main features of the scenarios:

1. Auction revenue falls with reduced permit issuance (at relatively stable permit prices), rises sharply with allowance reduction and coal retirement, and then rises steadily as permit price profile steepens in the latter half of the scenario interval.
2. Quantity effects dominate this market, i.e. the more stringent Interim Target and Core scenarios yield lower revenue because permit supplies fall faster than prices rise, at least until the last decade.
3. Offsets provide adjustment assistance to the entire market by depressing permit prices (up to about 12% by the last decade).

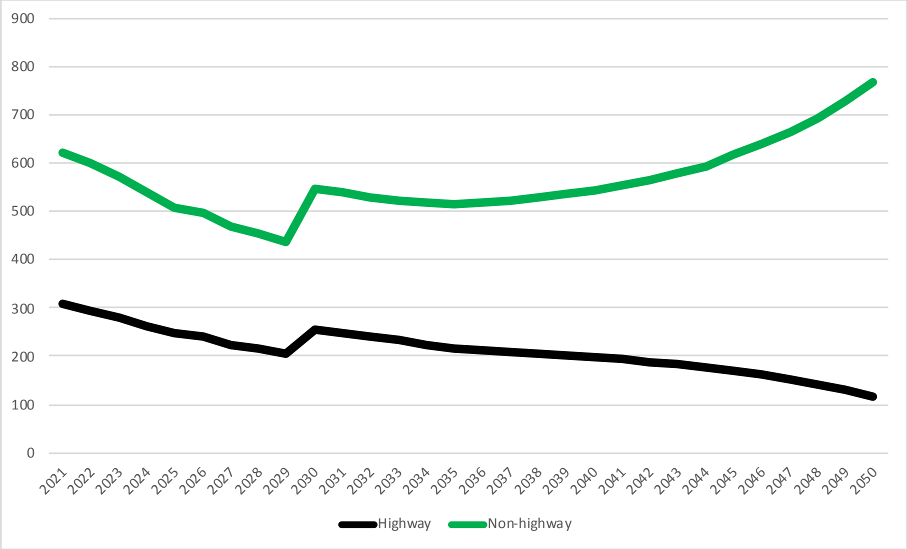
Figure 4.11: Estimated Permit Revenues by Mitigation Pathway



Source: Author estimates.

Revenues from auctioned permits are received by the state and allocated to two basic categories: funds from transport-related revenue and other funds. For cap-and-trade, the first category includes revenue from all permits sold to cover transport emissions, with which funds are currently mandated to Oregon highway maintenance, construction, and related projects. Because of the share of transport in total emissions and the fact that they receive no concessional permit allocation, about half of cumulative revenues would initially be assigned to the Highway Fund. However, over the next 30 years electrification of the vehicle fleet is projected to reduce fuel use by more than 80%. Despite rising permit prices, we estimate that this will reduce the Highway Fund share of revenues to about 100 million (2016) dollars by 2050.

Figure 4.12: Estimated Permit Revenue Allocation - Core Scenario (cumulative)

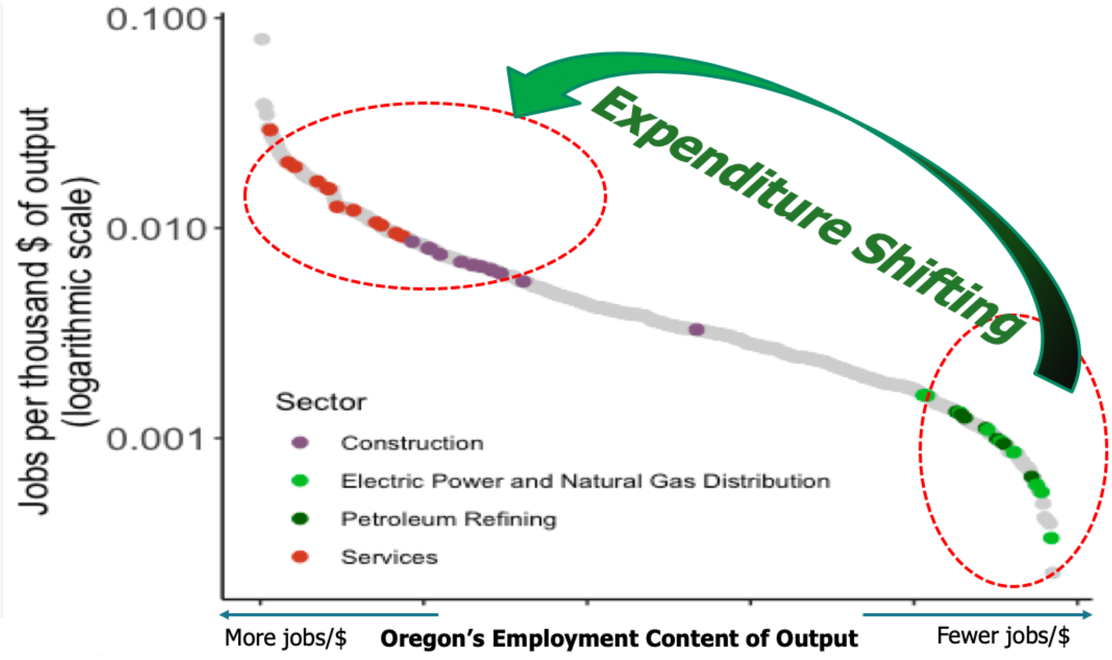


Source: Author estimates.

4.4 Macroeconomic Impacts from Cap-and-Trade

Using a state-of-the-art behavioral model, the BEAR model is calibrated to the most up-to-date information on the Oregon economy, emissions, and technology costs. This forecasting tool tracks interactions between multiple sectors and attendant patterns of demand, supply, employment, trade, investment, and many other variables, forecasting annually over a 34-year period. Despite many technical details, however, the macroeconomic impacts we estimate from cap-and-trade are consistent with straightforward economic reasoning: Technology adoption allows enterprises and households to save money on conventional energy resources, and these savings are recycled to stimulate more job-intensive employment and income growth.

Figure 4.13: How Energy Efficiency Creates Jobs



Source: US Bureau of Labor Statistics.

Energy efficiency results in economic savings if the economic benefit of reduced energy use outweighs the cost of adopting the more efficient technology. The best evidence available on this is California, which has maintained a combination of appliance and building standards and utility incentive programs since the early 1970's. In response to this, and even before AB32, the state went from parity to household electricity use levels that were 40% below the national average. These savings diverted household and enterprise expenditure from the carbon fuel supply chain to (mainly) services and manufactures, both of which are significantly more job intensive (Figure 4.13). If renewable penetration goes forward as expected, these savings can be compounded by declining unit costs of electricity supply, after discounting for and "rebound effect" that results from increased demand.[8]

To assess the economy-wide impacts of our efficiency and electric vehicle scenarios, we calibrated our model to the most recent information on present and future energy technology costs. These estimates, produced by ICF (2014) and E3 (2015), show net long term savings for both those who adopt electric vehicles and, because of capacity grid adjustments resulting from large scale EV adoption, reduced system wide electricity rates. Including their estimates of these incremental microeconomic benefits in our economy-wide model leads to gains for

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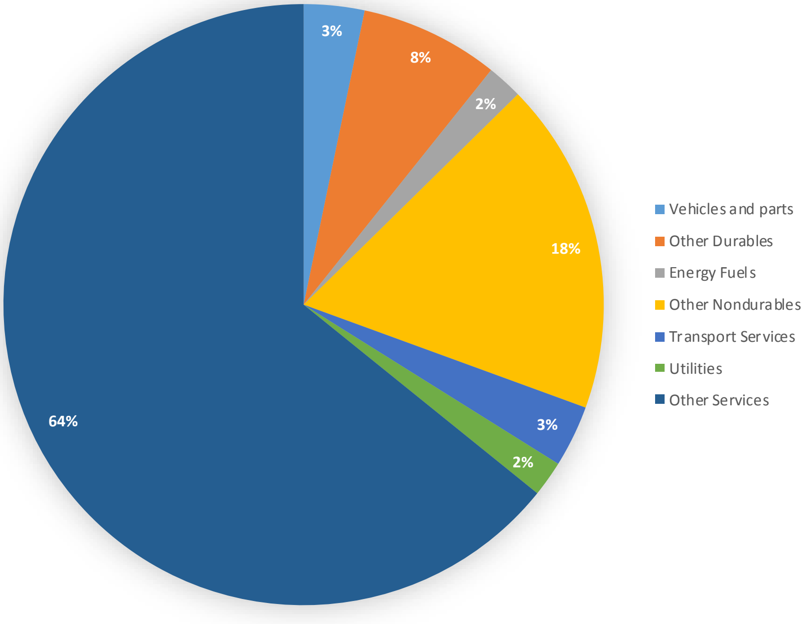
[8] There is general agreement the rebound effects in electricity demand are less than 20%, meaning the at least 80% of price reductions in electricity translate into ratepayer savings.

individual households and enterprises, amplified by multiplier effects from recycling their energy savings into other expenditures. For Oregon, expenditure shifting also has strong potential for broad based job creation and inclusive economic growth. As the following figure makes clear, over two-thirds of real household consumption in Oregon goes to services.

Figure 4.14: Oregon Household Consumption Expenditure (2017 percent shares)



Source: US Bureau of Economic Statistics

Permit prices will certainly escalate the costs of transport fuels, but this will only increase the potential savings available from new vehicle technologies. In our discussion of vehicle electrification below, we show that even in the absence of cap-and-trade, Oregon drivers can realize significant savings from electric vehicles. Over the next three decades, the average light vehicle owner will replace their car or truck three times. This opportunity for technology change can be the key to saving money on personal transportation and lower carbon economic growth.

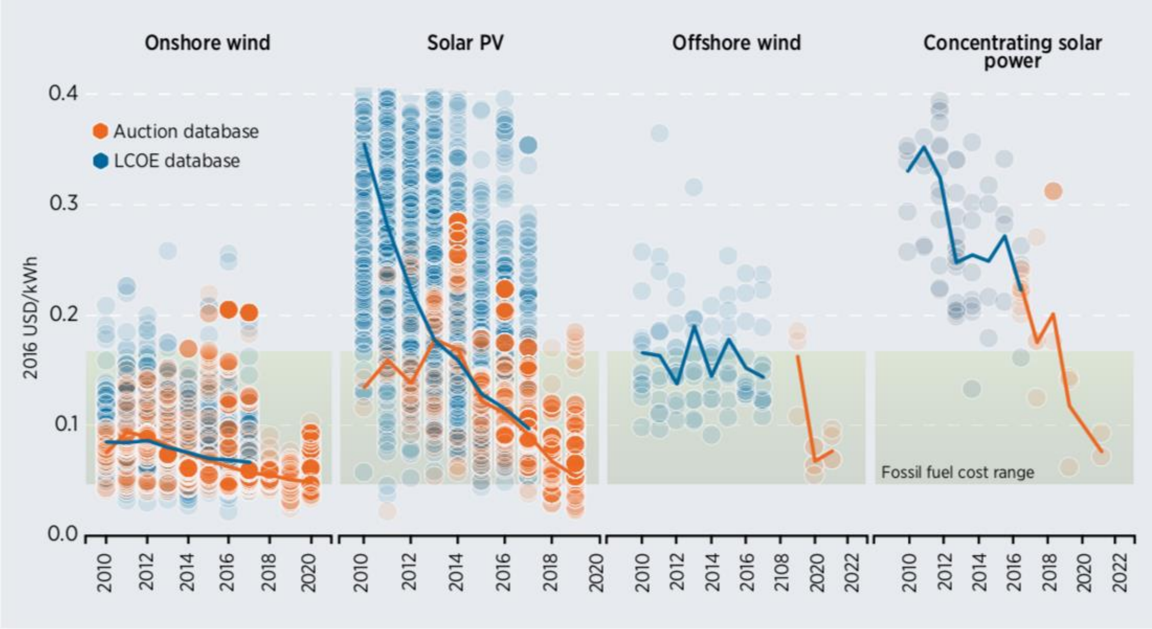
Taken together, these estimated effects suggest HB2020 and complementary policies would support higher and more inclusive long term economic growth for Oregon. The intuition behind this finding is the following: If you take a dollar out of the gas pump and give it to an average Oregon household, they will spend it on a diverse array of in-state goods and services that average 16 times the employment potential in terms of jobs per dollar of revenue.

4.5 Renewable Deployment

Renewable energy is playing a rapidly growing role in local, national, and global environmental policy, and Oregon set an ambitious 50% by 2040 Renewable Portfolio Standard (RPS) to affirm this fact. A large part of the renewable energy mix: solar, wind, and geothermal, represents a fundamentally new energy supply paradigm. Because they are exhaustible resources, fossil fuel supplies and prices are determined primarily by scarcity, while these renewables represent essentially boundless resources relative to today's energy requirements. In the latter case the constraint to supply is not scarcity, but technological change. Recent trends in renewable technology show that these costs can fall dramatically with scale and learning.

As mentioned above, the existing RPS commitment to 50% RPS by 2040 is incorporated into our Reference scenario. However, it must be recognized that, because of continuing trends in renewable competitiveness, cap-and-trade will certainly drive more diffusion of these technologies across the electric power sector. Indeed, this will be essential to achieving Oregon's 80% decarbonization target by 2050. Because of dramatic and continued reductions in renewable energy cost, solar and wind energy are now reaching the bottom of the price band for existing electric power from all fossil fuel sources (Figure 4.15).

Figure 4.15: Global Levelized Cost of Renewable Electricity and Auction Price Trends



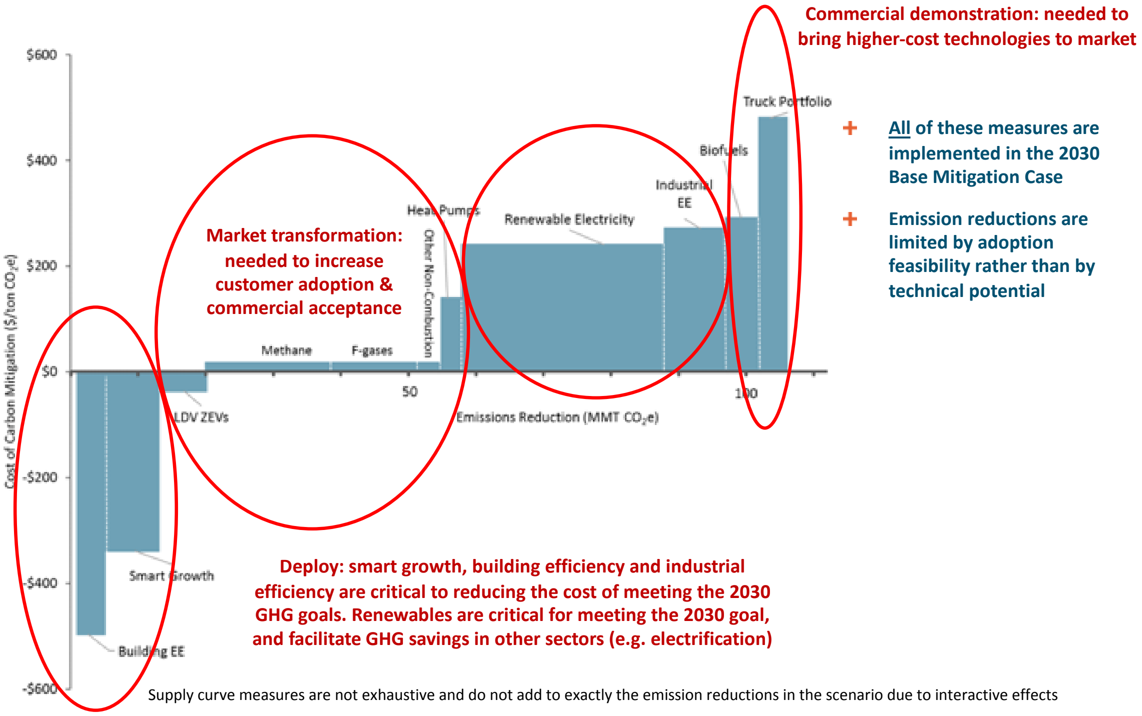
Source IRENA Renewable Cost Database

4.6 Mitigation Pathways

In a macroeconomic assessment like the present one, opportunities and actions for pollution reduction are generalized from average cost estimates, relative price changes, and responses of average enterprises across the Oregon economy. In this top-down framework, cost trends in renewable energy and energy efficient technologies facilitate parallel reductions in emissions and carbon fuel use, leading the economy toward its 2050 emission goals. The generality of this approach can be frustrating to those who might seek guidance about more detailed adjustment options and decisions by enterprises and stakeholders, but the fact is that every day the economy realizes and reconciles the independent decisions of millions of independent agents without a master planner in the background. More pointedly, economists can predict, but not dictate or even fully describe, all these activities.

Having said this, we can still learn much about mitigation pathways by examining the opportunities presented by existing technologies. For example, Figure 4.16 illustrates mitigation technology options available to California, in order of average adoption cost, and up to the mitigation goals set by this state for 2030. Of course all the same options are open to Oregon, and most would have comparable costs. A few important insights can be drawn from this more detailed data. First, all but the last 5% of emissions reductions could be achieved with technologies available today. Second, net costs of the first 20% are currently negative and for the next 40% they are negligible. Third, although net costs then rise substantially with renewable deployment, these are among the most rapidly declining technology costs, having fallen since the E3 study and probably continuing to do so, making this decarbonization pathway ever more affordable, reducing demand (and prices) for pollution permits. Finally, the above facts make it clear that achieving the Interim Targets is a question of behavior, not underlying cost. This of course means that policy determination will be essential to achieving the economic and social benefits of decarbonization.

Figure 4.16: Technology Options for Oregon to Reach It's 2035 Emissions Targets (California Example)



Commercial demonstration: needed to bring higher-cost technologies to market

\+ All of these measures are implemented in the 2030 Base Mitigation Case

\+ Emission reductions are limited by adoption feasibility rather than by technical potential

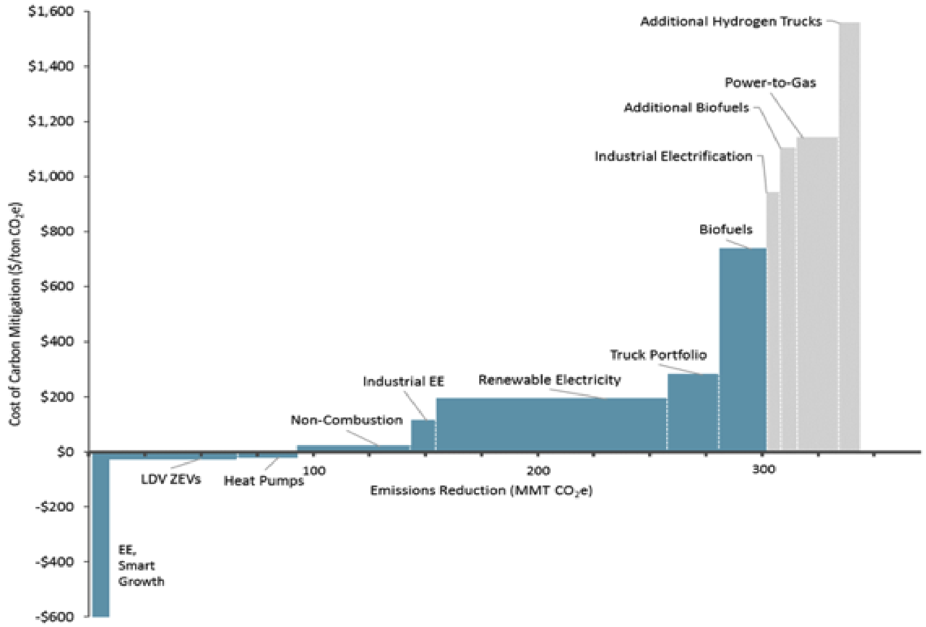
Market transformation: needed to increase customer adoption & commercial acceptance

Deploy: smart growth, building efficiency and industrial efficiency are critical to reducing the cost of meeting the 2030 GHG goals. Renewables are critical for meeting the 2030 goal, and facilitate GHG savings in other sectors (e.g. electrification)

Supply curve measures are not exhaustive and do not add to exactly the emission reductions in the scenario due to interactive effects

Source: E3 (2017).

Figure 4.17: Technology Options for California to Reach 2050 Emission Targets



Source: E3 (2017).

For comparison, the same estimates are presented in Figure 4.17 for California's 2050 emission goal, like Oregon an 80% reduction in GHG emissions from the 1990 reference level. Here we see more "reach" technologies, which will have to prove their emission and efficiency potential over the next three decades. Apart from these, however, most of the needed technologies await adoption now, but will probably only decline in cost with time. Again, we see that policy determination to effectively promote these technologies, using public information and incentives if needed, may be needed if marketing and carbon permit costs are not sufficient to achieve the necessary adoption and diffusion of low carbon technologies. Averaging the estimated costs over technologies to both 2030 and 2050, however, we see net costs per MT of GHG are comparable to Oregon – relatively low and stable in the first 15 years, rising appreciably but not prohibitively in the second 15 years. Of course, the second half of this interval will be inhabited by many different actors and technologies. A consistent price on carbon will certainly arouse the former to improve the latter.

4.7 Vehicle Technology Choice

Along with electric power, the transportation sector is a primary driver of global warming pollution in Oregon, comprising about half of the state's overall GHG emissions inventory. On-road vehicles constituted over 77% of transportation sector emissions. Of this category, light duty passenger vehicles accounted for approximately 69% of transport emissions in 2012. These emissions varied over the last decade, with the greatest decrease occurring at the time of the recession. In the summer of 2008, fuel prices reached a historic maximum, followed by a significant decrease in the consumption of gasoline and diesel fuel. Total transportation fuel consumption declined in 2008 and continued falling until 2014, but may be trending upward now.

It is unlikely for Oregon to achieve 80% decarbonization without a fundamental transition of its transportation system to electric power. Alternative fuels can be important sources of mitigation in the near term, but they cannot displace enough conventional fuel emissions to meet reductions by 2050 with current population growth trends and known technologies for biofuel production and distribution. Hydrogen is an emerging technology that may play an important role, but we do not evaluate it here.

We begin this section with a description of our modeling approach and assumptions regarding electrification of the light vehicle fleet. This is followed with an overview of prospects and challenges for leading Oregon policies toward this important sector. Our assumptions regarding vehicles explicitly recognize innovation processes and changing vehicle standards over the time period considered. To this end, we assume Internal Combustion Engine (ICE) vehicles attain higher average mpg in accordance with state and Federal regulations, and that conformity with these confers modestly higher costs, reaching a $2,000 premium over average 2012 prices by 2030 (less than 0.5% annual price appreciation). For PEV vehicles, we built our IVC estimates from the bottom up, using the most up-to-date electric vehicle technology data available. Batteries are a primary cost component in all PEVs, and here we have assumed steady but moderate progress or "learning" in this technology (see e.g. McKinsey: 2009a). The result, as indicated in Figure 4.18, is a cost/efficiency improvement of about 80% over the next two decades.[9]

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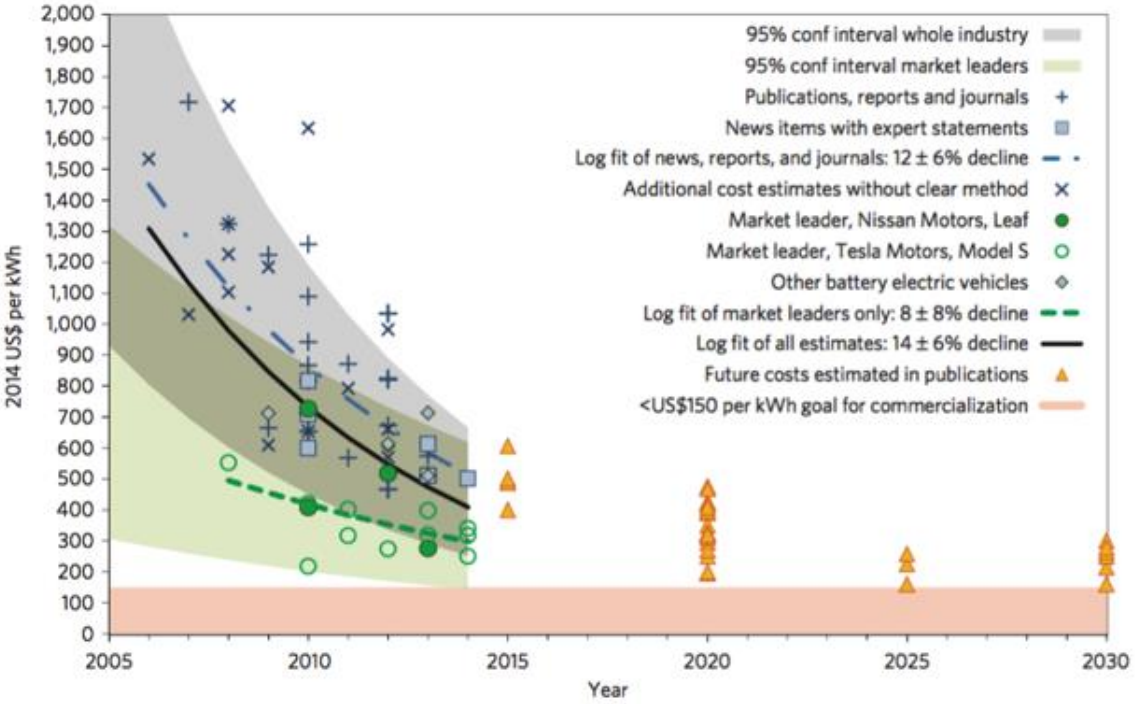
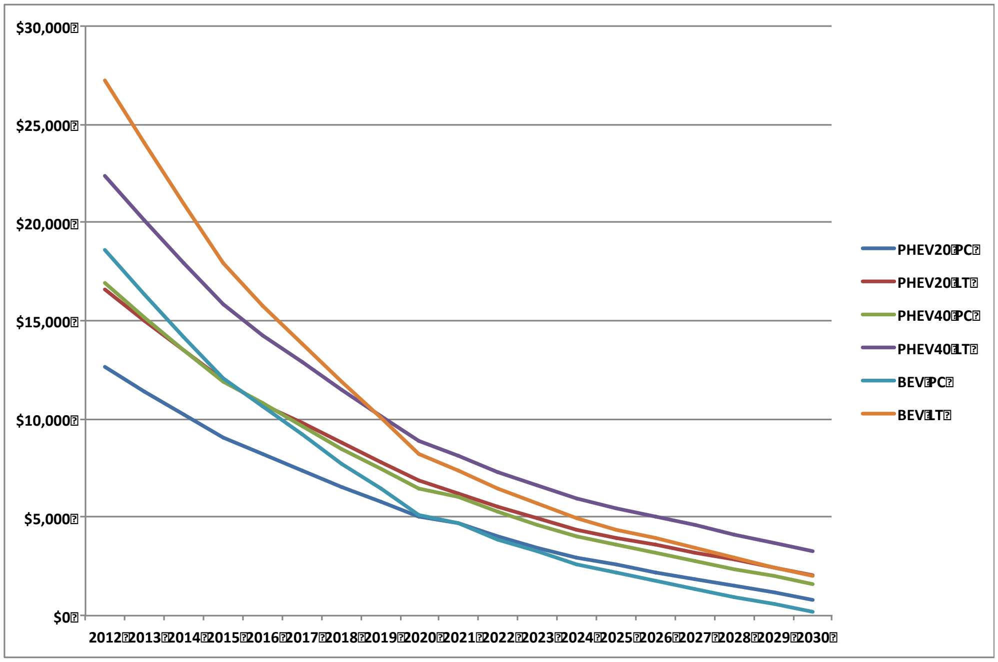
[9] The complete calculations are fully documented elsewhere, and can be made available up request.

Figure 4.18: Battery Cost/Efficiency: Look out below



Source: Nykvisk and Nilsson, Nature Climate Change.

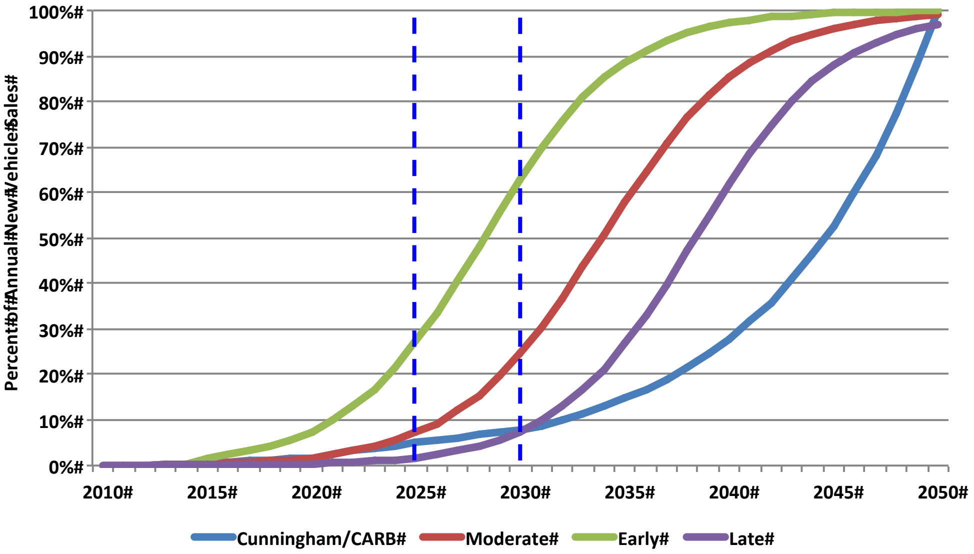
Figure 4.19: Incremental Vehicle Costs, by Vehicle Type



Sources: McKinsey, EPA, ARB, EPRI

After a review of the vehicle engineering literature and consultation with experts in this field, we have estimated incremental vehicle cost for PEVs using these battery cost profiles and a 30% mark-up on other power and drivetrain components. The resulting IVC trends for our analysis are summarized in Figure 4.20 for the six PEV vehicle types in our analysis (PC=passenger car, LT=light truck).

Figure 4.20: Scenarios for Battery Electric Vehicle Adoption



Our last scenario considers one of many possible adoption pathways for 100% light duty vehicle fleet electrification, or Battery Electric Vehicle (BEV) adoption, the Moderate profile in Figure 4.20. From a 2018 base of 4%, this calls for about 7% of new vehicles sales to be EV by 2025, increasing to 25% by 2030 and 100% by 2050.[10] For comparison, we also illustrate a California Air Resources Board proposal for more gradual early adoption, rapidly accelerating in the final decade.

Assuming the Moderate adoption profile for BEVs, along with an assumption of phasing out hybrid vehicles, we obtain the vehicle fleet transition implemented in the Core scenario and illustrated in Figure 4.21. With respect to current levels of BEV market penetration, this is a very different transportation sector, with far reaching implications for complementary technologies, infrastructure, electric power capacity, etc. All these issues require detailed evaluation to be most effectively supported by public policy and, in turn, for leading private stakeholders to effectively support climate policy. The state's ambitious goals have the best chance of success if they are based on this kind of constructive engagement.

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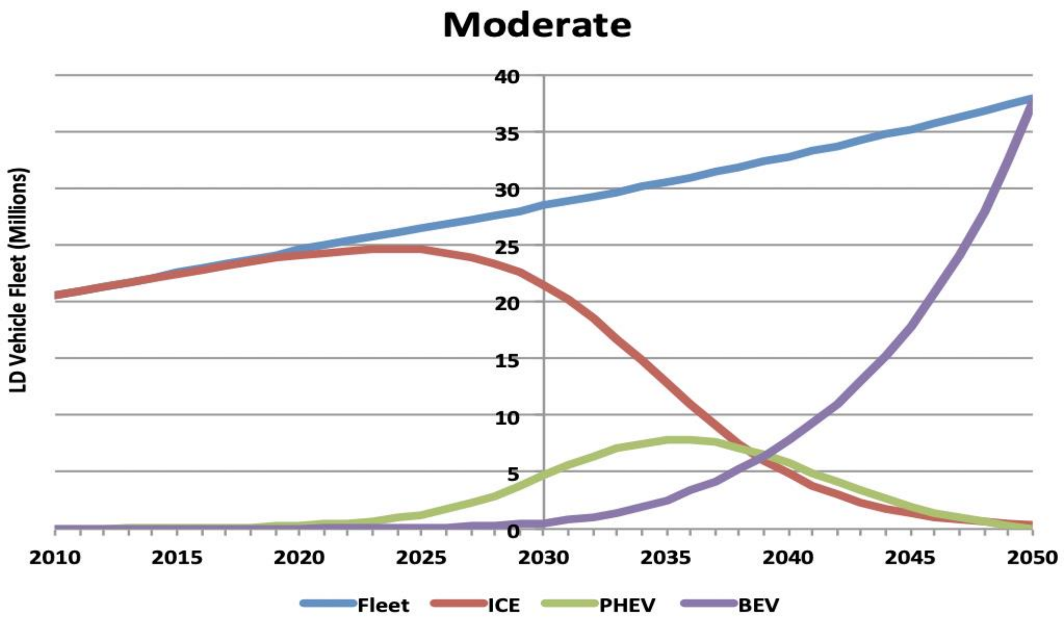
[10] To its credit, Oregon already has the second highest rate of EV adoption in the nation, according to the US Alliance of Auto Manufacturers.

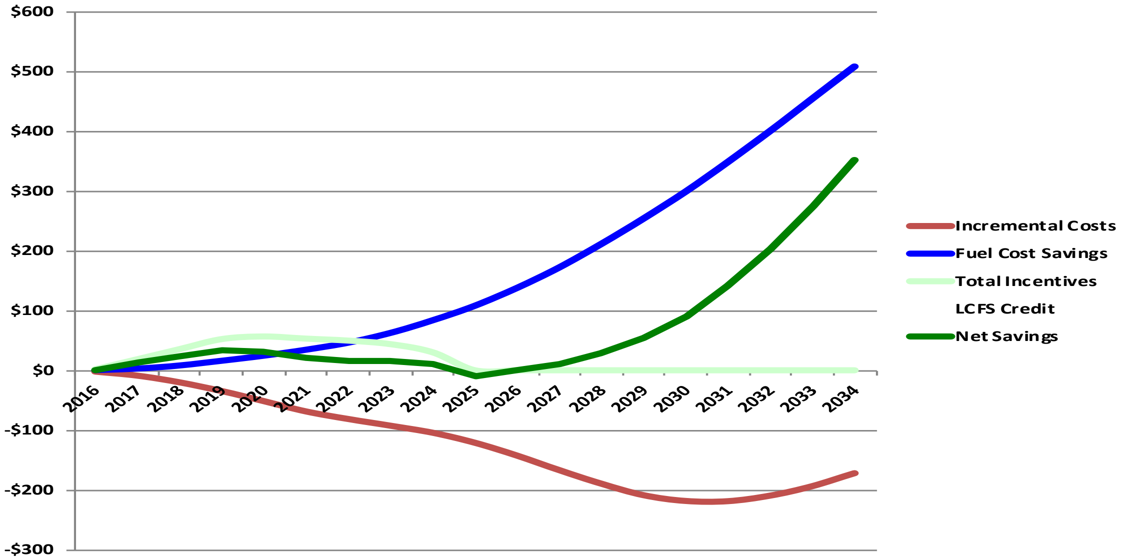
Figure 4.21: Oregon Vehicle Fleet – Moderate BEV Adoption Profile



Source: Author estimates. Vehicle classes are Internal Combustion Engine (ICE), Plug-in Hybrid Electric Vehicles (PHEV), and 100% electric or Battery Electric Vehicles (BEV)

Should the Moderate adoption pathway be achieved, the savings to Oregon drivers would be substantial. Figure 4.22 maps out aggregate vehicle costs and benefits for this adoption pathway, yielding nearly half a billion dollars in net savings by 2035. Via the expenditure shifting that these savings would enable, this would combine an important source of carbon mitigation with potential growth stimulus for the state economy.

**Figure 4.22: Potential Benefits and Costs of BEV Adoption
(2016 $ millions)**



Source: Author estimates.

We now provide an overview of climate related policies directed at transportation. Generally, Oregon's long-term criteria pollutant and GHG emissions goals will require four transportation-oriented strategies: (1) improve vehicle efficiency and develop zero emission technologies, (2) reduce the carbon content of fuels and provide market support to get these lower-carbon fuels into the marketplace, (3) plan and build communities to reduce vehicular GHG emissions and provide more transportation options, and (4) improve the efficiency and throughput of existing transportation systems.

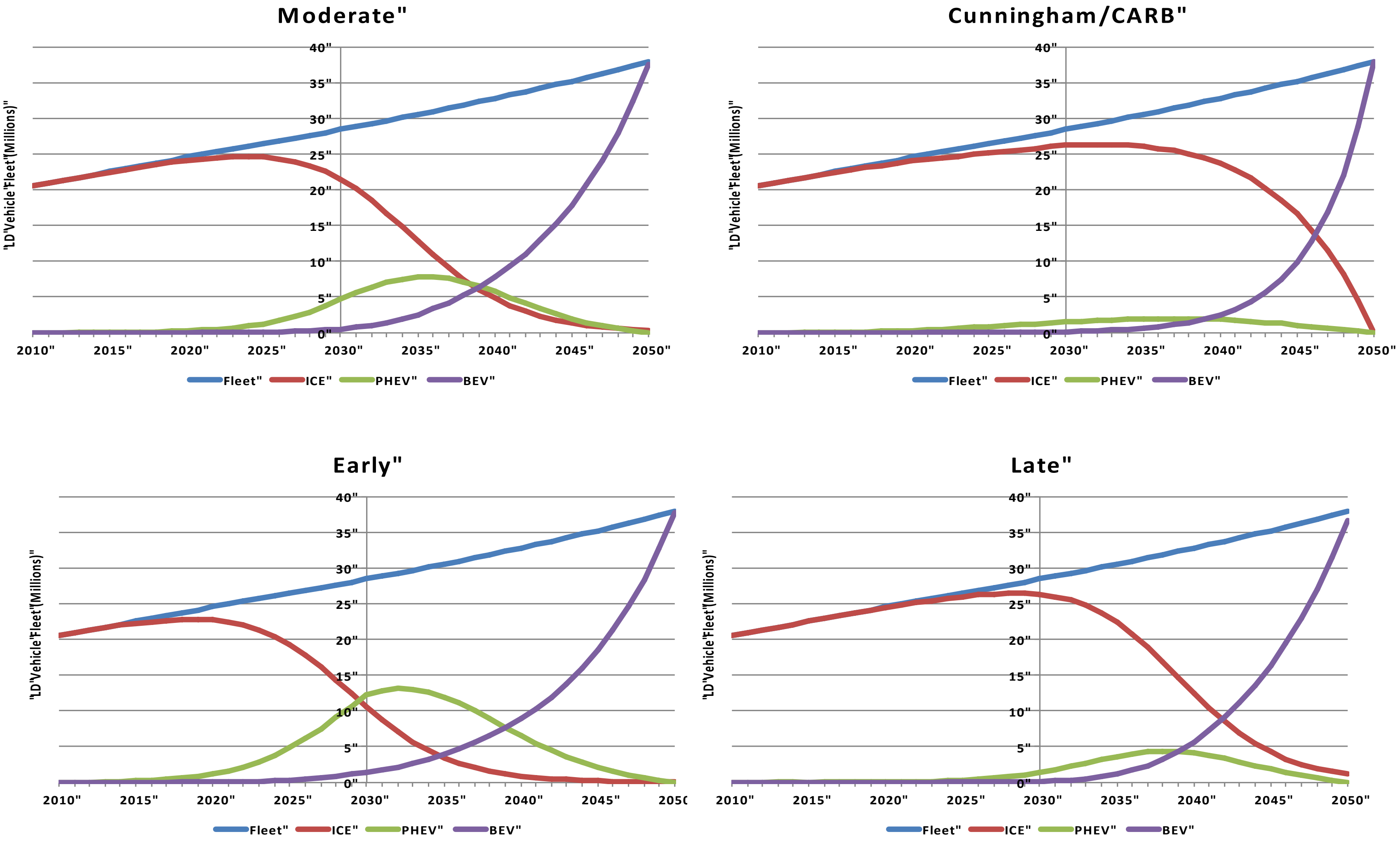
In summary,

- Light-duty vehicle electrification and vehicle fuel efficiency generally can be potent catalysts for Oregon's economic growth.
- Households and enterprises spend their fuel savings on new vehicle technology and a broad range of other goods and services, stimulating net employment growth across the state economy. On average, a dollar saved at the gas pump and spent on the other goods and services that households want creates 16 times more jobs.
- Unlike the fossil fuel supply chain, the majority of new demand financed by fuel efficient vehicle cost savings goes to in-state services, a source of diverse, bedrock jobs that cannot be outsourced.

- Individual Oregonians gain from economic growth associated with fuel cost savings due to vehicle electrification, whether they buy a new car or not. As a result of light-duty vehicle electrification, the average real wages and employment increase across the economy and incomes grow faster for low-income groups than for high-income groups.

- Creating a market to incubate the next generation of fuel efficient vehicles has could promote job growth across Oregon’s economy while capturing national and global market opportunities for technology development.

Figure 4.23: Alternative Scenarios for EV Diffusion in the Oregon Light Duty Fleet



4.8 Air Quality Improvements

Much of the debate about cap-and-trade revolves around costs and benefits of energy and energy use technologies while many societal benefits of reduced environmental pollution go unmeasured. This study attempts to quantify reduced health costs from improved air quality, a real economic impact that would be directly added to other economic benefits. Building on a rapidly growing body of public health research on climate policy, we estimate the economic benefits (i.e., avoided health costs) of reducing hazardous co-pollutants (PM2.5 and Ozone) associated with carbon fuel consumption. These pollutants are not only associated with the electric power and industry, but are a serious health risk in transportation corridors and densely populated urban environments.

In order to estimate health benefits from the proposed cap-and-trade policies, we leverage recently published research that uses a meteorological model to model the spatial relationship between emissions and criteria pollutants in 50km x 50km grid cells across the United States (Zhang et al 2017). Using this model and scaling modeled changes in emissions in Oregon to reflect the proposed cap-and-trade policies allows us to estimate changes in criteria pollutants across the state under each policy scenario. The EPA's BenMAP model is then used to relate changes in criteria pollutants to changes in the number of excess deaths from pollution (EPA BenMap 2018). Excess deaths are valued according to the EPA's Value of a Statistical Life (VSL) and EPA estimates of the relationship between mortality and morbidity health costs are used to approximate the magnitude of total health benefits.

Using this approach we estimate that the added public health benefits are substantial, comprising about 1/3 of total economic benefits from the proposed policies. However, in no scenario are they the determining factor that causes benefits to exceed costs. So while public health benefits are an addition to social wellbeing, including or excluding them from the analysis does not fundamentally change the cost-benefit calculation. These estimates are intended only to be indicative of the magnitude of potential health benefits from the proposed policies.

A detailed description of the methods used to estimate health benefits is included in an appendix below.

4.9 Trade Issues

Lower expenditures on conventional energy reduce Oregon's dependence on imports of raw energy fuels from other states and overseas. It is possible that the trade effect might reduce export opportunities in Oregon. However, conventional energy fuel imports will increase state employment as long as it results from efficiency. We have already observed that the carbon fuel supply chain has extremely low employment potential. For example, a dollar spent on Oregon gasoline generates less than 10% as many jobs as the average dollar of consumer spending ($.70 of which go to services). Even if Oregon's exports fell by an amount equal to the reduction in conventional energy fuel imports, the net job creation effect would be strongly positive. Since the state will likely rely on significant renewable energy imports (Wyoming wind in particular), this extreme outcome is unlikely.

Three other effects of fuel savings to households and enterprises are also likely to have an impact:

1. Spending fuel savings creates its own import demand. If Oregon imports are nearly 60% of GDP, this would offset about half the mercantile effect of reduced conventional energy imports.
2. Service spending has larger in-state multipliers than energy fuel spending.
3. Innovation benefits of new fuel and vehicle technologies increase state employment and income.

4.10 Market Failure Issues

Another type of skepticism regarding the benefits of HB2020 and related climate policies is based on a presumption of market efficiency. Simply put, this perspective holds that to justify intervention, we must identify specific market failures that are inhibiting otherwise voluntary mitigation efforts and/or technology adoption. Otherwise, markets know best and we are already using or pursuing the most cost-effective solutions.

In reality, of course, there are many market imperfections in the climate change context. Of course the most important one is the global carbon externality, an inconvenient disconnect between the private benefit of using energy services and the public cost of the greatest environmental risk in human history. If this isn't enough to justify intervention in today's energy systems, we might also acknowledge universal subsidies to conventional modes of transport, as well as oligopolies and/or local monopolies in vehicle, conventional fuel, and electric power sectors.

4.11 Employment Issues

The positive job creation resulting from our scenarios of course requires that supply conditions are conducive to new hiring. To be clear, BEAR is not a "full employment" model because Oregon historically has had an elastic supply of labor. Coming out of an adverse national macro cycle, the state had some structural unemployment and, like most economies, this will likely revisit the economy intermittently. Over the long term, however, Oregon has a higher-than-average elasticity of labor supply because of sustained inward migration. We take explicit account of this and, while it may not benefit the national economy, this kind of new job and income creation has always benefitted Oregon.[11]

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[11] Borenstein: 2015 is among prominent experts who caution about the risk of overestimating national benefits from state-specific job creation. This skepticism is certainly well founded, but states tend to place self-interest first when it comes to jobs and income growth.

5 ALTERNATIVE SCENARIOS

As indicated in Table 3.1, we also considered a few alternative policy scenarios, including two that allocate permit revenues for specific objectives and three different scenarios for Oregon’s participation in the Western Climate Initiative (WCI). For convenience, these are restated in Table 5.1.

Table 5.1: Alternative Cap-and-Trade Policy Scenarios

	Scenario	Description
5	**Incentive**	Beginning with the Core scenario, distribute 94% of non-highway permit revenue equally in three categories: 1. Forestry and Working Lands to promote sequestration. 2. Household energy efficiency subsidies. 3. Enterprise energy efficiency subsidies.
6	**WCI-Low**	Core scenario, with a permit price at the California Auction Reserve Price (ARP) low level. We assume in all three WCI scenarios that Oregon is a price taker in the regional market, obligated at the assumed border price of permits, and retains all permit revenue within state coffers. Costless permit allocations follow the core scenario, as do offset rules.
7	**WCI-Med**	Core scenario, with a permit price following the California Energy Commission Mid-level pathway.
8	**WCI-High**	Core scenario, with a permit price following the WCI Ceiling.

The macroeconomic impacts of these policies are listed in Table 5.2 (for 2050 only).

Table 5.2: Macroeconomic Impacts of Cap-and-Trade

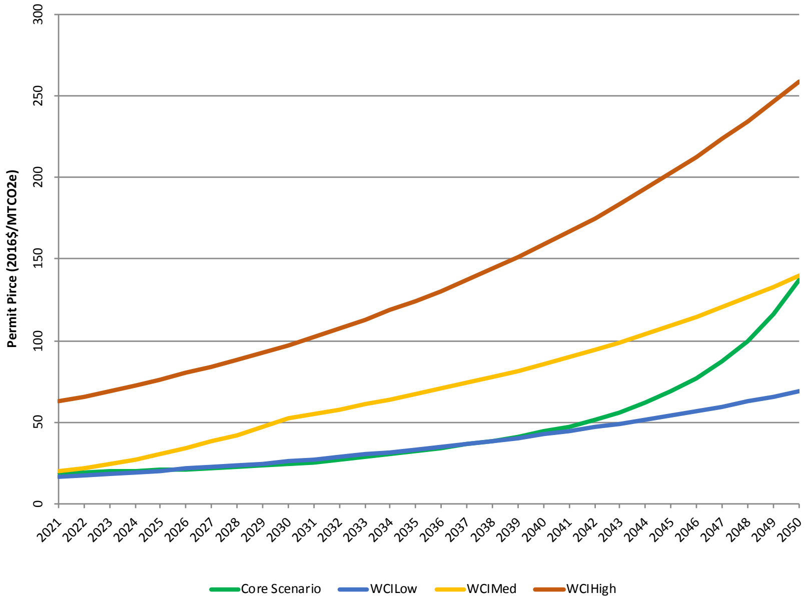
2050 Results

	Reference (levels)	Incentive	WCILow	WCIMed	WCIHigh
GSP ($B)	$526.2	2.53%	2.55%	2.53%	2.50%
Consumption	$266.3	2.17%	2.39%	2.38%	2.35%
Jobs	-	1.03%	1.08%	1.07%	1.05%
Wages	-	0.40%	0.47%	0.46%	0.44%
FTE ('000)	4,393	45	48	47	46
GHG (%)	-	-82%	-82%	-82%	-82%
GHG (MMTCO2e)	48.5	8.7	8.7	8.7	8.7

Notes: All entries except in Reference column represent changes from the Reference scenario in the year indicated, in percentage or the units given in parantheses. Gross Domestic Product (GDP, value added) and real household Consumption are measured in constant (2016) dollars. Employment chages are measured in thousands of Full Time Equivalent (FTE) annual jobs. GHG *measures annual Oregon covered emission changes (% from Reference) and levels (MMT) for the given year and scenario.*

Generally speaking, these scenarios have limited impact from a macroeconomic perspective. In all cases this is because the permit program is very small as percent of state GDP. As was emphasized above, cost saving technology adoption is the primary driver of overall Oregon economic benefits from cap-and-trade. Even these gains are in the low single digit percentages of GDP after 30 years. By 2050, our Reference case estimates that Oregon will be a half-trillion dollar economy. It is hardly surprising then that reallocating permit revenue, itself less 0.16% of GDP, would not move the aggregate economy. Directed revenue programs themselves can be expected to provide important direct and (by example) induced environmental benefits, but these are not captured in the BEAR model.

Figure 5.1: WCI Reference Prices and the Core Scenario



With respect to WCI options, Figure 5.1 shows our estimated permit price trajectory in the Core scenario, bracketed to reference cases used in the three scenarios. The lower range is the Auction Reserve Price or floor stipulated in the current WCI agreement, WCIMed corresponds the California Energy Commission Mid-level pathway, and the while the WCIHigh is a WCI recommended upper limit on what covered entities would have to pay. Macroeconomic impacts of these three are qualitatively consistent and logical (higher price pathways reduce growth potential) but the differences are again hundredths of a percent of GDP.

6 CONCLUSION

Oregon’s proposed cap-and-trade Policy (HB2020) has established ambitious public commitments to energy efficiency, pollution mitigation, and long-term environmental security. Under the right conditions, these policies have potential to both limit resource waste and climate risk and promote development of the next generation of clean and energy efficient technologies.

Using a state-of-the-art economic forecasting model, this study presents evidence that Oregon can meet its 2050 climate goals in ways that achieve higher aggregate economic growth and employment. An aggressive GHG mitigation pathway, reducing 2035 emissions 45% below 1990 levels, will confer greater benefits on the state economy, adding about 1% to GDP and about 11,000 new jobs. Sustaining these reductions to 80% below 1990 by 2050 would increase GDP over 2.5% and add about 23,000 new jobs.

Available energy efficiency and renewable electrification offer broad-based savings to enterprises and households, which can be a potent catalyst for more inclusive economic growth and job creation. These savings can be even greater if Cap-and-Trade and complimentary have their intended incentive effects on new technology investment and innovation.

To reach Oregon’s goal of deep decarbonization will require a fundamental restructuring of the state's energy system, including electrification of at least the light vehicle fleet, deep decarbonization of the electrical sector, and dramatically reduced direct use of natural gas in heating and industrial applications

Recognizing sector needs for short and medium term flexibility, adjustment costs for this economic transition can be substantially reduced. Limited directly allocated emissions permit allowances are an important part of this strategy, and BH2020 explicitly recognizes this in its treatment of electric power, Emissions Intensive Export Exposed industries, and selected large natural gas users.

Economic benefits of improved air quality, in terms of averted medical costs and premature mortality, are substantial, contributing about 1/3 to overall economic benefits from cap-and-trade driven reductions in toxic and criteria co-pollutants.

APPENDIX 1 – OVERVIEW OF THE BEAR MODEL

The Berkeley Energy and Resources (BEAR) model is in reality a constellation of research tools designed to elucidate economy-environment linkages in Oregon. The schematics in Figures A1.1 and A1.2 describe the four generic components of the modeling facility and their interactions. This section provides a brief summary of the formal structure of the BEAR model.[12] For the purposes of this report, the 2012 Oregon Social Accounting Matrix (SAM), was aggregated along certain dimensions. The current version of the model includes 50 activity sectors and ten households aggregated from the original Oregon SAM. The equations of the model are completely documented elsewhere (Roland-Holst: 2005), and for the present we only discuss its salient structural components.

1.1 Structure of the CGE Model

Technically, a CGE model is a system of simultaneous equations that simulate price-directed interactions between firms and households in commodity and factor markets. The role of government, capital markets, and other trading partners are also specified, with varying degrees of detail and passivity, to close the model and account for economywide resource allocation, production, and income determination.

The role of markets is to mediate exchange, usually with a flexible system of prices, the most important endogenous variables in a typical CGE model. As in a real market economy, commodity and factor price changes induce changes in the level and composition of supply and demand, production and income, and the remaining endogenous variables in the system. In CGE models, an equation system is solved for prices that correspond to equilibrium in markets and satisfy the accounting identities governing economic behavior. If such a system is precisely specified, equilibrium always exists and such a consistent model can be calibrated to a base period data set. The resulting calibrated general equilibrium model is then used to simulate the economywide (and regional) effects of alternative policies or external events.

The distinguishing feature of a general equilibrium model, applied or theoretical, is its closed-form specification of all activities in the economic system under study. This can be contrasted with more traditional partial equilibrium analysis, where linkages to other domestic markets and agents are deliberately excluded from

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[12] See Roland-Holst (2015) for a complete model description.

consideration. A large and growing body of evidence suggests that indirect effects (e.g., upstream and downstream production linkages) arising from policy changes are not only substantial, but may in some cases even outweigh direct effects. Only a model that consistently specifies economywide interactions can fully assess the implications of economic policies or business strategies. In a multi-country model like the one used in this study, indirect effects include the trade linkages between countries and regions which themselves can have policy implications.

The model we use for this work has been constructed according to generally accepted specification standards, implemented in the GAMS programming language, and calibrated to the new Oregon SAM estimated for the year 2012.[13] The result is a single economy model calibrated over the thirty-five year time path from 2015 to 2050. Using the very detailed accounts of the Oregon SAM, we include the following in the present model:

1.2 Production

All sectors are assumed to operate under constant returns to scale and cost optimization. Production technology is modeled by a nesting of constant-elasticity-of-substitution (CES) function.

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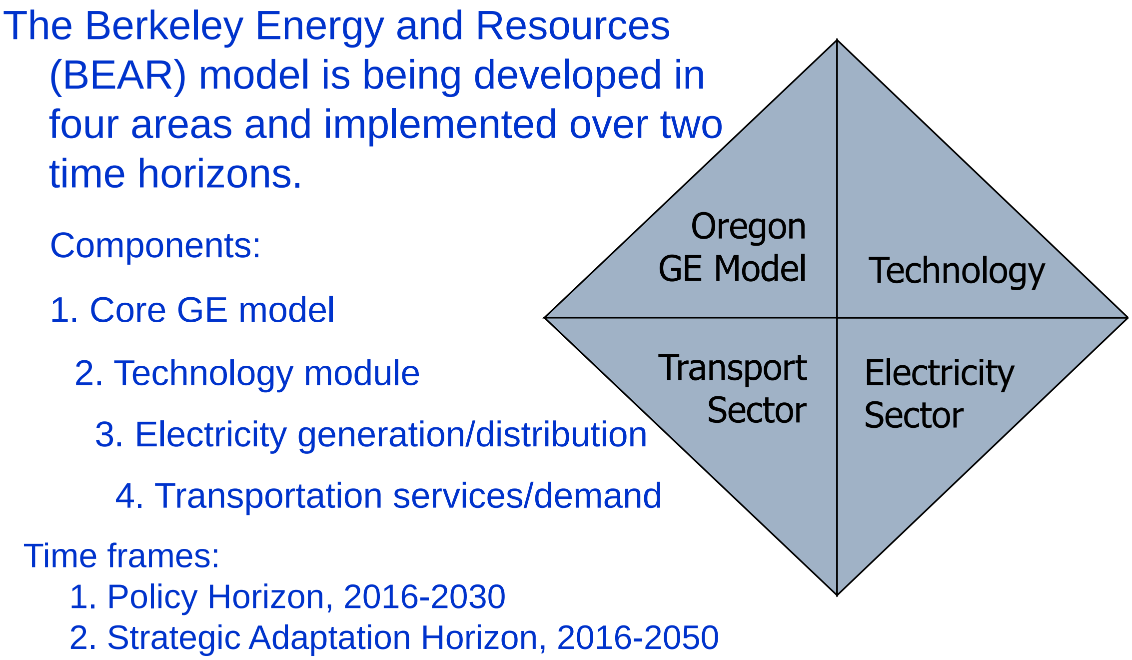
[13] See e.g. Meeraus et al (1992) for GAMS. Berck et al (2004) for discussion of the California SAM.

Figure A1.1: Component Structure of the Modeling Facility



The Berkeley Energy and Resources (BEAR) model is being developed in four areas and implemented over two time horizons.

Components:

1. Core GE model
2. Technology module
3. Electricity generation/distribution
4. Transportation services/demand

Time frames:

1. Policy Horizon, 2016-2030
2. Strategic Adaptation Horizon, 2016-2050

In each period, the supply of primary factors — capital, land, and labor — is usually predetermined.[14] The model includes adjustment rigidities. An important feature is the distinction between old and new capital goods. In addition, capital is assumed to be partially mobile, reflecting differences in the marketability of capital goods across sectors.[15] Once the optimal combination of inputs is determined, sectoral output prices are calculated assuming competitive supply conditions in all markets.

1.3 Consumption and Closure Rule

All income generated by economic activity is assumed to be distributed to consumers. Each representative consumer allocates optimally his/her disposable income among the different commodities and saving. The consumption/saving decision is completely static: saving is treated as a “good” and its amount is determined simultaneously with the demand for the other commodities, the price of saving being set arbitrarily equal to the average price of consumer goods.

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[14] Capital supply is to some extent influenced by the current period’s level of investment.

[15] For simplicity, it is assumed that old capital goods supplied in second-hand markets and new capital goods are homogeneous. This formulation makes it possible to introduce downward rigidities in the adjustment of capital without increasing excessively the number of equilibrium prices to be determined by the model.

The government collects income taxes, indirect taxes on intermediate inputs, outputs and consumer expenditures. The default closure of the model assumes that the government deficit/saving is exogenously specified.[16] The indirect tax schedule will shift to accommodate any changes in the balance between government revenues and government expenditures.

The current account surplus (deficit) is fixed in nominal terms. The counterpart of this imbalance is a net outflow (inflow) of capital, which is subtracted (added to) the domestic flow of saving. In each period, the model equates gross investment to net saving (equal to the sum of saving by households, the net budget position of the government and foreign capital inflows). This particular closure rule implies that investment is driven by saving.

1.4 Trade

Goods are assumed to be differentiated by region of origin. In other words, goods classified in the same sector are different according to whether they are produced domestically or imported. This assumption is frequently known as the *Armington* assumption. The degree of substitutability, as well as the import penetration shares are allowed to vary across commodities. The model assumes a single Armington agent. This strong assumption implies that the propensity to import and the degree of substitutability between domestic and imported goods is uniform across economic agents. This assumption reduces tremendously the dimensionality of the model. In many cases this assumption is imposed by the data. A symmetric assumption is made on the export side where domestic producers are assumed to differentiate the domestic market and the export market. This is modeled using a *Constant-Elasticity-of-Transformation* (CET) function.

1.5 Dynamic Features and Calibration

The current version of the model has a simple recursive dynamic structure as agents are assumed to be myopic and to base their decisions on static expectations about prices and quantities. Dynamics in the model originate in three sources: i) accumulation of productive capital and labor growth; ii) shifts in production technology; and iii) the putty/semi-putty specification of technology.

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[16] In the reference simulation, the real government fiscal balance converges (linearly) towards 0 by the final period of the simulation.

1.6 Capital accumulation

In the aggregate, the basic capital accumulation function equates the current capital stock to the depreciated stock inherited from the previous period plus gross investment. However, at the sectoral level, the specific accumulation functions may differ because the demand for (old and new) capital can be less than the depreciated stock of old capital. In this case, the sector contracts over time by releasing old capital goods. Consequently, in each period, the new capital vintage available to expanding industries is equal to the sum of disinvested capital in contracting industries plus total saving generated by the economy, consistent with the closure rule of the model.

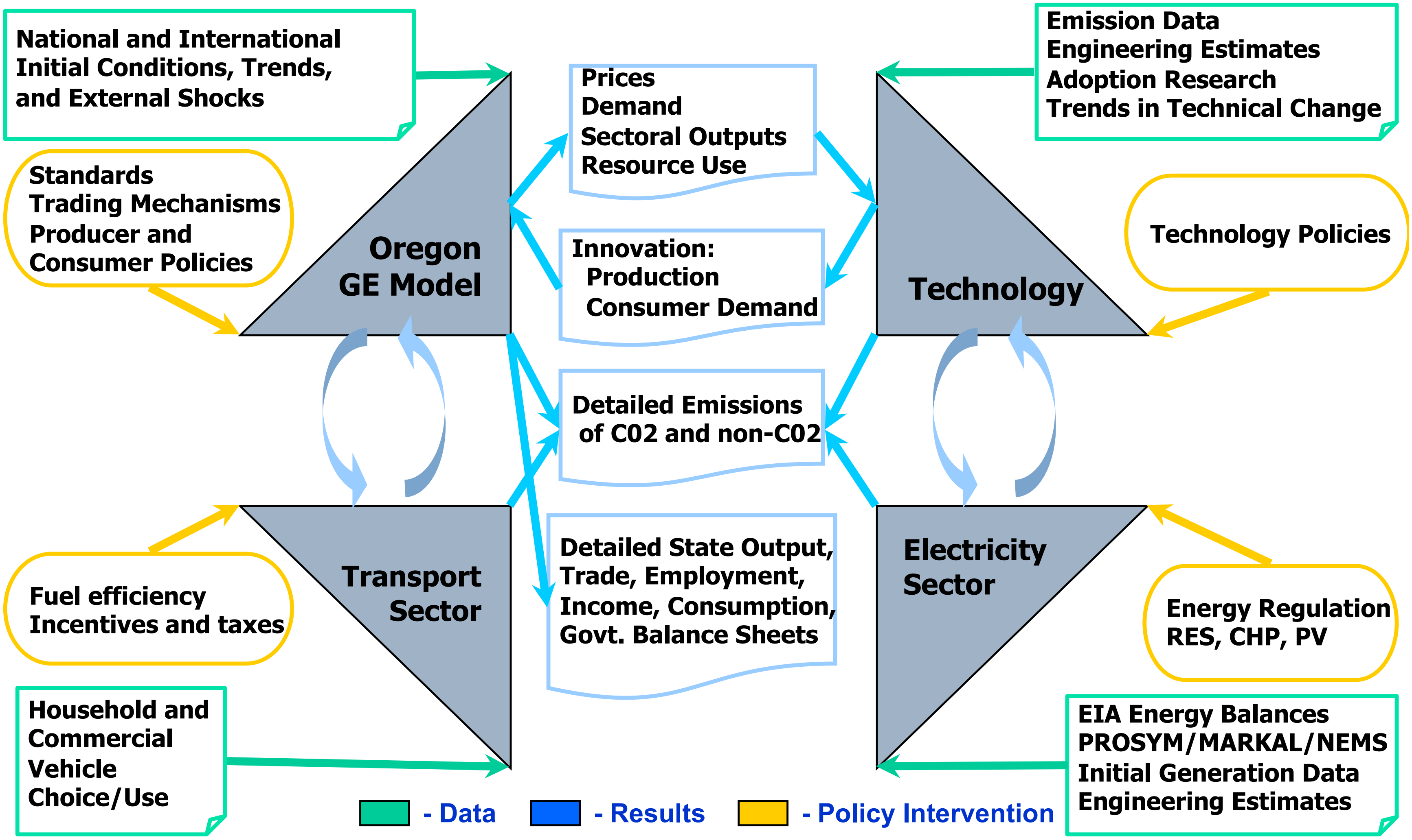
1.7 The putty/semi-putty specification

The substitution possibilities among production factors are assumed to be higher with the new than the old capital vintages — technology has a putty/semi-putty specification. Hence, when a shock to relative prices occurs (e.g. the imposition of an emissions fee), the demands for production factors adjust gradually to the long-run optimum because the substitution effects are delayed over time. The adjustment path depends on the values of the short-run elasticities of substitution and the replacement rate of capital. As the latter determines the pace at which new vintages are installed, the larger is the volume of new investment, the greater the possibility to achieve the long-run total amount of substitution among production factors.

1.8 Profits, Adjustment Costs, and Expectations

Firms output and investment decisions are modeled in accordance with the innovative approach of Goulder and co-authors (see e.g. Goulder et al: 2009 for technical details). In particular, we allow for the possibility that firms reap windfall profits from events such as free permit distribution. Absent more detailed information on ownership patterns, we assume that these profits accrue to US and foreign residents in proportion to equity shares of publically traded US corporations (16% in 2009, Swartz and Tillman:2010). Between Oregon and other US residents, the shares are assumed to be proportional to GDP in GDP.

Figure A1.2: Schematic Linkage between Model Components



1.9 Dynamic calibration

The model is calibrated on exogenous growth rates of population, labor force, and GDP. In the so-called Baseline scenario, the dynamics are calibrated in each region by imposing the assumption of a balanced growth path. This implies that the ratio between labor and capital (in efficiency units) is held constant over time.[17] When alternative scenarios around the baseline are simulated, the technical efficiency parameter is held constant, and the growth of capital is endogenously determined by the saving/investment relation.

1.10 Modelling Emissions

The BEAR model captures emissions from production activities in agriculture, industry, and services, as well as in final demand and use of final goods (e.g. appliances and autos). This is done by calibrating emission functions to each of these activities that vary depending upon the emission intensity of the inputs used for the activity in question. We model both CO2 and the other primary greenhouse gases, which are converted to CO2 equivalent. Following standards set in the research literature, emissions in production are modeled as factors inputs. The base version of the model does not have a full representation of emission reduction or abatement. Emissions abatement occurs by substituting additional labor or capital for emissions when an emissions tax is applied. This is an accepted modeling practice, although in specific instances it may either understate or overstate actual emissions reduction potential.[18] In this framework, mission levels have an underlying monotone relationship with production levels, but can be reduced by increasing use of other, productive factors such as capital and labor. The latter represent investments in lower intensity technologies, process cleaning activities, etc. An overall calibration procedure fits observed intensity levels to baseline activity and other factor/resource use levels. In some of the policy simulations we evaluate sectoral emission reduction scenarios, using specific cost and emission reduction factors, based on our earlier analysis (Hanemann and Farrell: 2006).

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[17] This involves computing in each period a measure of Harrod-neutral technical progress in the capital-labor bundle as a residual. This is a standard calibration procedure in dynamic CGE modeling.

[18] See e.g. Babiker et al (2001) for details on a standard implementation of this approach.

The BEAR model has the capacity to track 13 categories of individual pollutants and consolidated emission indexes, each of which is listed in Table A1.1 below. Our focus in the current study is the emission of CO2 and other greenhouse gases, but the other effluents are of relevance to a variety of environmental policy issues. For more detail, please consult the full model documentation.

Table A1.1: Emission Categories

Air Pollutants		
1.	Suspended particulates	PART
2.	Sulfur dioxide (SO_2)	SO2
3.	Nitrogen dioxide (NO_2)	NO2
4.	Volatile organic compounds	VOC
5.	Carbon monoxide (CO)	CO
6.	Toxic air index	TOXAIR
7.	Biological air index	BIOAIR
Water Pollutants		
8.	Biochemical oxygen demand	BOD
9.	Total suspended solids	TSS
10.	Toxic water index	TOXWAT
11.	Biological water index	BIOWAT
Land Pollutants		
12.	Toxic land index	TOXSOL
13.	Biological land index	BIOSOL

Table A1.2: Social Accounting Matrix for Oregon, 2016
Structural Characteristics

1.	103 production activities
2.	103 commodities (includes trade and transport margins)
3.	24 factors of production
4.	22 labor categories
5.	Capital
6.	Land
7.	9 Household types, defined by BLS income tax bracket
8.	Enterprises
9.	Federal Government (7 fiscal accounts)
10.	State Government (27 fiscal accounts)
11.	Local Government (11 fiscal accounts)
12.	Consolidated capital account
13.	External Trade Account

These data enable us to trace the effects of responses to climate change and other policies at unprecedented levels of detail, tracing linkages across the economy and clearly indicating the indirect benefits and tradeoffs that might result from comprehensive policies pollution taxes or trading systems. As we shall see in the results section, the effects of climate policy can be quite complex. In particular, cumulative indirect effects often outweigh direct consequences, and affected groups are often far from the policy target group. For these reasons, it is essential for policy makers to anticipate linkage effects like those revealed in a general equilibrium model and dataset like the ones used here.

It should be noted that the SAM used with BEAR departs in a few substantive respects from the original 2016 Oregon SAM. The two main differences have to do with the structure of production, as reflected in the input-output accounts, and with consumption good aggregation. To specify production technology in the BEAR model, we rely on both activity and commodity accounting, while the original SAM has consolidated activity accounts. We chose to maintain separate activity and commodity accounts to maintain transparency in the technology of emissions and patterns of tax incidence. The difference is non-trivial and considerable additional effort was needed to reconcile use and make tables separately. This also facilitated the second SAM extension, however, where we maintained final demand at the full 119 commodity level of aggregation, rather than adopting six aggregate commodities like the original SAM.

Emissions Data

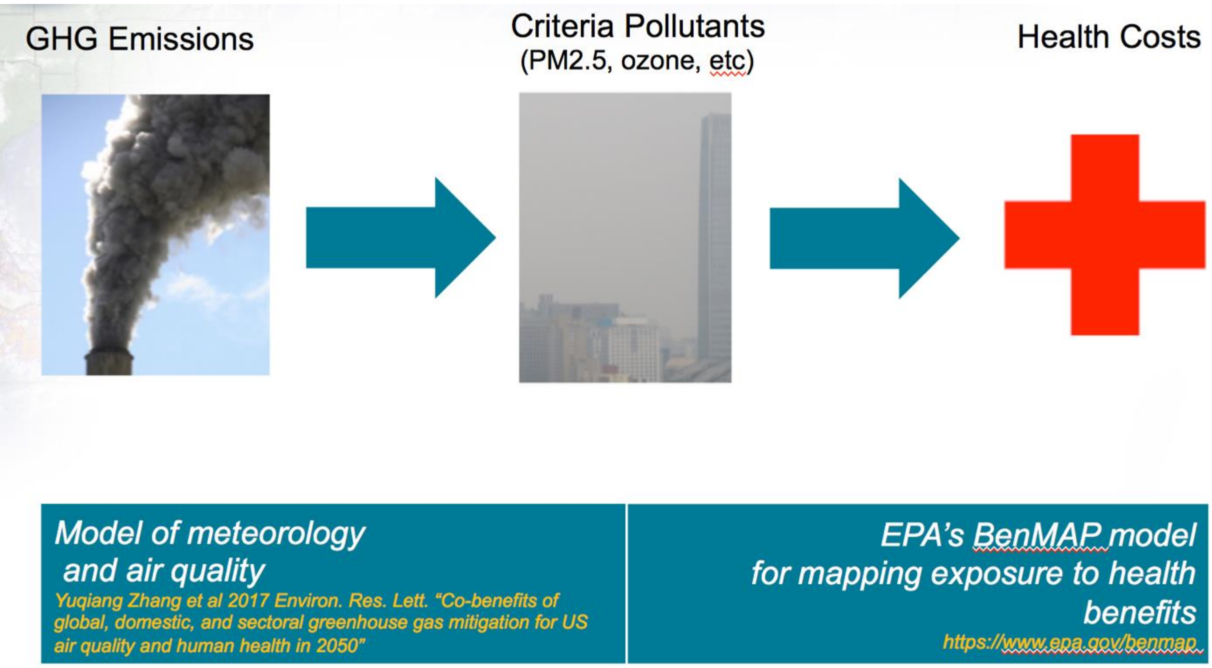
Emissions data were obtained form Oregon's own detailed emissions inventory. In most of the primary pollution databases like this, measured emissions are directly associated with the volume of output. This has several consequences. First, from a behavioral perspective, the only way to reduce emissions, with a given technology, is to reduce output. This obviously biases results by exaggerating the abatement-growth tradeoff and sends a misleading and unwelcome message to policy makers.

More intrinsically, output based pollution modeling does not reflect the observed pattern of abatement behavior. Generally, firms respond to abatement incentives and penalties in much more complex and sophisticated ways by varying internal conditions of production. These responses include varying the sources, quality, and composition of inputs, choice of technology, etc. The third shortcoming of the output approach is that it give us no guidance about other important pollution sources outside the production process, especially pollution in use of final goods. The most important example of this category is household consumption. The BEAR model estimates pollution in both production and consumption (e.g. fuel and energy use). In all cases, we calibrate to the Oregon inventory for initial emission intensity, but going forward the model captures price sensitive fuel and technology substitution by enterprises and households. This is more consistent with observed reality.

APPENDIX 2 – MEASURING HEALTH BENEFITS FROM REDUCTION IN GHG EMISSIONS

Poor air quality imposes substantial public health costs across the state. Conversely, averting such costs is an important co-benefit of reductions in GHG emissions and associated improvements in air quality. As part of this study, we present an exploratory analysis to quantify the value of health benefits (i.e., avoided health costs) associated with a reduction in GHG emissions from Oregon's proposed cap-and-trade policies. We do this in three sequential steps.

Figure A2.1: Broad overview of health benefits analysis



GHG Emissions

Criteria Pollutants
(PM2.5, ozone, etc)

Health Costs

Model of meteorology and air quality

Yuqiang Zhang et al 2017 Environ. Res. Lett. "Co-benefits of global, domestic, and sectoral greenhouse gas mitigation for US air quality and human health in 2050"

EPA's BenMAP model for mapping exposure to health benefits

https://www.epa.gov/benmap

Step 1: Estimating how reductions in GHG emissions reduce concentrations of criteria pollutants

Air quality is negatively correlated with GHG emissions, and criteria pollutants (e.g. PM2.5 and Ozone) have been linked to harmful effects on human health. However, the relationship between reduced GHG and criteria emissions is not 1:1 (i.e., a 5% reduction in GHG emissions does not necessarily translate to a 5% reduction in PM2.5) and this relationship varies over time and space. Modeling the relationship between GHG emissions and criteria pollutants is therefore the important first step to estimating health benefits. Until recently this relationship has not been well understood, but new research has shed important light on these linkages.

We are not able to directly model how reductions in GHG emissions from cap-and-trade policies will specifically translate into lower criteria pollutant concentrations, however. Doing so would require an intensive modeling effort by physicists and environmental scientists and is far beyond the scope of the current project. Fortunately, we have been able to leverage recent work by Zhang et al 2017 on the link between GHG emissions and mortality risk across the United States. Their model evaluates the RCP 4.5 scenario (see Thomson et al 2011 for details), a generic suite of cost minimizing policies that reduce national GHG emissions. These emissions reductions come from across the economy and are modeled to the year 2050. The data from the Zhang et al study include ~50km x 50km gridded estimates of reductions in PM2.5 and Ozone across the United States for a given change in GHG emissions. We use this relationship between changes in emissions and changes in criteria pollutants over space to model how changes in GHG emissions from Oregon's proposed cap-and-trade policies will affect criteria pollutants.

Step 2: Estimating the effects of lower criteria pollutant concentrations on avoided pre-mature deaths

The Zhang et al data also include 50x50km gridded estimates for the number of avoided pre-mature deaths due to avoided PM2.5 exposure and the number of avoided pre-mature deaths due to avoided Ozone exposure. The avoided pre-mature deaths estimates were derived from the EPA's BenMAP model. This model takes as inputs criteria pollution concentrations and outputs mortality risk estimates so it can be used to input the predicted reductions in PM2.5 and Ozone concentrations and output estimates for reductions in pre-mature deaths (EPA BenMAP 2018).

Step 3: Valuing mortality and morbidity

The standard approach for valuing the cost of an avoided pre-mature death is to use a concept known as the Value of a Statistical Life (VSL). We utilize the EPA's Value of a Statistical Life ($9.2M in 2018 dollars), which also represents a de facto consensus from legal actuaries. This value does not mean that the EPA places a dollar value on individual lives. It represents a survey based estimate of how much people are willing to pay for small reductions in their risk of dying from adverse health conditions that may be caused by environmental hazards and scale these estimates to represent a death.[19]

Multiplying the number of avoided pre-mature deaths by the EPA's VSL provides an estimate of the value of avoided pre-mature deaths, however, it ignores the costs associated with morbidity from air pollution. These comprise all averted medical costs due to lower incidence of respiratory and other air pollution related illness (e.g. asthma) which for OECD populations is normally estimated to be larger than mortality costs. Note however, that this estimate is still conservative because it does not value non-medical costs like absenteeism, reduced effort, productivity, etc.

Directly estimating morbidity costs would require extensive information health costs incurred by cause, again outside this study and in many cases unavailable. We therefore rely on the EPA's regulatory assessment for the Review of the Particulate Matter National Ambient Air Quality Standards (NAAQS) to get an idea about the ratio of total health costs (mortality + morbidity) to mortality costs alone. In this regulatory assessment, the EPA estimated morbidity benefits to be 2.5x larger than mortality benefits. Scaling our benefits estimates by a factor of 2.5 we estimate the value of total health benefits associated with the volume of reductions in GHG emissions forecast from Oregon's proposed cap-and-trade policies in 2050.

Caveats

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[19] https://www.epa.gov/environmental-economics/mortality-risk-valuation

These estimates rely on nationally modeled 50x50km gridded health benefits estimates from GHG emissions reductions and are intended to be illustrative of the potential magnitude of benefits. However, studies devoted specifically to analyzing policies at the local level are required in order to illuminate highly localized effects.

Another main caveat is that we are not specifically modeling detailed GHG reductions from cap-and-trade policies. Zhang et al model benefits from GHG reductions due to transformations in the energy, transport, and industry sectors including changes in electric power generation and energy extraction and transformation. We then scale these emissions to reflect the expected emissions reductions from the proposed cap-and-trade policies. We are therefore assuming that the spatial patterns of criteria pollutant reduction from changes modeled by Zhang et al are the same as the spatial patterns of criteria pollutant reductions from the proposed cap-and-trade policies.

The other main assumption is that total health benefits and avoided pre-mature deaths conform to a 2.5 multiple relationship observed at the national level. This assumption is based on previous work by the EPA and takes averages from estimates in the EPA regulatory assessment for the National Ambient Air Quality Standards. It should be noted, however, that EPA estimates of morbidity costs in this study range widely and while we take the average, other estimates within the confidence interval would result in some variation of total avoided health cost estimates.

Additional assumptions include the following:

- value of a statistical life is $9.2M,
- BenMAP, a national assessment tool, appropriately estimates the number of avoided deaths from reductions in criteria pollutants[20],
- the total number of avoided deaths in a 50x50km area will be realized proportionately to population within that area

Lastly, we have assumed that, because most of the cap-and-trade policies affect dispersed pollutants, mitigation is achieved uniformly across the state. Criteria

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[20] See https://www.epa.gov/benmap/how-benmap-ce-estimates-health-and-economic-effects-air-pollution for more details

pollutants can be more localized, but we currently lack data on how cap-and-trade policies would affect these patterns.

In addition to the caveats above, it should also be noted that this study does not cover all potential co-benefits from GHG emissions reductions.[21]

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[21] For more information on non-health co-benefits from reductions in GHG emissions, including examples of studies estimating damages to each of the mentioned outcomes (and more), see Carleton and Hsiang "Social and economic impacts of climate", Science 2016.

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