ECONOMIC RESEARCH CENTER
at THE BUCKEYE INSTITUTE

Economic Research Center Analysis: The Impact of Renewables Portfolio Standards on the Ohio Economy

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Executive Summary

Ohio's Renewables Portfolio Standard (RPS), enacted in 2008, requires electricity providers to supply at least 12.5% of their sales with renewable energy such as wind and solar power. The law's schedule gradually increases the required level of renewable energy supplied each year until the state meets the 12.5% goal by 2025. In 2014, the General Assembly suspended the RPS program by freezing the required renewable energy levels for two years and extended the statutory compliance deadline from 2025 to 2027.† The RPS program restarted in 2017 after the Governor vetoed further reforms, even as some state policymakers expressed interest in reforming the mandates.

As the government requires more and more electricity to be generated from expensive renewable sources, costs for electricity providers will continue to rise. Those higher costs will be passed along to employers, manufacturers, and consumers, raising the prices for electricity and manufactured goods. Ultimately, the economic burdens imposed by the RPS will reduce job opportunities and shrink Ohio's gross domestic product (GDP) as companies and families are forced to pay higher prices for energy over the next decade.

The Economic Research Center (ERC) at The Buckeye Institute analyzed the likely economic impacts of the RPS by applying the ERC's proprietary dynamic model of Ohio's economy. The ERC's findings support repealing the mandates entirely. Under four different scenarios estimating Ohio's economic future, the ERC's analytical model showed fewer job prospects and a smaller state economy as a result of the RPS mandates. In the worst case scenario, the RPS standards rise to 12.5% and compliance costs increase over time. In such a scenario, Ohio would suffer 134,100 fewer jobs and a loss of $15.5 billion in GDP by 2026. Even in the best case scenario—in which policymakers immediately and indefinitely freeze the mandates at 2016 levels and compliance costs remain fixed at 2014 levels—the RPS will still cause employment opportunities to decline by 6,800 jobs accounting for a loss of $806 million in GDP by 2026.

Ohio should not sacrifice hundreds or even thousands of jobs per year in the state's traditional industries in order to benefit a small cadre of "green" job holders. Several RPS advocacy groups have promised an influx of jobs in the renewable energy industry if the standards continue, and have predicted massive job losses if the standards are frozen indefinitely or repealed. The ERC's analysis, however, shows that the foregone employment in "non-green" industries will far outstrip the estimated employment growth in the renewable energy sector—results consistent with other economic studies on the effects of green energy subsidies and mandates. Ohio's policymakers should repeal the RPS in 2017 in order to maximize job opportunities and economic growth for families and businesses.

Introduction

In 2008, the Ohio General Assembly enacted a Renewables Portfolio Standard (RPS) that requires electricity providers to supply at least 12.5% of their sales with renewable energy such as wind and solar power. [1] The law's schedule gradually increases the required level of renewable energy supplied each year until the state meets the 12.5% goal in 2025.

In 2014, the General Assembly suspended the RPS program by freezing the required renewable energy levels for two years, extending the statutory compliance deadline from 2025 to 2027, and creating the Energy Mandates Study Committee to study the impact of the RPS mandates on the state's economy.[2] Following its review, the Committee recommended an indefinite suspension of the mandates in 2015.[3] The General Assembly subsequently considered legislation in 2016 that would have implemented the Committee's recommendation and suspended the standards indefinitely, but that legislation was not enacted. Instead, the legislature extended the 2014 suspension for an additional two years (until 2019), but Governor Kasich vetoed that extension.

Today, the General Assembly and the Governor continue to disagree about the best road forward, with some legislators expressing a willingness to overhaul the state's entire energy policy including the RPS.[4] To assist in the state's reform effort, the following discussion analyzes the likely economic impacts of the RPS by applying the Economic Research Center's (ERC) proprietary dynamic model of Ohio's economy.

Dynamic economic models are better suited than static input-output models for assessing the potential economic impacts of policies like RPS. Input-output models fail to account correctly for behavioral changes such as the effects that a price increase has on firms' electricity demand and total output—especially in energy-intensive industries. In other words, input-output models incorrectly assume that "green jobs" will be created without taking resources away from other, "non-green" sectors of the economy. In theory, however, the increase in electricity prices caused by the RPS should force job losses and reductions in hiring growth in other sectors that do not receive the benefits of the mandate. The RPS increases electricity prices, because green energy is more expensive to produce than existing, traditional energy sources.[5]

Applying the ERC's dynamic model of the Ohio economy measures the likely economic effects of RPS on Ohio. The ERC's findings support repealing the mandates. If the RPS standards continue to 2026, Ohio will experience significant net losses in potential employment opportunities and gross domestic product (GDP). In the worst case scenario, the standards resume to 12.5% and compliance costs increase over time. Such a scenario would witness a loss of 134,100 jobs and $15.5 billion in GDP by 2026 as compared to an economy that never suffers the RPS imposed costs. Even in the best case scenario—in which policymakers immediately enact an indefinite freeze of the mandates at 2016 levels (as some legislators have previously proposed) and compliance costs stay constant at 2014 levels—the RPS will cause losses of 6,800 jobs and $806 million in GDP by 2026.

Prior Studies on Renewables Portfolio Standards

Research shows that some RPS policies affect electricity prices. One study found that RPS mandates caused electricity prices to increase, but noted that the effect on prices remained significantly lower in states with higher wind and solar energy potential, such as Arizona and California.[6] Ohio, however, ranks 32nd in the country for total renewable energy potential, which means that RPS mandates will likely affect electricity prices in Ohio more than in states with plentiful alternative energy sources.[7] The study also found that an RPS mandate's effect on electricity rates increases as the renewable requirement increases.[8] Another study revealed that RPS requirements raise residential and commercial electricity prices while holding coal prices and personal income constant.[9] Such effects on electricity prices are significant because the rising cost of electricity negatively impacts labor markets. Deschenes (2010) demonstrated, for example, that a 1% change in the price of electricity leads to a 0.13% to 0.12% reduction in full-time employment.[10]

Proponents of RPS programs argue that, despite rising electricity prices, renewable energy policies will create well-paying jobs. For example, one study claims that the U.S. economy added half a million "green jobs" between 2003 and 2010, and that those jobs paid 13% more than the average job.[11] Another study points to positive "ripple effects" on energy intensive industries.[12] These claims are not without their detractors, however. Michaels and Murphy observed, for example, that artificially pumping up employment in the green energy sector through subsidies and mandates ultimately drives-up costs in the broader economy, which limits overall net job creation and economic growth.[13] This is likely because when labor and energy are complementary inputs in production, labor demand in energy intensive sectors falls, while higher prices reduce the purchasing power of private households.

As demonstrated and discussed below, applying the ERC's dynamic state model to Ohio's RPS program reveals that allowing the RPS to continue will lead to foregone employment opportunities and reduce potential state gross domestic product. This analysis confirms earlier findings of electricity price increases and net job losses around the country due to other RPS programs.

Overview

The economic impact of Ohio's RPS is estimated by obtaining historical data on RPS compliance costs and calculating the percent increase in electricity prices caused by those compliance costs. Electricity providers satisfy their RPS requirements by purchasing renewable energy credits (RECs). The RPS requires electricity providers to pay additional money for RECs above the cost of merely buying and distributing wholesale electricity—and in turn, electricity providers pass the REC costs along to customers.[14] Thus, the RPS functions much like a tax on electricity because it increases the product's price without providing the consumer with any additional value. Putting past and projected electricity price increases caused by the RPS into the

ERC's dynamic model allows for an estimate of how this electricity "tax" affects state GDP and employment.*

The estimate of the RPS program's future economic impact is provided in four scenarios. Scenario I assumes that the RPS remains suspended at 2014-2016 levels indefinitely and REC prices stay constant at 2014 levels. Scenario II assumes the RPS is suspended indefinitely at 2014-2016 levels and REC prices gradually rise from 2014 levels to their historical maximum in 2026. Scenario III assumes that the RPS mandates increase to 12.5% in 2026 and REC prices stay constant at 2014 levels. Scenario IV assumes that the RPS mandates increase to 12.5% in 2026 and REC prices gradually increase from 2014 levels to their historical maximum in 2026. As seen in the tables below, Scenario I shows the least economic impact, and effectively provides a "best case" RPS scenario. Scenario IV reveals the most economic impact, offering a "worst case" RPS scenario. The four scenarios provided here are measured against a baseline estimate without RPS costs, which serves as a counterfactual that predicts what the Ohio economy would have looked like without an RPS in place, and what the Ohio economy would likely become if the RPS is repealed entirely.

Future REC prices are uncertain, of course, but REC prices likely will rise for three reasons. First, demand for RECs will grow as (1) annual compliance targets increase in states with existing RPS laws, (2) many states (e.g., New York and California) seek to increase existing or implement new RPS targets, and (3) companies (e.g., Amazon and Facebook) seek to "offset" more of their fossil fuel- and nuclear-generated electricity with renewables.[15] Second, the demand for RECs will likely outpace the supply of renewable energy, causing REC prices to rise. Building new renewable generation sources greatly depends on federal tax credits and subsidies—and the most significant of those are scheduled to sunset within the next three to seven years (i.e., 2020 for wind, and 2024 for solar).[16] With the current Trump Administration in charge for at least four years, new federal support and regulations favoring renewable generation investments appear unlikely. Finally, by regulation, Ohio electricity providers may only purchase RECs produced by renewable energy generators located in Ohio or her neighboring states.[17] Ohio's REC supply is further constrained because her bordering states rank well below-average in renewable energy potential and therefore are not strong candidates for future renewable energy investments.[18]

Results

As presented in Tables 1-3 below, the model predicts that Ohio's RPS policy will cause net GDP and employment losses. All four scenarios within each table show the same results from 2011-2014 because of the historical data used to calculate the electricity price increase caused by the RPS for those years; but because different assumptions inform each scenario to project costs from 2015 through 2026, those price changes—and therefore estimated effects—vary.

* For more detail on the RPS compliance cost methodology, please see Appendix A; for more detail on the model, please see Appendix B; and for more detail on how the model is calibrated to match the Ohio economy and used to estimate scenarios, please see Appendices C and D.

Table 1: Effects of RPS on Industrial Sectors

	Baseline Levels		Effect of RPS (Difference from No RPS Baseline)							
	No RPS		Scenario I		Scenario II		Scenario III		Scenario IV	
Year	GDP	Empl.	GDP	Empl.	GDP	Empl.	GDP	Empl.	GDP	Empl.
2011	112,402	1,031,500	-427	-4,100	-427	-4,100	-427	-4,100	-427	-4,100
2012	111,256	1,058,100	-278	-2,800	-278	-2,800	-278	-2,800	-278	-2,800
2013	114,186	1,077,900	-354	-3,600	-354	-3,600	-354	-3,600	-354	-3,600
2014	123,485	1,113,000	-235	-2,200	-235	-2,200	-235	-2,200	-235	-2,200
2015	125,441	1,113,000	-226	-2,100	-251	-2,300	-226	-2,100	-251	-2,300
2016	127,428	1,113,000	-229	-2,100	-280	-2,600	-229	-2,100	-280	-2,600
2017	129,446	1,113,000	-298	-2,700	-414	-3,800	-414	-3,800	-583	-5,200
2018	131,497	1,113,000	-289	-2,600	-460	-4,100	-526	-4,700	-828	-7,500
2019	133,579	1,113,000	-294	-2,600	-508	-4,500	-641	-5,600	-1,122	-9,900
2020	135,695	1,113,000	-285	-2,400	-570	-4,900	-746	-6,600	-1,479	-12,800
2021	137,844	1,113,000	-289	-2,400	-634	-5,500	-855	-7,300	-1,902	-16,200
2022	140,028	1,113,000	-280	-2,300	-700	-5,900	-966	-8,100	-2,394	-20,000
2023	142,246	1,113,000	-284	-2,300	-782	-6,500	-1,081	-8,900	-2,973	-24,600
2024	144,499	1,113,000	-275	-2,200	-867	-7,100	-1,170	-9,600	-3,656	-29,800
2025	146,787	1,113,000	-279	-2,200	-969	-7,800	-1,277	-10,200	-4,462	-35,700
2026	149,112	1,113,000	-268	-2,200	-1,074	-8,600	-1,387	-10,900	-5,398	-42,600

Note: Total GDP of industrial sectors in millions of 2009$
Employment in units of full-time equivalent jobs, rounded to the nearest hundred.

Table 1 shows the impact of the RPS on the industrial sector, which includes manufacturing; agriculture, forestry, fishing and hunting; mining, including oil and gas extraction; and construction. The model estimates that the industrial sector produces thousands of fewer job opportunities each year because of higher costs brought on by the RPS mandate. The employment figure represents jobs lost or job opportunities that would have been created but were not due to RPS costs. In the worst-case scenario in 2026, the industrial sector is projected to have 3.8% fewer job opportunities for Ohioans and produce 3.6% less GDP than without the mandates.

Table 2: Effects of RPS on Commercial Sectors

	Baseline Levels		Effect of RPS (Difference from No RPS Baseline)							
	No RPS		Scenario I		Scenario II		Scenario III		Scenario IV	
Year	GDP	Empl.	GDP	Empl.	GDP	Empl.	GDP	Empl.	GDP	Empl.
2011	328,523	3,372,100	-756	-8,100	-756	-8,100	-756	-8,100	-756	-8,100
2012	338,593	3,438,900	-542	-5,800	-542	-5,800	-542	-5,800	-542	-5,800
2013	339,651	3,495,100	-679	-7,300	-679	-7,300	-679	-7,300	-679	-7,300
2014	342,343	3,533,800	-445	-4,600	-445	-4,600	-445	-4,600	-445	-4,600
2015	347,765	3,533,800	-417	-4,600	-469	-4,900	-417	-4,600	-469	-4,900
2016	353,273	3,533,800	-424	-4,200	-530	-5,700	-424	-4,200	-530	-5,700
2017	358,869	3,533,800	-538	-5,700	-790	-8,100	-754	-8,100	-1,077	-11,300
2018	364,553	3,533,800	-547	-5,700	-875	-8,800	-984	-10,200	-1,531	-15,900
2019	370,327	3,533,800	-555	-5,700	-963	-9,500	-1,185	-12,000	-2,111	-21,200
2020	376,193	3,533,800	-527	-5,300	-1,053	-10,600	-1,392	-13,800	-2,746	-27,600
2021	382,152	3,533,800	-535	-5,300	-1,185	-11,700	-1,605	-15,500	-3,554	-34,600
2022	388,205	3,533,800	-505	-4,900	-1,320	-12,700	-1,825	-17,300	-4,464	-43,100
2023	394,353	3,533,800	-513	-4,900	-1,459	-13,800	-2,011	-19,100	-5,560	-52,700
2024	400,600	3,533,800	-521	-4,900	-1,602	-15,200	-2,203	-20,500	-6,810	-64,000
2025	406,945	3,533,800	-529	-4,600	-1,791	-16,600	-2,401	-21,900	-8,342	-76,700
2026	413,391	3,533,800	-537	-4,600	-2,026	-18,400	-2,604	-23,300	-10,087	-91,500

Note: Total GDP of industrial sectors in millions of 2009$
Employment in units of full-time equivalent jobs, rounded to the nearest hundred.

Table 2 shows the impact of the RPS on the commercial sector, which encompasses all other production sectors such as education, healthcare, and finance and insurance. In the worst-case scenario, the commercial sector will produce 2.6% fewer job opportunities for Ohioans in 2026 than would be otherwise employed without the mandate, and produce 2.4% less GDP. Although the industrial sector is more energy intensive and harder hit by the mandate in percentage terms, the commercial sector is a much larger share of Ohio's GDP, so the negative impact of the RPS cost to the commercial sector has a larger effect on the state's economy.

Table 3: Effects of RPS on Industrial and Commercial Sectors

	Baseline Levels		Effect of RPS (Difference from No RPS Baseline)							
	No RPS		Scenario I		Scenario II		Scenario III		Scenario IV	
Year	GDP	Empl.	GDP	Empl.	GDP	Empl.	GDP	Empl.	GDP	Empl.
2011	440,925	4,403,600	-1,183	-12,200	-1,183	-12,200	-1,183	-12,200	-1,183	-12,200
2012	449,850	4,497,000	-820	-8,600	-820	-8,600	-820	-8,600	-820	-8,600
2013	453,837	4,573,000	-1,033	-10,900	-1,033	-10,900	-1,033	-10,900	-1,033	-10,900
2014	465,828	4,646,800	-680	-6,800	-680	-6,800	-680	-6,800	-680	-6,800
2015	473,206	4,646,800	-643	-6,700	-720	-7,200	-643	-6,700	-720	-7,200
2016	480,701	4,646,800	-653	-6,300	-810	-8,300	-653	-6,300	-810	-8,300
2017	488,315	4,646,800	-836	-8,400	-1,204	-11,900	-1,168	-11,900	-1,659	-16,500
2018	496,050	4,646,800	-836	-8,300	-1,335	-12,900	-1,510	-14,900	-2,360	-23,400
2019	503,907	4,646,800	-849	-8,300	-1,470	-14,000	-1,826	-17,600	-3,233	-31,100
2020	511,888	4,646,800	-812	-7,700	-1,623	-15,500	-2,138	-20,400	-4,225	-40,400
2021	519,996	4,646,800	-824	-7,700	-1,819	-17,200	-2,460	-22,800	-5,456	-50,800
2022	528,232	4,646,800	-785	-7,200	-2,020	-18,600	-2,791	-25,400	-6,859	-63,100
2023	536,599	4,646,800	-797	-7,200	-2,241	-20,300	-3,092	-28,000	-8,533	-77,300
2024	545,098	4,646,800	-795	-7,100	-2,469	-22,300	-3,374	-30,100	-10,466	-93,800
2025	553,732	4,646,800	-808	-6,800	-2,759	-24,400	-3,678	-32,100	-12,805	-112,400
2026	562,503	4,646,800	-806	-6,800	-3,099	-27,000	-3,991	-34,200	-15,485	-134,100

Note: Total GDP of industrial sectors in millions of 2009$
Employment in units of full-time equivalent jobs, rounded to the nearest hundred.

Finally, Table 3 combines the effects on commercial and industrial sectors to show the impact on all Ohio employers and job opportunities. In the worst case scenario, potential employment in Ohio is expected to fall 2.9% and GDP by 2.8%. Such a decline means that 134,000 fewer people will be employed in Ohio. Even in the best case scenario, if the Energy Mandates Study Committee's recommendation of an indefinite freeze is implemented immediately and REC prices stay constant, Ohio will employ thousands fewer people and produce $806 million less output by the final year of compliance. The results of the modeled four scenarios strongly support an outright repeal of the mandates.

Conclusion

The Economic Research Center's dynamic model of the Ohio economy shows that by continuing to allow the state's Renewables Portfolio Standard to remain in effect, the future Ohio economy will be much smaller, with fewer jobs, than it otherwise could be. Policymakers should repeal the RPS program to promote job creation and strengthen the economy.

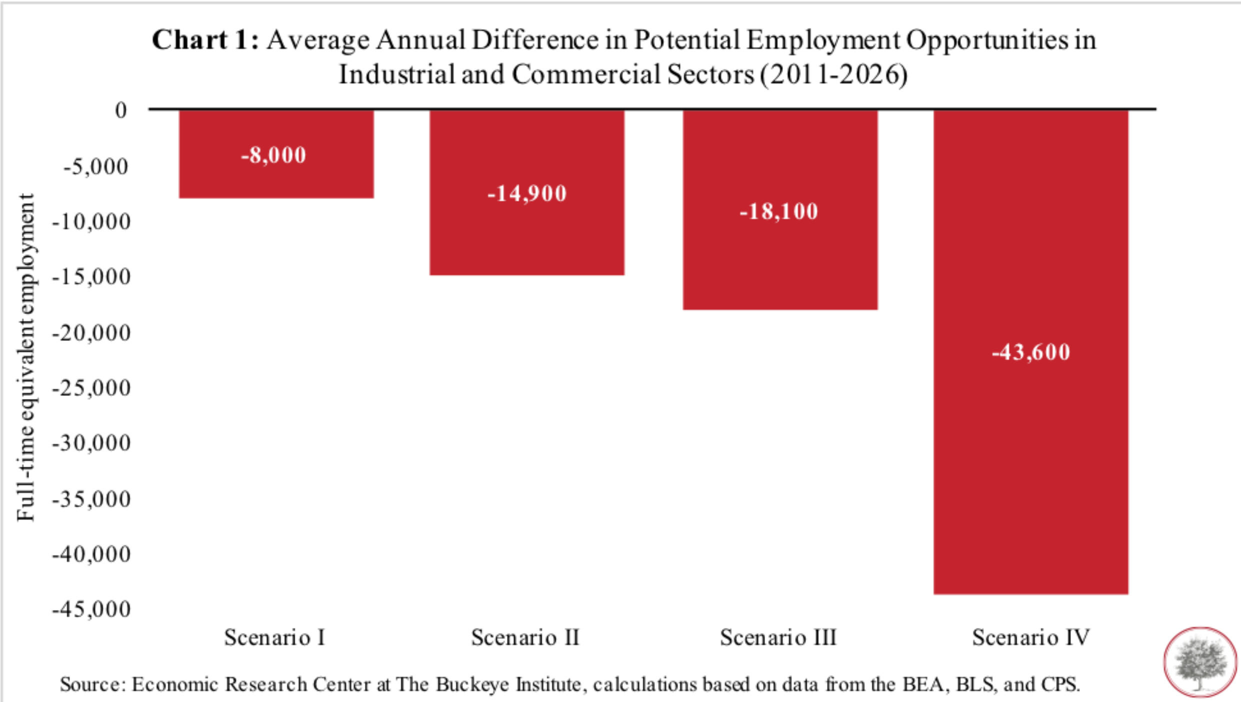
Chart 1: Average Annual Difference in Potential Employment Opportunities in Industrial and Commercial Sectors (2011-2026)
Full-time equivalent employment
0
-5,000
-10,000
-15,000
-20,000
-25,000
-30,000
-35,000
-40,000
-45,000
-8,000
-14,900
-18,100
-43,600
Scenario I
Scenario II
Scenario III
Scenario IV
Source: Economic Research Center at The Buckeye Institute, calculations based on data from the BEA, BLS, and CPS.

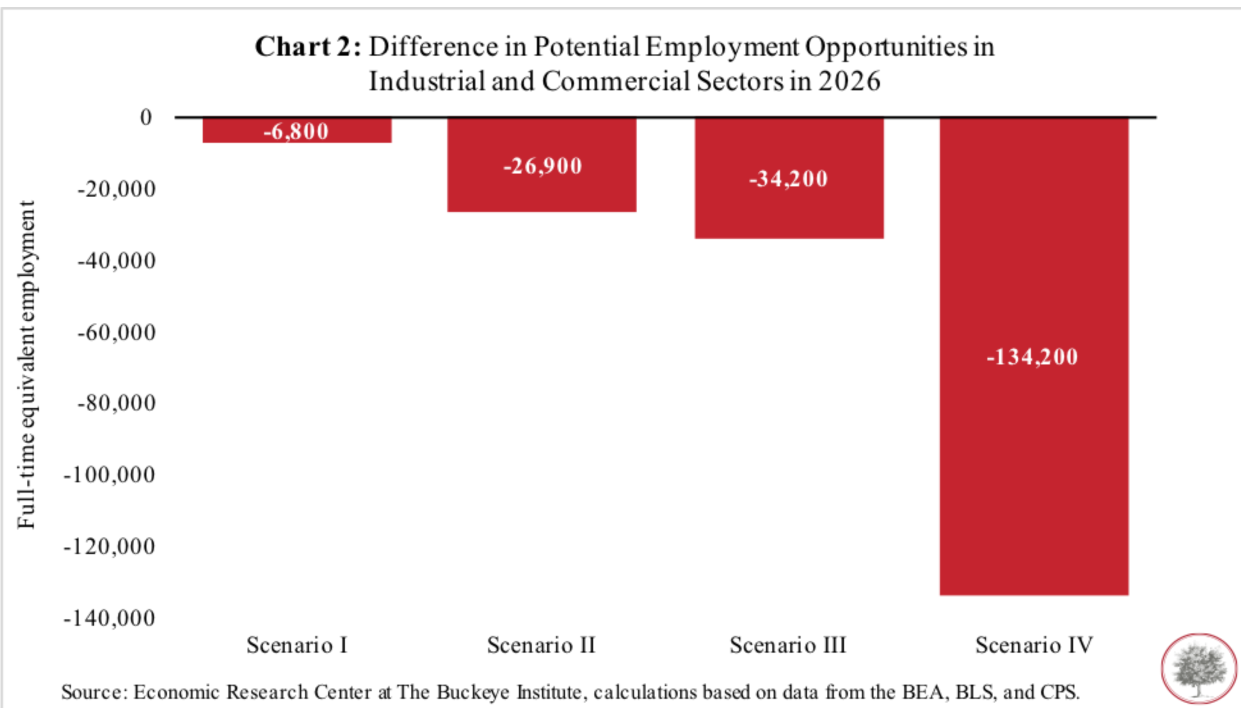
Chart 2: Difference in Potential Employment Opportunities in Industrial and Commercial Sectors in 2026
Full-time equivalent employment
0
-20,000
-40,000
-60,000
-80,000
-100,000
-120,000
-140,000
-6,800
-26,900
-34,200
-134,200
Scenario I
Scenario II
Scenario III
Scenario IV
Source: Economic Research Center at The Buckeye Institute, calculations based on data from the BEA, BLS, and CPS.

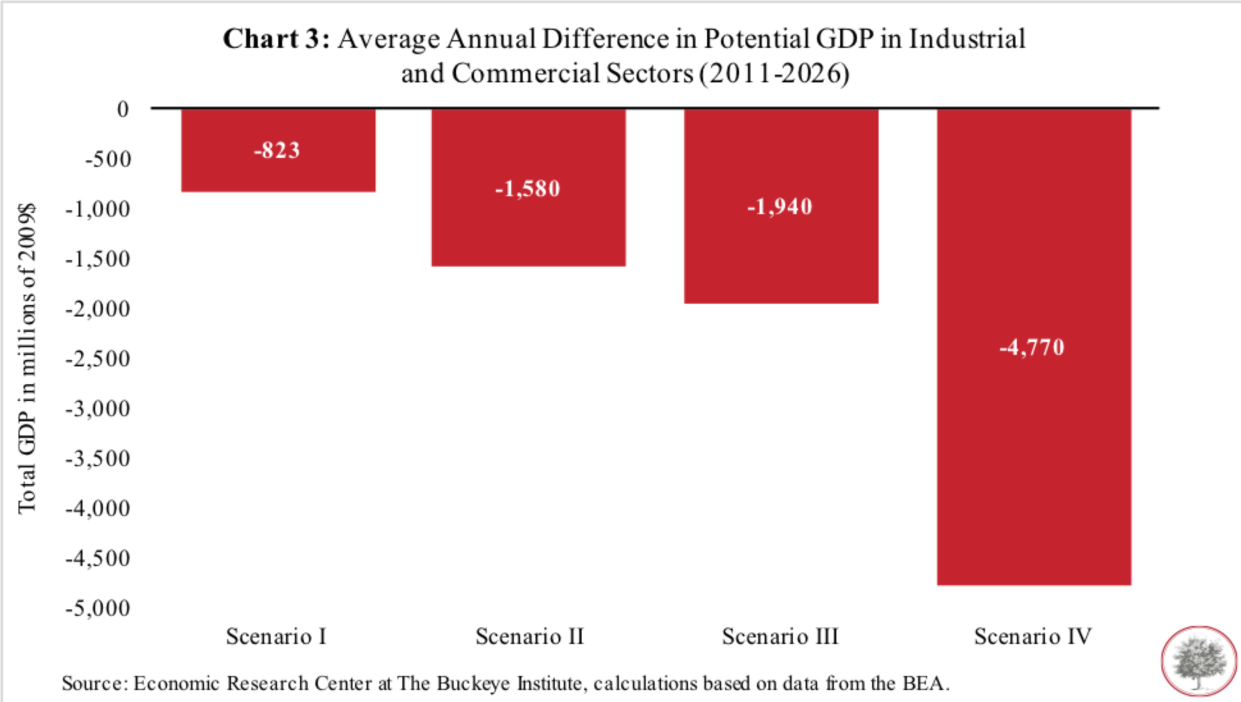
Chart 3: Average Annual Difference in Potential GDP in Industrial and Commercial Sectors (2011-2026)
Total GDP in millions of 2009$
0
-500
-1,000
-1,500
-2,000
-2,500
-3,000
-3,500
-4,000
-4,500
-5,000
-823
-1,580
-1,940
-4,770
Scenario I
Scenario II
Scenario III
Scenario IV
Source: Economic Research Center at The Buckeye Institute, calculations based on data from the BEA.

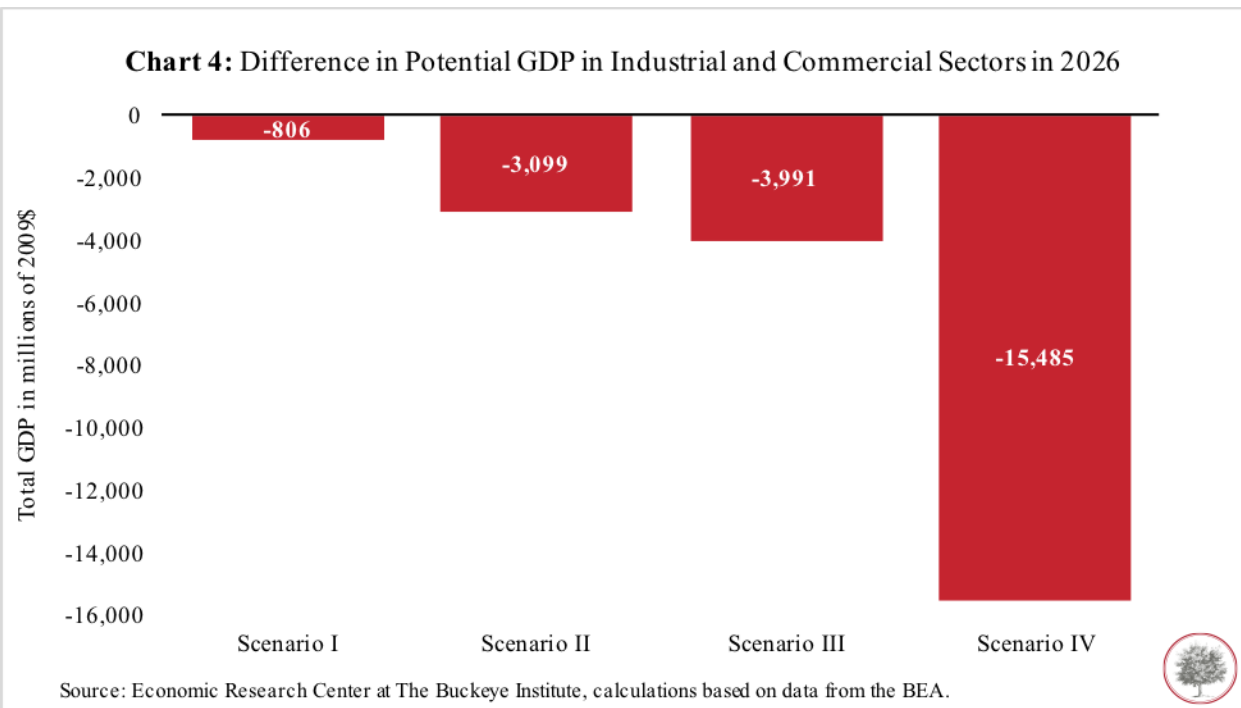
Chart 4: Difference in Potential GDP in Industrial and Commercial Sectors in 2026
Total GDP in millions of 2009$
0
-2,000
-4,000
-6,000
-8,000
-10,000
-12,000
-14,000
-16,000
-806
-3,099
-3,991
-15,485
Scenario I
Scenario II
Scenario III
Scenario IV
Source: Economic Research Center at The Buckeye Institute, calculations based on data from the BEA.

End Notes

† Corrected to clarify extended compliance deadline.

[1] Am. Sub. S.B. 221, 127th, Ohio General Assembly, (2008).

[2] Sub. S.B. 310, 130th Ohio General Assembly, (2014).

[3] Jeremy Pelzer, “Ohio lawmakers recommend halting state’s renewable energy, efficiency mandates,” *The Cleveland Plain Dealer*, September 30, 2015, http://www.cleveland.com/open/index.ssf/2015/09/ohio_lawmakers_recommend_halti.html.

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[8] *Ibid.*

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[14] Public Utilities Commission of Ohio, “Renewable/Alternative Energy Portfolio Standard Reports,” http://www.puco.ohio.gov/industry-information/industry-topics/ohioe28099s-renewable-and-advanced-energy-portfolio-standard/#sthash.Uby01I2R.dpbs.

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[17] Ohio Administrative Code, 4901:1-40-01, http://codes.ohio.gov/oac/4901:1-40-01.

[18] US Department of Energy, National Renewable Energy Laboratory, *Data of RE Technical Potential*, updated February 2, 2016, http://www.nrel.gov/gis/re_potential.html.

About the Authors

Orphe Divounguy is an Economist with The Buckeye Institute's Economic Research Center. In this role at Buckeye, Divounguy analyzes the impact of federal and state government policy on economic outcomes in Ohio.

Divounguy joined The Buckeye Institute after earning his Ph.D. from England's University of Southampton, where he also obtained his master's degree. After receiving his Ph.D., Divounguy served as a teaching and research fellow. He also worked as an international economic consultant. His research focused on labor policy, migration policy, and economic development.

Before his time in higher education, Divounguy interned at the United Nations Department of Economic and Social Affairs in New York, and Cato Institute in Washington, D.C. Divounguy lives in downtown Columbus, Ohio with his wife.

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Prior to that, he was a Director of the Center for Data Analysis (CDA) at The Heritage Foundation, where he served as the organization's top "number cruncher." After joining Heritage in 1995, he was a founding member of the CDA, in 1997, when it was created to provide state-of-the-art economic modeling, database products, and original studies. Hederman oversaw Heritage's technical research on taxes, healthcare, income and poverty, entitlements, energy, education, and employment, among other policy and economic issues, and was responsible for managing its legislative statistical analysis and econometric modeling for Heritage policy initiatives.

In 2014, Hederman was admitted into the prestigious Cosmos Club as a recognition of his scholarship. He graduated from Georgetown Public Policy Institute with a Master of Public Policy degree and holds a Bachelor of Arts degree in history and foreign affairs from the University of Virginia. Hederman resides with his wife, Caryn, who is an attorney, and their three sons in Powell, Ohio.

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Prior to his position at Buckeye, Nichols obtained his Bachelor of Arts in Economics from Denison University in Granville, Ohio. During college, Nichols worked for a law firm, the Denison Admissions Office, and a local farm. He lives in Newark, Ohio, with his wife, two young sons, and dog.

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Born and raised in Austria, Spitzwieser received his Master's degree in Economics from the Vienna University of Economics and Business, where he also received his undergraduate degree with a major in Economics. Additionally, Spitzwieser holds a second Bachelor's degree in Agriculture from the University of Natural Resources and Life Sciences, Vienna.

APPENDIX A: CALCULATING THE RPS COST AND PROJECTING FUTURE SCENARIOS

The cost of Renewables Portfolio Standard compliance is measured by the percentage increase in electricity prices caused by electricity suppliers having to purchase renewable energy credits (RECs) in order to comply with the RPS mandate. As defined by the U.S. EPA, RECs are "instrument[s] that represent[] the property rights to the environmental, social[,] and other non-power attributes of renewable electricity generation. RECs are issued when one megawatt-hour (MWh) of electricity is generated and delivered to the electricity grid from a renewable energy resource."[1] Electricity providers may satisfy the RPS requirements by buying RECs from companies that own renewable electricity generators such as wind and solar farms.

In Ohio, each time a renewable electricity generator produces a megawatt-hour of electricity, the regional power grid operator creates a REC for the owner of the renewable generator. The owner of the REC may then sell that credit to another energy company to use for RPS compliance; or—if the credit owner is an electricity supplier—use the REC for its own compliance.

We estimate future RPS compliance costs under four hypothetical scenarios. Scenario I assumes that the RPS remains suspended at 2014-2016 levels indefinitely and REC prices stay constant at 2014 levels. Scenario II assumes the RPS is suspended indefinitely at 2014-2016 levels and REC prices gradually rise from 2014 levels to their historical maximum in 2026. Scenario III assumes that the RPS mandates increase to 12.5% in 2026 and REC prices stay constant at 2014 levels. Scenario IV assumes that the RPS mandates increase to 12.5% in 2026 and REC prices gradually increase from 2014 levels to their historical maximum in 2026.[*]

These four scenarios are measured against a baseline estimate without RPS costs, which serves as a counterfactual that predicts what the Ohio economy would have looked like without an RPS in place, and what the Ohio economy would likely become if the RPS is repealed entirely.

The annual cost of purchasing RECs in Ohio for 2011 through 2014 was derived by calculating the weighted average REC price and multiplying it by the total number of RECs required for the given year.[2] Then the annual RPS cost is divided by the number of kilowatt-hours sold to obtain the RPS cost per-kilowatt-hour.[3] Finally, the estimated RPS cost per kilowatt-hour and the retail price of electricity per kilowatt-hour reveal the percent increase in price caused by the RPS requirements.[4] We estimate the increase on both commercial and industrial prices.

Using the method described above, we project the increase in electricity prices caused by the RPS for 2015 through 2026 by also assuming that electricity sales remain flat after 2014, while electricity prices grow each year at 2.25% (the approximate long-run average yearly growth rate).[5] Future RPS compliance costs from 2015 through 2026 are estimated by multiplying that year's compliance target by projected electricity sales to obtain the compliance obligation, then

[*] The average REC price in Ohio during 2011 was approximately $59. By 2014, that price had fallen to approximately $15. Much of the price-decline may be attributed to the 2014 repeal of quotas requiring suppliers to buy a certain percentage of RECs from in-state sources. Scenarios II and IV estimate REC prices gradually returning to $59, in nominal terms, in 2026.

multiplying the compliance obligation by projected REC prices to obtain the total compliance cost. As with the historical data, the compliance cost is then divided by projected sales to obtain the per-kilowatt-hour RPS cost, and then divided by the projected price to estimate the RPS percent price increase.

The RPS law currently imposes a "cost cap" which states that electricity providers may ask the Public Utilities Commission of Ohio to reduce its RPS compliance obligation if satisfying that obligation would exceed the cost of procuring electricity without any RPS compliance obligation by 3 percent or more. This provision gives wide discretion to the utility and PUCO and is in no way a guarantee that the RPS will not cause prices to increase by 3 percent or more, therefore, in scenarios that cause greater than 3 percent price increases, we assume the full price increase goes into effect without any cost cap restriction.

The annual percentage increases in electricity price caused by RPS are:

Table A.1: RPS Charge Data

Year	Scenario I		Scenario II		Scenario III		Scenario IV	
	Commercial	Industrial	Commercial	Industrial	Commercial	Industrial	Commercial	Industrial
2011	0.53%	0.84%	0.53%	0.84%	0.53%	0.84%	0.53%	0.84%
2012	0.36%	0.55%	0.36%	0.55%	0.36%	0.55%	0.36%	0.55%
2013	0.46%	0.69%	0.46%	0.69%	0.46%	0.69%	0.46%	0.69%
2014	0.29%	0.42%	0.29%	0.42%	0.29%	0.42%	0.29%	0.42%
2015	0.28%	0.40%	0.31%	0.45%	0.28%	0.40%	0.31%	0.45%
2016	0.27%	0.39%	0.34%	0.49%	0.27%	0.39%	0.34%	0.49%
2017	0.35%	0.50%	0.49%	0.71%	0.49%	0.71%	0.69%	0.99%
2018	0.34%	0.49%	0.54%	0.78%	0.62%	0.89%	0.97%	1.40%
2019	0.34%	0.48%	0.59%	0.85%	0.74%	1.06%	1.30%	1.87%
2020	0.33%	0.47%	0.65%	0.93%	0.85%	1.23%	1.69%	2.42%
2021	0.32%	0.46%	0.71%	1.02%	0.96%	1.38%	2.13%	3.06%
2022	0.31%	0.45%	0.78%	1.12%	1.07%	1.53%	2.65%	3.80%
2023	0.31%	0.44%	0.85%	1.22%	1.17%	1.68%	3.24%	4.65%
2024	0.30%	0.43%	0.93%	1.34%	1.26%	1.81%	3.92%	5.63%
2025	0.29%	0.42%	1.02%	1.47%	1.35%	1.94%	4.71%	6.75%
2026	0.29%	0.41%	1.12%	1.61%	1.44%	2.06%	5.61%	8.04%

Source: Author’s calculations based on data from EIA and PUCO

The Renewables Portfolio Standard target for each year as set by the General Assembly:

Table A.2: Ohio RPS Targets by Year[6]

Year	RPS target	In-state renewable energy supplied[2]	Solar energy supplied[3]
2009	0.25%	0.125%	0.004%
2010	0.50%	0.250%	0.010%
2011	1.00%	0.500%	0.030%
2012	1.50%	0.750%	0.060%
2013	2.00%	1.000%	0.090%
2014	2.50%	0.000%	0.120%
2015	2.50%	0.000%	0.120%
2016	2.50%	0.000%	0.120%
2017	3.50%	0.000%	0.150%
2018	4.50%	0.000%	0.180%
2019	5.50%	0.000%	0.220%
2020	6.50%	0.000%	0.260%
2021	7.50%	0.000%	0.300%
2022	8.50%	0.000%	0.340%
2023	9.50%	0.000%	0.380%
2024	10.50%	0.000%	0.420%
2025	11.50%	0.000%	0.460%
2026	12.50%	0.000%	0.500%

[1] U.S. Environmental Protection Agency, *Renewable Energy Certificates*, updated July 15, 2016, https://www.epa.gov/greenpower/renewable-energy-certificates-recs.

[2] Public Utilities Commission of Ohio, "Renewable/Alternative Energy Portfolio Standard Reports," http://www.puco.ohio.gov/industry-information/industry-topics/ohioe28099s-renewable-and-advanced-energy-portfolio-standard/#sthash.Uby01I2R.dpbs. In 2011, the PUCO made sufficient information available for the first time to estimate the weighted average REC price. The most recent report available is for the 2014 compliance year.

[3] US Energy Information Administration, "Retail Sales of Electricity to Ultimate Consumers, Annual, By sector, by state, by provider (back to 1990)," released October 21, 2015, http://www.eia.gov/electricity/data.cfm#sales.

[4] US Energy Information Administration, "Average Retail Price of Electricity to Ultimate Consumers, Annual, By sector, by state, by provider (back to 1990)," released October 21, 2015, http://www.eia.gov/electricity/data.cfm#sales.

[5] The assumption of flat sales from 2014-2026 is supported by the Public Utilities Commission. See Public Utilities Commission of Ohio, "Ohio Long Term Forecast of Energy Requirements," July 22, 2015, pp. 57-63, https://www.puco.ohio.gov/industry-information/statistical-reports/ohio-long-term-energy-forecast/ohio-ltfr-2014-2033/.

[6] In 2014, the General Assembly repealed the requirement to procure some renewable energy credits from in-state sources and froze the standards for 2015 and 2016.

APPENDIX B: DESCRIPTION OF THE MODEL

A Small Open Economy Real Business Cycle Model with Intermediate Goods

The Model

The model is similar to Schmitt-Grohé and Uribe in the sense that households can borrow from the world financial market at the world interest rate.[1] We follow Schmitt-Grohé and Uribe in assuming a risk premium that causes interest rates to rise as the level of household debt increases. We include a government sector that purchases goods with any excess revenues collected into a rainy-day fund. In addition, our production technology includes the production of intermediate goods.

Production

We consider a three-factor two-level aggregate production function with inputs capital ($k_{s,t-1}$), labor ($n_{s,t}$) and energy ($m_{s,t}$):

$$y_{s,t} = \left[\sigma\left(k_{s,t-1}\right)^{-\rho} + (1-\sigma)\left(n_{s,t}\right)^{-\rho}\right]^{-1/\rho}$$

Then this first level function is nested into the second level function of $q_{s,t}$ and $m_{s,t}$

$$q_{s,t} = z_t \quad \left[\alpha\left(q_{s,t}\right)^{-\theta} + (1-\alpha)\left(m_{s,t}\right)^{-\theta}\right]^{-1/\theta}$$

Substituting the first level into the second level yields the two-level CES function:

$$y_{s,t} = z_t \quad \left[\alpha\left(\left[\sigma\left(k_{s,t-1}\right)^{-\rho} + (1-\sigma)\left(n_{s,t}\right)^{-\rho}\right]^{-1/\rho}\right)^{-\theta} + (1-\alpha)\left(m_{s,t}\right)^{-\theta}\right]^{-1/\theta}$$

where $\theta \in (0,1)$, $\rho \in (0,1), \alpha \in (0,1)$. θ denotes the elasticity of substitution between capital-labor and material inputs. ρ is the elasticity of substitution between capital and labor. σ is the capital share and α is the capital-labor share of production.

z_t denotes a random productivity shock variable that is assumed to follow a stationary mean zero autoregressive process of order 1 in the log. The shock ϵ_t is drawn from a standard normal distribution.

$$(z_t) = \rho_z(z_{t-1}) + \epsilon_t$$

The intermediate good producers' problem: The producer chooses the quantity of intermediates that maximizes profits by hiring labor and capital inputs. μ_t is the cost associated with compliance in a regulated market. σ is the capital share.

$$\max_{\{k_{m,s,t}, n_{m,s,t}\}} \left(k_{m,s,t}\right)^{\sigma} \left(n_{m,s,t}\right)^{(1-\sigma)} - (\mu_t)\, m_{s,t} - \left(w_{m,s,t}\right) n_{m,s,t} - \left(r_{m,s,t}\right) k_{m,s,t}$$

The solution to the problem can be summarized as:

$$\sigma\left(k_{m,s,t}\right)^{\sigma-1}\left(n_{m,s,t}\right)^{(1-\sigma)}-(\mu_t)\sigma\left(k_{m,s,t}\right)^{\sigma-1}\left(n_{m,s,t}\right)^{(1-\sigma)}=r_{m,s,t}$$

$$(1-\sigma)\left(k_{m,s,t}\right)^{\sigma}\left(n_{m,s,t}\right)^{(-\sigma)}-(\mu_t)(1-\sigma)\left(k_{m,s,t}\right)^{\sigma}\left(n_{m,s,t}\right)^{(-\sigma)}=w_{m,s,t}$$

The consumer goods producer's problem: Taking $\{p_{q,s,t}, r_{s,t}, w_{s,t}\}$ as given, the large representative firm in the perfectly competitive industry s solves at each point in time:

$$\max_{\{k_{s,t},n_{s,t}\}} q_{s,t}-\left(r_{s,t}\right)k_{s,t}-\left(w_{s,t}\right)n_{s,t}-p_{q,s,t}m_{s,t}$$

$r_{s,t}k_{s,t}$ is the total cost of capital $w_{s,t}n_{s,t}$is the total cost of labor inputs and $p_{q,s,t}m_{s,t}$ is the total cost of intermediate goods.

The solution to the goods producer's problem is summarized as:

$$-\frac{1}{\theta}z_t\left[\alpha\left[\sigma\left(k_{s,t-1}\right)^{-\rho}+(1-\sigma)\left(n_{s,t}\right)^{-\rho}\right]^{\frac{\theta}{\rho}}+(1-\alpha)\left(m_{s,t}\right)^{-\theta}\right]^{\frac{-1-\theta}{\theta}}\alpha\frac{\theta}{\rho}\left[\sigma\left(k_{s,t-1}\right)^{-\rho}+(1-\sigma)\left(n_{s,t}\right)^{-\rho}\right]^{\frac{\theta-\rho}{\rho}}\sigma(-\rho)\left(k_{s,t-1}\right)^{-\rho-1}=r_{s,t}$$

$$-\frac{1}{\theta}z_t\left[\alpha\left[\sigma\left(k_{s,t-1}\right)^{-\rho}+(1-\sigma)\left(n_{s,t}\right)^{-\rho}\right]^{\frac{\theta}{\rho}}+(1-\alpha)\left(m_{s,t}\right)^{-\theta}\right]^{\frac{-1-\theta}{\theta}}\alpha\frac{\theta}{\rho}\left[\sigma\left(k_{s,t-1}\right)^{-\rho}+(1-\sigma)\left(n_{s,t}\right)^{-\rho}\right]^{\frac{\theta-\rho}{\rho}}(1-\sigma)(-\rho)\left(n_{s,t}\right)^{-\rho-1}=w_{s,t}$$

$$-\frac{1}{\theta}z_t\left[\alpha\left[\sigma\left(k_{s,t-1}\right)^{-\rho}+(1-\sigma)\left(n_{s,t}\right)^{-\rho}\right]^{\frac{\theta}{\rho}}+(1-\alpha)\left(m_{s,t}\right)^{-\theta}\right]^{\frac{-1-\theta}{\theta}}(1-\alpha)(-\theta)\left(m_{s,t}\right)^{-\theta-1}=p_{q,s,t}$$

Each of these final goods $q_{s,t}$ can be used for household consumption $c_{s,t}$, government purchases $g_{s,t}$, investment in the production of consumer goods $x_{s,t}$ and investment in the production of materials $x_{m,s,t}$. Therefore,

$$c_{s,t}+g_{s,t}+x_{s,t}+x_{m,s,t}+TB_{s,t}=q_{s,t}$$

Consumption, $c_{s,t}$ investment $x_{s,t}, x_{m,s,t}$ are solutions from the household problem that we describe in the next section and $TB_{s,t}$ is the trade balance. $g_{s,t}$ is government purchases that is exogenously fixed.

Households

Time is discrete and lasts forever. We now introduce a large number of identical households with preferences described by the following utility function:

$$E_0 \sum_{t=0}^{\infty} \beta^t U(c_t, 1-n_t)$$

where β is a constant discount factor. Households work and invest in the production of both consumer goods and material goods. Households derive utility from consumption c_t and leisure $1-n_t$. We assume the utility function takes the form:

$$U(c_t, 1-n_t) = \sum \gamma_s \ln c_{s,t} - \chi\, n_t^{1+1/\varphi}$$

$$n_t = \sum_{s=1}^{S} \gamma_s n_{s,t}$$

The period by period budget constraint of the household is given by:

$$\begin{aligned} d_t = {} & (1+\tau_t^c)\sum_{s=1}^{S} c_{s,t} + \sum_{s=1}^{S} x_{s,t} + \sum_{s=1}^{S} x_{m,s,t} + \left(1+i_{m,t-1}\right)d_{t-1} + \sum_{s=1}^{S}\left[\frac{\phi}{2}\left(k_{s,t}-k_{s,t-1}\right)^2\right] \\ & + \tau_t^k \sum_{s=1}^{S} k_{s,t-1} - \ (1-\tau_t^n - \tau_t^l - \tau_t^{n,f})\left[\sum_{s=1}^{S} w_{s,t} n_{s,t} + \sum_{s=1}^{S} w_{ms,t} n_{m,s,t}\right] \\ & - (1-\tau_t^r - \tau_t^l - \tau_t^{r,f})\left[\sum_{s=1}^{S} r_{s,t} k_{s,t-1} + \sum_{s=1}^{S} r_{m,s,t} k_{m,s,t-1}\right] \end{aligned}$$

$$k_0 > 0, k_{T+1} = 0$$

The budget constraint states that foreign debt is equal to household expenditures on consumption, investment, debt servicing, capital adjustment costs, and other taxes minus total household income. The capital stock evolves according to:

$$\sum_{s=1}^{S} k_{s,t} = \sum_{s=1}^{S} x_{s,t} + (1-\delta)\sum_{s=1}^{S} k_{s,t-1}$$

$$\sum_{s=1}^{S} k_{m,s,t} = \sum_{s=1}^{S} x_{m,s,t} + (1-\delta)\sum_{s=1}^{S} k_{m,s,t-1}$$

and δ is a constant rate of depreciation of physical capital. τ_t^c is the tax on household consumption purchases, τ_t^n is the tax on labor income, τ_t^r is the tax on dividend income and τ_t^k is a tax on the stock of capital owned by households. τ_t^l is the share of income paid in licenses and fees to the state government. $\tau_t^{r,f}$ and $\tau_t^{n,f}$ are federal taxes on investment and labor income respectively.

$i_{m,t}$ denotes the interest rate at which domestic residents can borrow from international markets in period t, d_t is household debt, c_t denotes consumption, x_t, denotes gross investment, and k_t denotes physical capital.

We assume $i_{m,t} = i_{m,w} + \eta(\exp(d_t - d) - 1)$ where $i_{m,w}$ is the world interest rate faced by domestic agents and is assumed to be constant, η and d are also constant parameters. $\eta(\exp(d_t - d) - 1)$ is the state specific interest rate premium that increases with the level of debt.

Households choose processes $\{c_t, x_t, n_t, k_{t+1}, d_t\}_{t=0}^{\infty}$ so as to maximize the utility function subject to the resource constraint and a no-ponzi scheme constraint of the form:

$$\lim_{j\to\infty} E_t \frac{d_{t+j}}{\prod_{w=1}^{j}(1+i_{m,w})} \leq 0$$

which states that as time approaches infinity no debt can be outstanding.

We describe the behavior of government purchases in what follows. The rainy-day fund $\{RF_t\}$ is the excess of tax revenue plus federal government transfers net of government spending added to the previous period's balance.

$$RF_t = T_t^h + FF_t - g_t + (1 + i_{m,t-1})RF_{t-1}$$

Tax revenues T_t are given by:

$$T_t = \tau_t^c \sum_{s=1}^{S} c_{s,t} + \tau_t^n \left[\sum_{s=1}^{S} w_{s,t} n_{s,t} + \sum_{s=1}^{S} w_{ms,t} n_{m,s,t}\right] + \tau_t^r \left[\sum_{s=1}^{S} r_{s,t} k_{s,t-1} + \sum_{s=1}^{S} r_{m,s,t} k_{m,s,t-1}\right] + \tau_t^k \left[\sum_{s=1}^{S} k_{s,t-1} + \sum_{s=1}^{S} k_{ms,t-1}\right] + \tau_t^s \sum_{s=1}^{S} m_{s,t} + \tau_t^l q_t$$

Government spending policy is assumed to evolve according to:

$$\kappa_t = (1 - \rho_{g,h})(\kappa) + \rho_{g,h}(\kappa_{t-1}) + \epsilon_g$$

where κ is the state share of income spent by the government sector in steady-state. This specification implies that $g_t = \kappa y_t$ which means that the size of government reflects changes in GDP. Variables without the time subscript denote steady-state values.

The tax instruments follow the exogenous processes:

$$\tau_t^n = (1-\rho_n)\tau^n + \rho_n \tau_{t-1}^n + \epsilon_n$$

$$\tau_t^r = (1-\rho_r)\tau^r + \rho_r \tau_{t-1}^r + \epsilon_r$$

$$\tau_t^c = (1-\rho_c)\tau^c + \rho_c \tau_{t-1}^c + \epsilon_c$$

$$\tau_t^k = (1-\rho_k)\tau^k + \rho_k \tau_{t-1}^k + \epsilon_k$$

$$\tau_t^l = (1-\rho_l)\tau^l + \rho_l \tau_{t-1}^l + \epsilon_l$$

$$\tau_t^{n,f} = (1-\rho_{n,f})\tau^{n,f} + \rho_{n,f} \tau_{t-1}^{n,f} + \epsilon_{n,f}$$

$$\tau_t^{r,f} = (1-\rho_{r,f})\tau^{r,f} + \rho_{r,f} \tau_{t-1}^{r,f} + \epsilon_{r,f}$$

As in Schmitt-Grohé and Uribe, we write the trade balance to GDP ratio (TB) in steady state as:

$$TB = 1 - \frac{[c + x + g]}{q}$$

Taking the first order conditions with respect to c_t, n_t, k_t, d_t:

$$\frac{\partial L}{\partial c_{s,t}} = 0 \rightarrow \frac{\gamma_s}{(1+\tau_t^c)c_{s,t}} = \lambda_t$$

$$\frac{\partial L}{\partial c_{s,t+1}} = 0 \rightarrow \beta \frac{\gamma_s}{(1+\tau_{t+1}^c)c_{s,t+1}} = \lambda_{t+1}$$

$$\frac{\partial L}{\partial k_t} = 0 \rightarrow \frac{\left[(1-\tau_{t+1}^r - \tau_{t+1}^l - \tau_{t+1}^{r,f})r_{t+1} + (1-\delta) + \phi(k_{t+1}-k_t) - \tau_{t+1}^k\right]}{[1 + \phi(k_t - k_{t-1})]} = \frac{\lambda_t}{\lambda_{t+1}}$$

$$\frac{\partial L}{\partial k_{m,t}} = 0 \rightarrow (1-\tau_{t+1}^r - \tau_{t+1}^l - \tau_{t+1}^{r,f})r_{m,t+1} + (1-\delta) - \tau_{t+1}^k = \frac{\lambda_t}{\lambda_{t+1}}$$

$$\frac{\partial L}{\partial d_t} = 0 \rightarrow (1 + i_{m,t}) = \frac{\lambda_t}{\lambda_{t+1}}$$

$$\frac{\chi \gamma_s \, n_{s,t}^{\frac{1}{\varphi}}(1+\frac{1}{\varphi})}{(1-\tau_t^n - \tau_t^l - \tau_t^{n,f})\, w_{s,t}} = \frac{\gamma_s}{(1+\tau_t^c)c_{s,t}}$$

[1] Stephanie Schmitt-Grohé and Martin Uribe, "Closing Small Open Economy Models," *Journal of International Economics* 61, no. 1 (October 2003): 163-185.

APPENDIX C: APPLICATION OF THE THEORY

The Economic Research Center's dynamic model of Ohio's economy is calibrated to annual data from 1990-2015. Parameters are such that the household chooses their share of time spent working, N=0.24. The specific value of the Frisch labor supply elasticity is important for estimating the effect of policy changes on employment (hours worked) in our model. The model is solved for a labor supply elasticity of φ =1 as estimated by Kimball and Shapiro.[1] This elasticity falls between φ =0.27 to φ=3. The former (φ =0.27) is used by the Congressional Budget Office;[2] the latter (φ=3) is taken from the macroeconomics literature, most notably Cooley and Prescott (1995).[3] Table C.1 below provides an overview of the model parameters.

Table C.1: Baseline Calibration (1990-2015)

Variable	Value	Description	Restriction
τ^n	0.04	State labor income tax rate	STC
$\tau^{n,f}$	0.19	Federal labor income tax rate	IRS-SOI
$\tau^{r,f}$	0.27	Federal capital income tax rate	IRS-SOI
τ^c	0.04	State sales tax rate	STC
τ^s	0.01	State severance tax	STC
τ^l	0.03	Licenses/fees and other charges	Residual*
FF/Y	0.04	Transfers from the federal government	STC
ϑ	0.02	Annual growth rate of GDP	BEA
C/Y	0.64	Consumption to GDP ratio	BEA
I/Y	0.22	Investment to GDP ratio	BEA
G/Y	0.12	Government spending to GDP ratio	BEA
NX/Y	0.02	Net exports to GDP ratio	BEA
$\frac{m_i}{q_i}$	0.03	Electricity to GDP ratio in industrial sectors	EIA
$\frac{m_c}{q_c}$	0.01	Electricity to GDP ratio in commercial sectors	EIA
N	0.24	Hours worked / available hours	CPS
$i_{m,w}$	0.04	Avg. annual real interest rate (1950-2015)	FRED
ϕ	0.028	Capital adjustment cost	Schmitt-Grohé, Uribe (2003)
η	0.000742	Elasticity of interest rate to debt	Schmitt-Grohé,Uribe (2003)
χ	2.22	Disutility of labor	To match equilibrium hours

* Using tax rates and total tax collections, we can estimate the share of revenues collected from licenses/fees and other charges since $T_t = \tau_t^c \sum_{s=1}^{S} c_{s,t} + \tau_t^n \left[\sum_{s=1}^{S} w_{s,t} n_{s,t} + \sum_{s=1}^{S} w_{ms,t} n_{m,s,t}\right] + \tau_t^r \left[\sum_{s=1}^{S} r_{s,t} k_{s,t-1} + \sum_{s=1}^{S} r_{m,s,t} k_{m,s,t-1}\right] + \tau_t^k \left[\sum_{s=1}^{S} k_{s,t-1} + \sum_{s=1}^{S} k_{ms,t-1}\right] + \tau_t^s \sum_{s=1}^{S} m_{s,t} + \tau_t^l q_t$

σ	0.45	Capital share in production	BEA
$1-\alpha_i$	0.03	Industrial sectors electricity share	BEA, EIA
$1-\alpha_c$	0.01	Commercial sectors electricity share	BEA, EIA
ρ	0.7	Elasticity of substitution between capital and labor	Pessoa, Pessoa and Rob (2004)
θ_i	0.03	Industrial sectors elasticity of substitution between electricity and other inputs	
θ_c	0.01	Commercial sectors elasticity of substitution between electricity and other inputs	
δ	0.11	Annual depreciation rate of capital (long-run US-average)	BEA
φ	0.27-0.53	Frisch elasticity of labor supply	CBO
φ	1	Frisch elasticity of labor supply	Kimball and Shapiro (2008)
φ	3	Frisch elasticity of labor supply	Cooley and Prescott (1995)

Table C.2 reflects the model's ability to replicate the Ohio economy given the parameter values.

Table C.2: The Model Closely Replicates Long-run Facts about the Ohio Economy

Calibration	Model Baseline Economy	Ohio Economy
C/Y	0.639	0.640
I/Y	0.221	0.220
G/Y	0.120	0.120
NX/Y	0.020	0.020
N	0.243	0.240

All variables are reported in real (2009$) per capita terms using the US GDP deflator reported by the Bureau of Economic Analysis (BEA) and, if not declared otherwise, refer to the period of 1990-2015. The share of hours spent working is taken from the US Census Bureau's Current Population Survey (CPS). Effective federal tax rates are calculated using Internal Revenue Service Statistics of Income (IRS-SOI) data. Effective state tax rates are calculated using the US Census Bureau's Annual Survey of State Tax Collections (STC). Interest and depreciation rates are drawn from Federal Reserve Bank of St. Louis Economic Data (FRED). Electricity data is from the Energy Information Administration (EIA). Most of the preference parameters are standard in the economics literature. All macroeconomic values are calculated from BEA data.

Gross Domestic Product

Real gross domestic product (GDP) per capita, which is the primary variable of economic output, is calculated by dividing the total real GDP at the state-level by the total state population (also available from the BEA Regional Economic Accounts – GDP by State). Our GDP does not include residential investments. Our GDP projections use the latest GDP values and apply the observed long-run annual growth rate of 1.6%. This assumption is consistent with the Ohio Office of Budget and Management's fiscal year 2018-2019 forecast of annual state GDP growth, which also uses a 1.6% growth rate.[4]

Consumption

We use consumption data from the BEA Regional Economic Accounts – Personal Consumption Expenditures (PCE). Consumption expenditures on durable goods are subtracted from total PCE in order to calculate our measure of consumption. We consider durable goods as investment goods, which is standard in the macroeconomics literature. The values for PCE are not available on the state-level prior to 1997. We therefore use the long-run average share of consumption in GDP to obtain the level of consumption for each year from 1990-1997.

Investment

Because the BEA does not report private fixed investment at the state-level, we use the US share of non-residential investment in GDP from the BEA (Table 1.1.5)[5] and multiply it by the state GDP in order to estimate Ohio's non-residential investment. The sum of Ohio non-residential investment and consumption expenditures on durable goods represents our measure of investment. Note that our methodology excludes residential investment from our measure of investment and, therefore, residential investment is also excluded from GDP.

Trade Balance/Net Exports

We calculate the value of the trade balance by using the resource constraint of $GDP = C + I + G + TB$, where G represents the total state, local, and federal government spending on the state-level.

Employment

Our employment data (number of non-farm jobs) is collected from the BLS. We took the average weekly hours worked from the Annual Social and Economic Supplement (ASEC) of the Current Population Survey (CPS). The average weekly hours worked at all jobs is divided by the total number of hours per week (168 hours) to calculate the measure of labor, n, used for model calibration. The employment level in the industrial sector is the sum of employment in the sectors given by EIA's definition for industrial sector, which includes the following industries: manufacturing; agriculture, forestry, fishing and hunting; mining, including oil and gas extraction; and construction.6 The employment level in the industrial sector is the sum of employment in the corresponding sectors; subtracting industrial and government employment from total non-farm employment yields commercial employment.

We used the following methodology to estimate the effects of RPS scenarios on employment because the model measures employment in hours worked *(intensive margin)*. First, we use non-farm employment multiplied by the average hours worked per year (2108 hours). This total number of hours worked per year is multiplied by the magnitude of the corresponding RPS scenario in order to obtain the change in total hours worked caused by the RPS. Finally, the change in hours is converted into the number of full-time equivalent jobs gained or lost by dividing it by 2,080 which is the number of hours worked by a full-time equivalent employee according to the Congressional Budget Office's (CBO) definition.[7]

Table C.3 below shows each sector's share of Ohio's GDP. The values represent the average share of GDP contributed by each sector for 1997-2015.

Table C.3: Ohio's sectors ranked by size

Industrial Sectors	24%
Government	12%
Real estate and rental and leasing	11%
Finance and insurance	8%
Health care and social assistance	8%
Retail trade	7%
Wholesale trade	6%
Professional, scientific, and technical services	5%
Information	3%
Administrative and waste management services	3%
Transportation and warehousing	3%
Management of companies and enterprises	3%
Other services, except government	2%
Accommodation and food services	2%
Utilities	2%
Arts, entertainment, and recreation	<1%
Educational services	<1%

Source: BEA Regional Economic Accounts

Electricity Data

All electricity data is from the EIA and converted to real values (2009$) using the GDP deflator provided by the BEA. We calculate the ratio of electricity revenues from the corresponding sector relative to its output (expressed as $\frac{m}{q}$) to obtain the electricity-related variables needed to calibrate the model. The sectors are aggregated into industrial sectors and commercial sectors as described above.

We use the revenues of electricity sold to the industrial sector and the average price per kilowatt-hour paid by that sector as reported by EIA. To calculate the revenues of electricity sold to the commercial sector, we first subtract the residential electricity revenues from the total revenues to obtain the total non-residential electricity revenues.[8] Then, we subtract the electricity revenues of the industrial and government sector from total non-residential electricity revenues, which yields the revenues of electricity sold to the commercial sector. The revenues from electricity sold to the government sector are determined by multiplying the total non-residential electricity revenues by the government share of the GDP. The EIA provides us with the average price paid for electricity by commercial customers.[9]

The real output q of the industrial sectors is the sum of GDP produced by the industrial sectors as defined by EIA. To determine the commercial sectors output, we subtract industrial and government output from total output.

To calibrate the macroeconomic model, we use the long-run averages of the ratio of electricity revenues relative to output, $\frac{m}{q}$. These averages are for 1990-2015.

[1] Miles S. Kimball and Matthew D. Shapiro, "Labor Supply: Are the Income and Substitution Effects Both Large or Both Small?" *NBER Working Paper 14208*, July 2008, http://www.nber.org/papers/w14208.
[2] Robert McClelland and Shannon Mok, "A Review of Recent Research on Labor Supply Elasticities," *Congressional Budget Office Working Paper 2012-02*, October 2012, https://www.cbo.gov/sites/default/files/112th-congress-2011-2012/workingpaper/10-25-2012-Recent_Research_on_Labor_Supply_Elasticities_0.pdf.
[3] Thomas F. Cooley and Edward C. Prescott, "Economic Growth and Business Cycles," in *Frontiers of Business Cycle Research*, edited by Thomas F. Cooley (Princeton: Princeton University Press, 1995), 1-38.
[4] Ohio Office of Budget and Management, "The State of Ohio Budget Recommendations, Fiscal Years 2018-2019," http://budget.ohio.gov/doc/budget/FY18-19_Budget_Recommendations.pdf.
[5] Bureau of Economic Analysis, "Table 1.1.5: Gross Domestic Product," National Economic Accounts, revised January 27, 2017, https://bea.gov/iTable/iTable.cfm?ReqID=9.
&step=1#reqid=9&step=3&isuri=1&904=1990&903=5&906=a&905=2016&910=x&911=0.
[6] U.S. Energy Information Administration, "Industrial Sector," *Glossary*, http://www.eia.gov/tools/glossary/index.cfm?id=Industrial_sector.
[7] Edward Harris and Shannon Mok, "How CBO Estimates the Effects of the Affordable Care Act on the Labor Market," *Congressional Budget Office Working Paper 2015-09*, December 7, 2015, https://www.cbo.gov/publication/51065.
[8] US Energy Information Administration, "Average Revenue from Sales of Electricity to Ultimate Consumers, Annual, By sector, by state, by provider (back to 1990)," released October 21, 2015, http://www.eia.gov/electricity/data.cfm#sales.
[9] US Energy Information Administration, "Average Retail Price of Electricity to Ultimate Consumers, Annual, By sector, by state, by provider (back to 1990)," released October 21, 2015, http://www.eia.gov/electricity/data.cfm#sales.

APPENDIX D: TAX RATES ESTIMATION

Average Marginal Federal Tax Rate on Labor Income for Ohio Residents

The average marginal federal tax rate on labor income for Ohio residents is calculated using IRS Statistics of Income data following Tuerck et. al.[1] For each Adjusted Gross Income (AGI) group, the marginal federal tax rate is computed as the change in tax liability per change in gross income bracket. Therefore, the marginal federal tax rate for income group *i* is written as:

$$\tau_{t,i}^{fpy} = \frac{T_{t,i}^{fpy} - T_{t,i-1}^{fpy}}{Y_{t,i}^{fy} - Y_{t,i-1}^{fy}}$$

where $T_{t,i}^{fpy}$ is the average federal tax liability for AGI group *i* in period *t*, calculated by dividing the total tax liability by the number of returns for the respective AGI group; and $Y_{t,i}^{fy}$ is the average gross income for AGI group *i* in period *t*, calculated by dividing the total gross income by the number of returns for AGI group *i*.

Then, the average marginal federal tax rate on labor income for Ohio, which is $\tau_i^{n,f}$, is calculated by multiplying wages and salaries in each AGI class by the marginal tax rate for that class, and then dividing by the total wages and salaries in period *t*.

$$\tau_i^{n,f} = \frac{\sum_i Y_{t,i}^{n,f} \tau_{t,i}^{fpy}}{\sum_i Y_{t,i}^{n,f}}$$

where $Y_{t,i}^{n,f}$ represents total wages and salaries for AGI group *i* in period *t*.

Finally, $\tau^{n,f}$ is computed as the long-run average of $\tau_i^{n,f}$. The average marginal federal tax rate on labor income for Ohio residents over the time period of 1990 through 2014 is $\tau^{n,f} = 0.1871$.

Average Marginal Federal Tax Rate on Capital Income for Ohio Residents

For computing the federal tax rate on capital income, we apply a similar methodology as above. First, for each AGI group *i* we compute the marginal tax rate as follows:

$$\tau_{t,i}^{fy} = \frac{T_{t,i}^{fy} - T_{t,i-1}^{fy}}{TY_{t,i}^{fy} - TY_{t,i-1}^{fy}}$$

where $T_{t,i}^{fy}$ is the average federal tax liability for AGI group *i* in period *t*, calculated by dividing the total tax liability by the number of returns for the respective AGI group; and $TY_{t,i}^{fy}$ is the average taxable income for AGI group *i* in period *t*, calculated by dividing the taxable income by the number of returns for AGI group *i*. The average marginal federal tax rate on capital income for Ohio residents, $\tau_i^{r,f}$, is calculated by multiplying capital income *D* in each AGI class by the marginal tax rate for that class, and then, dividing by the total capital income from all AGI groups in period *t*.

$$\tau_i^{r,f} = \frac{\sum_i D_{t,i} \tau_{t,i}^{fy}}{\sum_i D_{t,i}}$$

where $D_{t,i}$ is the sum of income from *Ordinary Dividends* and *Net Capital Gains* for AGI group *i* in period *t*.

Finally, $\tau^{r,f}$ is computed as the long-run average of $\tau_i^{r,f}$. The average marginal federal tax rate on capital income for Ohio residents over the time period of 1990 through 2014 is $\tau^{r,f} = 0.2726$.

Effective Tax Rate on Consumption for Ohio

To compute the effective rate of a tax, we use the revenue of a specific tax and divide it by its corresponding tax base. For the total sales tax, τ^C, the sum of total sales and gross receipts from the US Census Bureau minus the commercial activity tax revenue as reported by the Ohio Department of Taxation is divided by consumption expenditures. Consumption is defined as personal consumption expenditures less consumption of durable goods which are reported by the Bureau of Economic Analysis (BEA).

Effective Severance Tax Rate for Ohio

Following the methodology above, for the severance tax, τ^S, we take severance tax revenue as reported by the US Census Bureau and divide by the tax base, which is mining sector GDP less support services to mining sector GDP according to the BEA (for years 1997 and prior, this is simply reported as mining sector GDP by BEA).

Effective Personal Income Tax Rate for Ohio

Following the methodology above, for Ohio's personal income tax, τ^N, we take individual income tax as reported by the US Census Bureau as the revenue, and wage and salary income as reported by the BEA as the tax base.

[1] David G. Tuerck, Jonathan Haughton, In-Mee Baek, James Connolly, and Scott Frontaine, "The Texas State Tax Analysis Modeling Program (Texas-STAMP): Methodology and Applications," The Beacon Hill Institute for Public Policy Research at Suffolk University, February 1999, http://www.beaconhill.org/BHIStudies/TexasSTAMPFinal19Feb99.pdf.