
A Welfare Analysis of Policies Impacting Climate Change
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Robert Metcalfe, Ben Sprung-Keyser
POLICY
IMPACTS

What Are the Most Effective Ways to Address Climate Change?

- Robust literature measuring the causal effect of environmental policy changes, often measuring cost per ton of CO_2 abated

- Comparing estimates of cost per ton suffers from three limitations:

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1) Input assumptions differ across papers
   - Grid and vehicle emissions differ drastically over time (and across space)

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1) Input assumptions differ across papers

2) "Cost" per ton of CO_2 abated has at least 3 conceptually distinct and (often conflated) definitions in the literature
   - Resource cost per ton; government cost per ton; social cost per ton

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2) "Cost" per ton of CO_2 abated has at least 3 conceptually distinct and (often conflated) definitions in the literature

3) "Cost per ton" methods each fail to fully capture welfare consequences

   -Treatment of inframarginal transfers and non-CO_2 benefits

The MVPF of Policies Impacting Climate Change

- This paper: Extend and apply the Marginal Value of Public Funds (MVPF) framework to study the welfare impacts of US spending and revenue-raising policies addressing climate change

$$MVPF = \frac{Net\ Benefits\ to\ Individuals}{Net\ Government\ Cost}$$

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- Transfers
- Global and local environmental benefits
- Learning by doing externalities
- Profits

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Net Government Cost

- Upfront policy cost
- Impact of behavioral response on government budget (i.e., “fiscal externality”)

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- Suppose: Policy 1 has $MVPF_1 = 1$ and Policy 2 has $MVPF_2 = 2$
  - More spending on Policy 2 financed by less on 1 increases social welfare iff prefer to take $1 from Policy 1 beneficiaries to give $2 to Policy 2 beneficiaries
  - Can be transparent about a preference for equity
  - Can compare across policy domains (Hendren and Sprung-Keyser, 2020)

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For subsidy

Higher MVPF is better

Infinite is Pareto improvement

For tax

Lower MVPF is better

Can be negative

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Higher MVPF is better	Lower MVPF is better
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The willingness to pay for a small increase in the subsidy, dτ, is given by WTP = xdτ + Vdx

- Monetary value of the subsidy (holding behavior fixed due to the envelope theorem), and the second term is the WTP from the change in the environmental externality.
- These two terms are sufficient for measuring WTP if we assume perfect competition and full pass-through.

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The net cost to the government of the subsidy has two terms: Cost= $x d\tau + \tau dx$

- The first term holds x fixed and the second term captures the fiscal impact of the change in x.
- This cost, τdx, is paid by the government but is not valued by individuals due to the envelope theorem.

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$$MVPF = \frac{xd\tau + Vdx}{xd\tau + \tau dx} = \frac{1 + \frac{V}{p}(-\epsilon)}{1 + \frac{\tau}{p}(-\epsilon)}$$

- where ϵ = dx/dp . p/x is the price elasticity of demand so that −ϵ is the percentage change in consumption of x in response to a 1% increase in the consumer price.
- policies with high MVPFs tend to have higher magnitudes of the price elasticity,−ϵ, higher environmental benefits per dollar of spending on the good, V/p, and lower preexisting subsidies, τ/p.

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Net benefits for a subsidy = MVPF x Size (cost) of the policy

Sample

- Construct MVPFs for a comprehensive set of spending and revenue-raising policies affecting greenhouse gas emissions rigorously evaluated using RCT or quasi-experimental methods

- Journal search from 2000–2024 in 18 journals and NBER working papers 2018+

- Full sample of 96 policies
  - 40 Subsidies: Wind, solar, EVs, HEVs, appliance rebates, vehicle retirement, weatherization
  - 11 Nudges and Marketing Policies (243 RCTs): Home Energy Reports (HERs), other nudges
  - 31 Revenue-raisers: Gasoline/fuel taxes, critical peak pricing, and cap and trade auctions.
  - 14 International Policies: Cookstoves, deforestation prevention, rice-burning prevention, energy efficiency rebates

Data and Approach

- Use a consistent method to translate causal effects into benefits and costs

- Translate behavior (e.g., purchase new EV) into externality (e.g., CO_2, etc.)
  - Vehicle externalities (VMT, MPG, lifespan), Grid composition (AVERT, EPA 2024)

- Translate externality into monetary valuations
  - SCC of $193 in 2020 with 2% discount rate, robustness to $76 and $337
  - Local pollutants using AP3 with $9.5M VSL (Tschofen, Azevedo, and Muller 2019)

- For each policy, construct two types of MVPFs
  - In-Context using measures from time and place where policy occurred
  - Baseline analysis as if the policy was implemented nationally in 2020 (assuming elasticities generalize)

Roadmap

1. Subsidies
2. Nudges
3. Revenue Raisers
4. International Policies
5. Comparison to Cost per Ton Metrics

Roadmap

1. Investments that directly displace dirty electricity production have highest MVPFs (5+ for wind PTCs; 3-4 for residential solar; 1.5 for EVs; others ~1)
2. **Nudges**
3. **Revenue Raisers**
4. **International Policies**
5. **Comparison to Cost per Ton Metrics**

Roadmap

1. Investments that directly displace dirty electricity production have highest MVPFs (5+ for wind PTCs; 3-4 for residential solar; 1.5 for EVs; others ~1)

2. Nudges to reduce electricity use have high MVPFs (3+) in places with dirty grids, but lower (<1) in clean grid areas (e.g. CA and Northeast)

3. **Revenue Raisers**

4. **International Policies**

5. **Comparison to Cost per Ton Metrics**

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3. Taxes on polluting goods (e.g., gas taxes) are relatively efficient (MVPFs < 0.7)

4. **International Policies**

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5. Common cost per ton metrics do not fully capture these lessons and often yield different rankings across definitions

Roadmap

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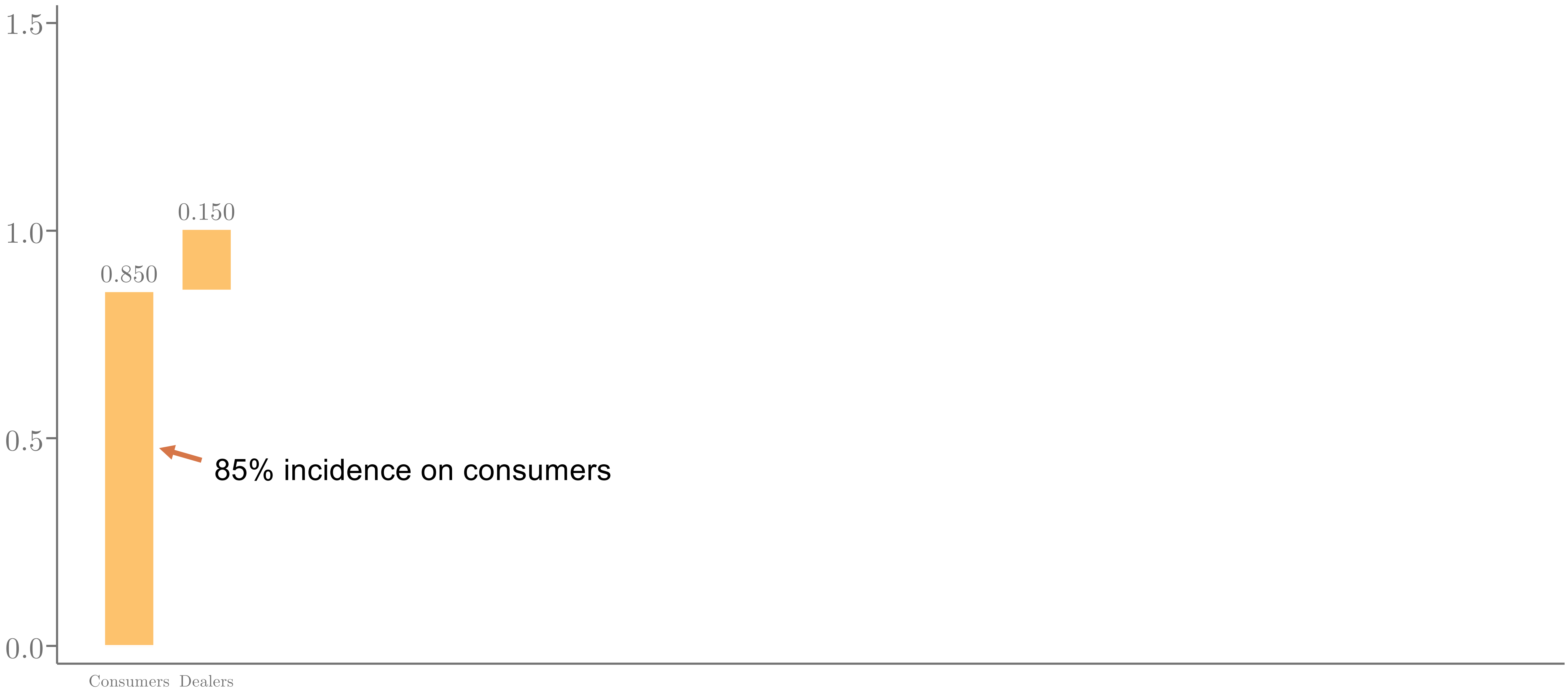
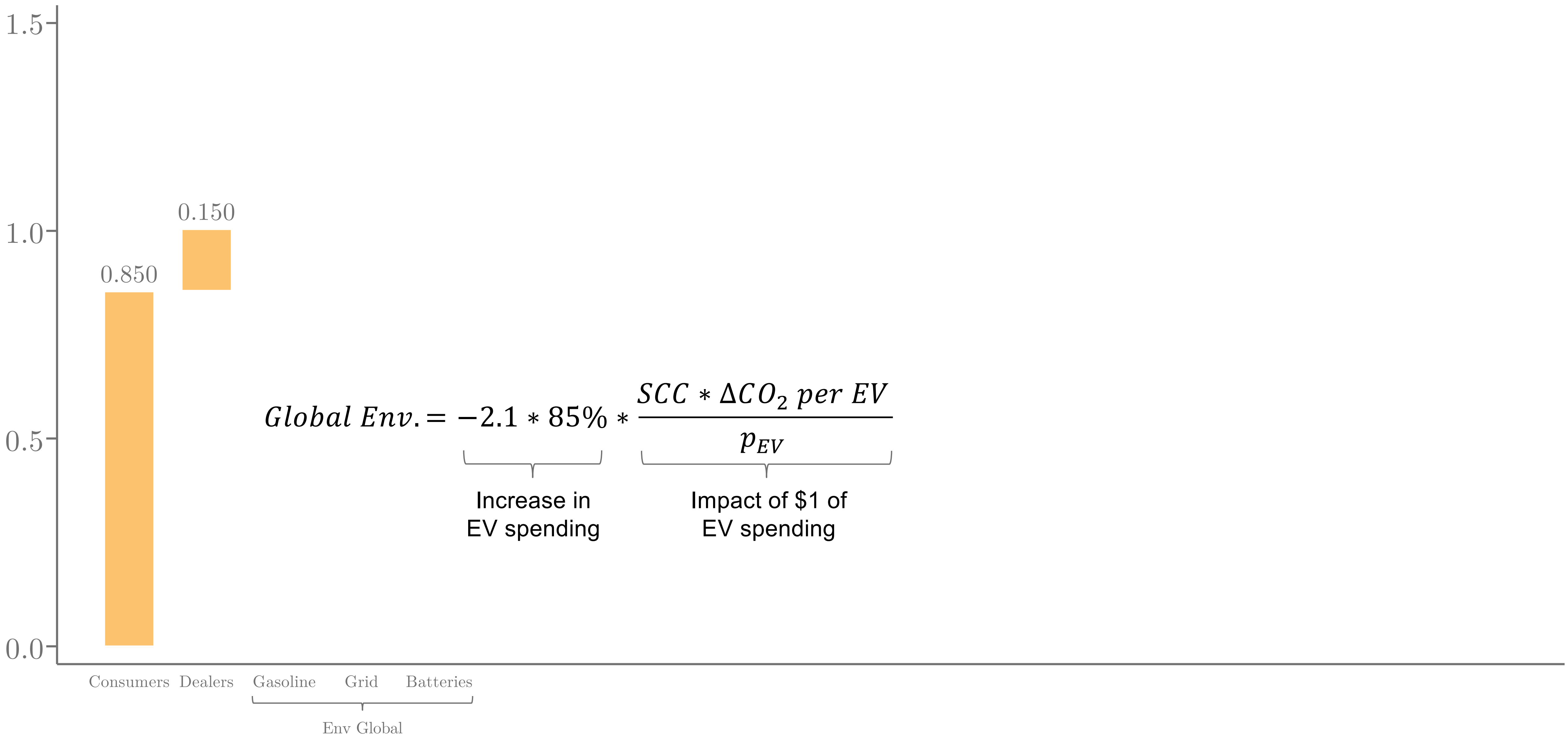
Electric Vehicles: Example MVPF

- Consider an EV subsidy studied by Muehlegger and Rapson (2022)
- Use zip code variation in subsidies as part of the California Enhanced Fleet Modernization Program
- Estimate a price elasticity of demand of -2.1 and find that 85% of subsidy is passed to consumers
- How do we construct the MVPF? Consider a $1 increase in federal EV subsidies in 2020.

Electric Vehicles: Subsidy Pass Through

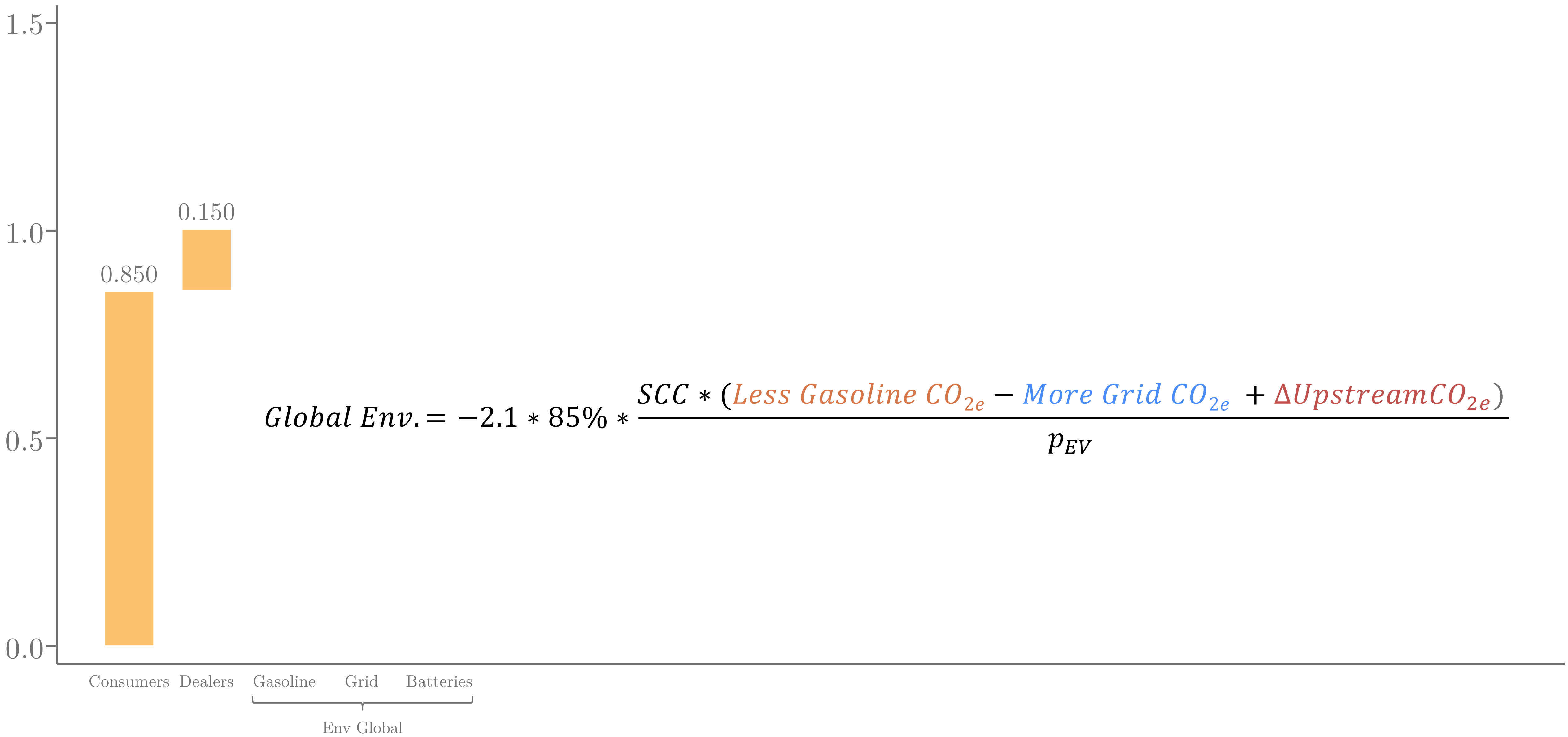


Electric Vehicles: Global Environmental Benefits



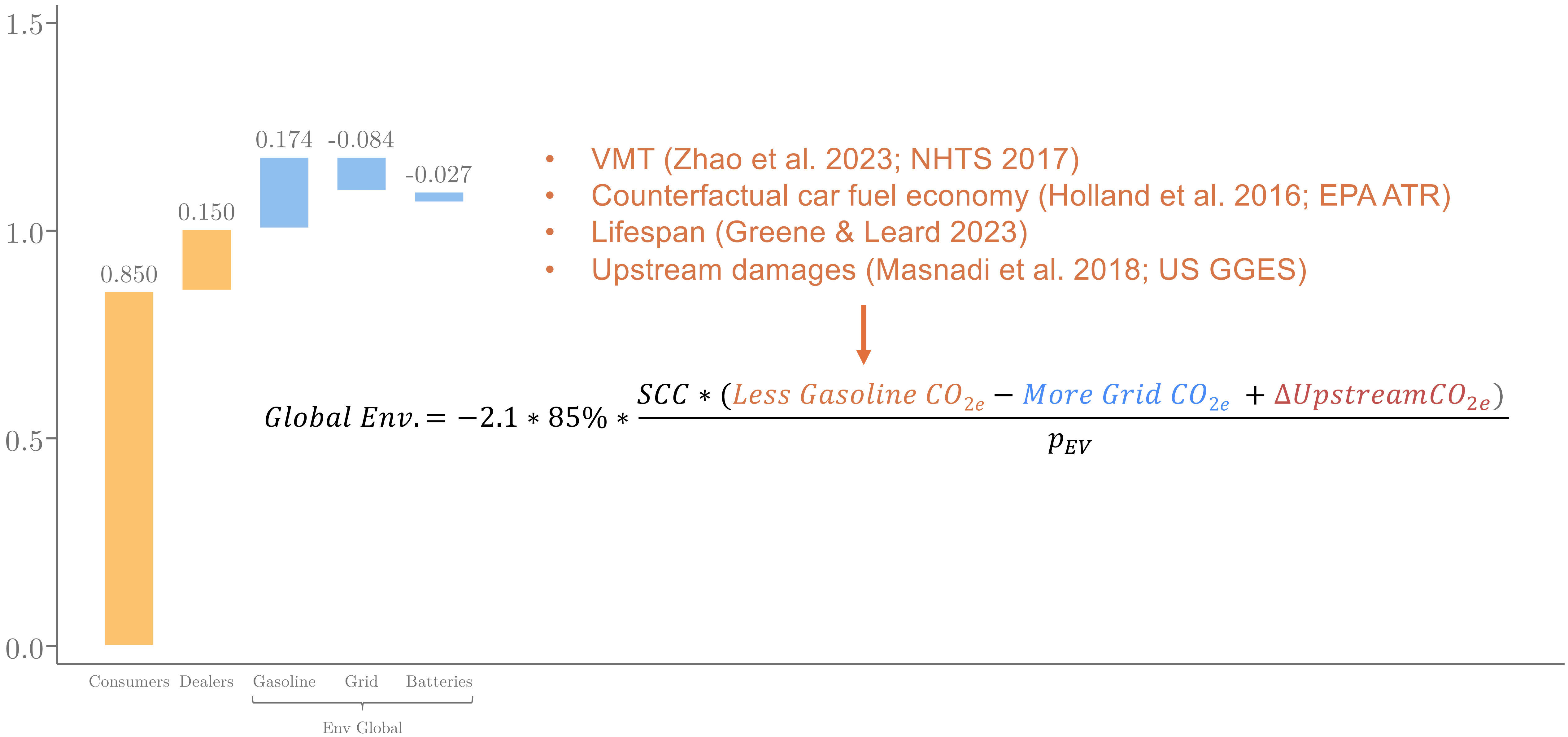
$$Global\ Env. = -2.1 * 85\% * \frac{SCC * \Delta CO_2\ per\ EV}{p_{EV}}$$

Electric Vehicles: Global Environmental Benefits



$$Global\ Env. = -2.1 * 85\% * \frac{SCC * (Less\ Gasoline\ CO_{2e} - More\ Grid\ CO_{2e} + \Delta Upstream CO_{2e})}{p_{EV}}$$

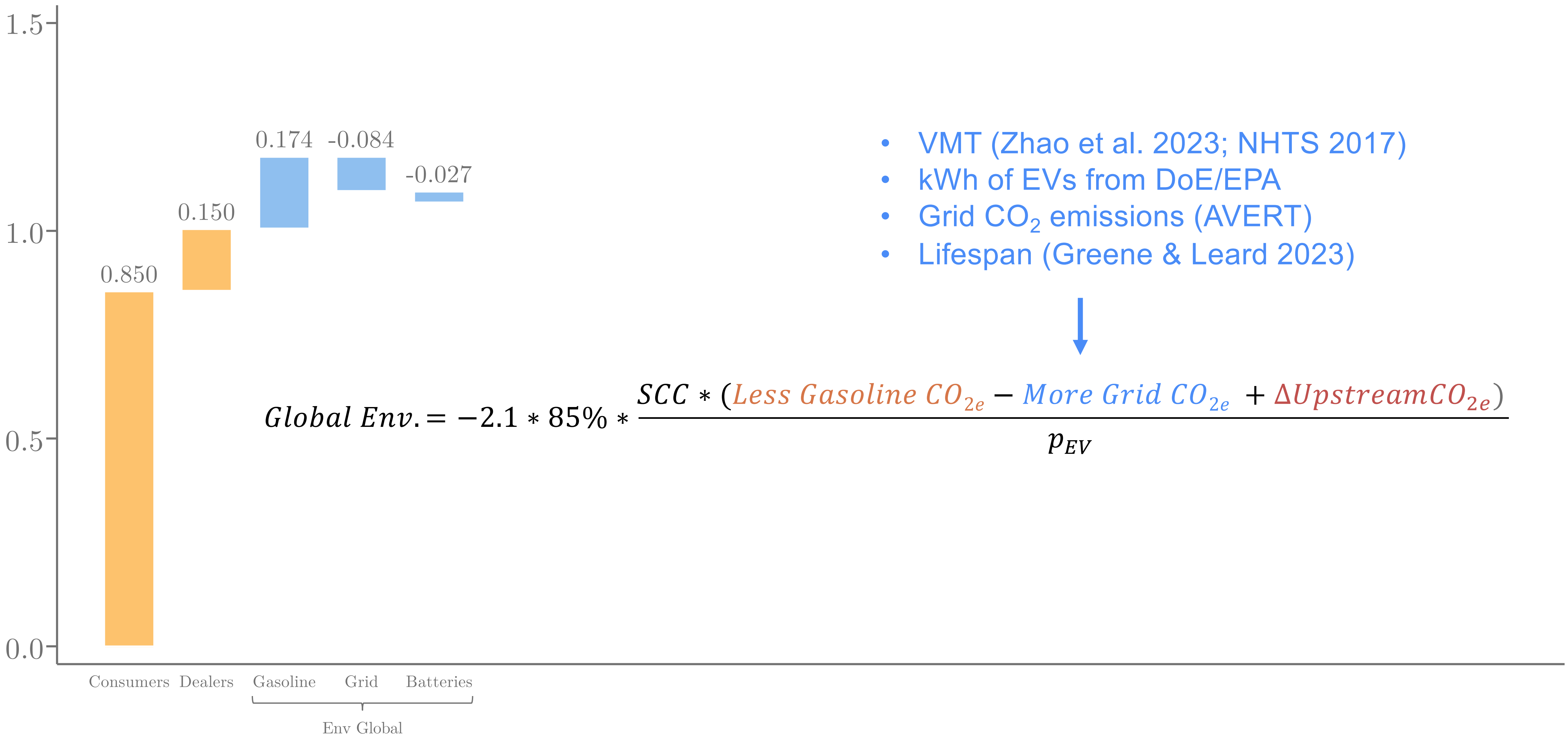
Electric Vehicles: Global Environmental Benefits



- VMT (Zhao et al. 2023; NHTS 2017)
- Counterfactual car fuel economy (Holland et al. 2016; EPA ATR)
- Lifespan (Greene & Leard 2023)
- Upstream damages (Masnadi et al. 2018; US GGES)

$$Global\ Env. = -2.1 * 85\% * \frac{SCC * (Less\ Gasoline\ CO_{2e} - More\ Grid\ CO_{2e} + \Delta Upstream CO_{2e})}{p_{EV}}$$

Electric Vehicles: Global Environmental Benefits



- VMT (Zhao et al. 2023; NHTS 2017)
- kWh of EVs from DoE/EPA
- Grid CO_2 emissions (AVERT)
- Lifespan (Greene & Leard 2023)

$$Global\ Env. = -2.1 * 85\% * \frac{SCC * (Less\ Gasoline\ CO_{2e} - More\ Grid\ CO_{2e} + \Delta Upstream CO_{2e})}{p_{EV}}$$

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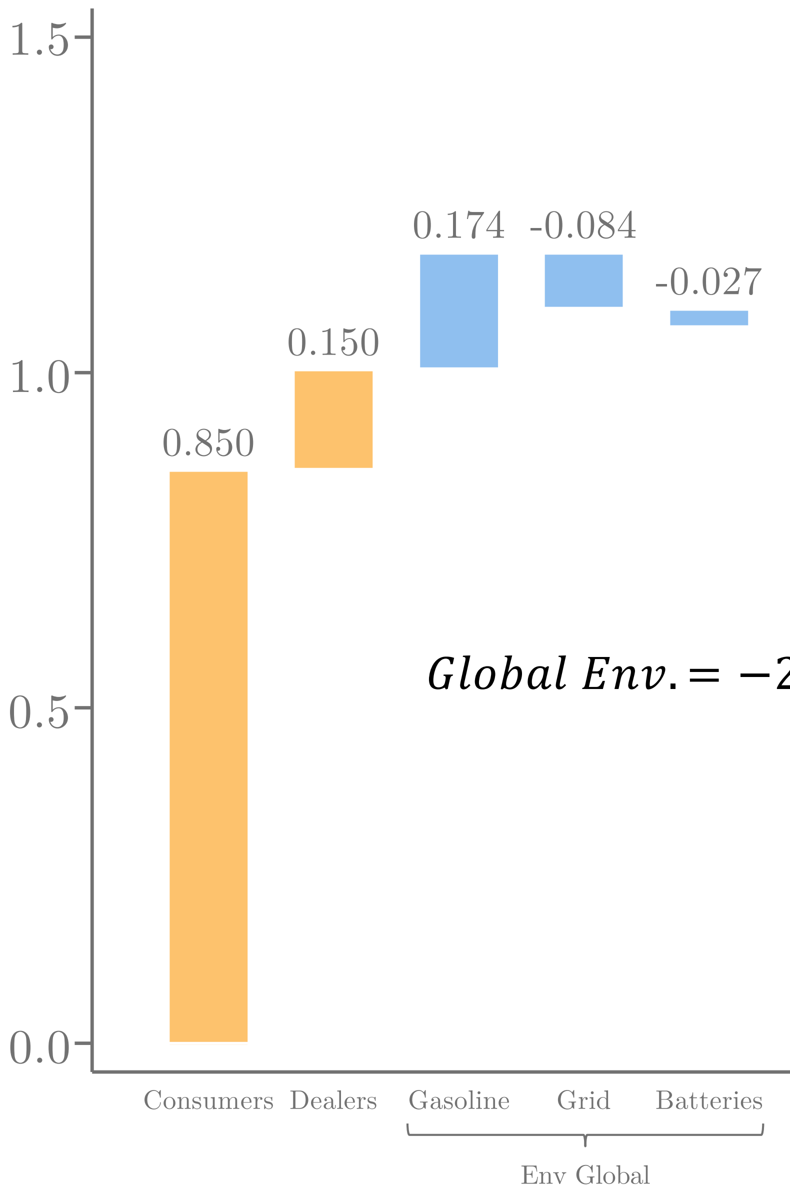
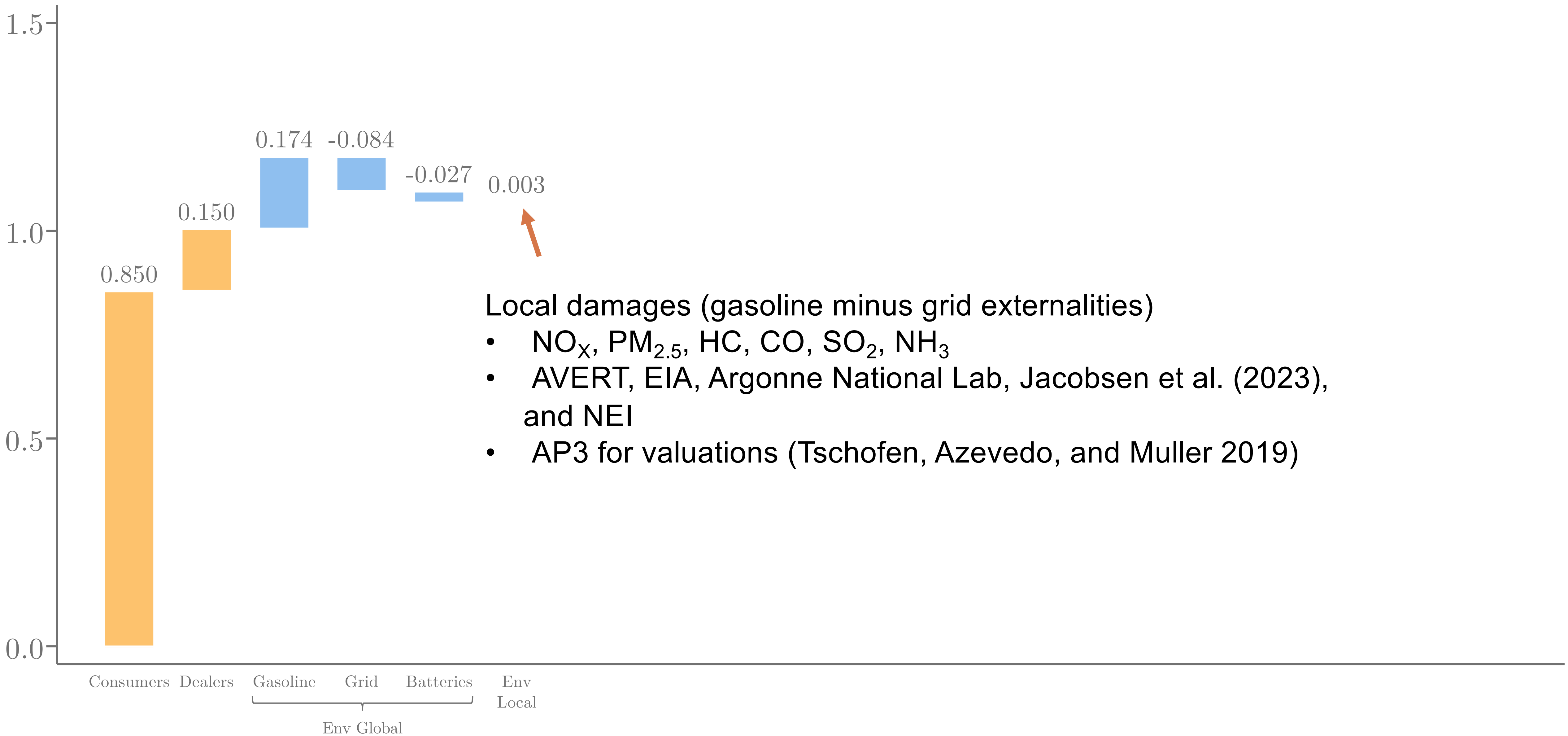


Winjobi et al. (2022)

$$Global\ Env. = -2.1 * 85\% * \frac{SCC * (Less\ Gasoline\ CO_{2e} - More\ Grid\ CO_{2e} + \Delta Upstream CO_{2e})}{p_{EV}}$$

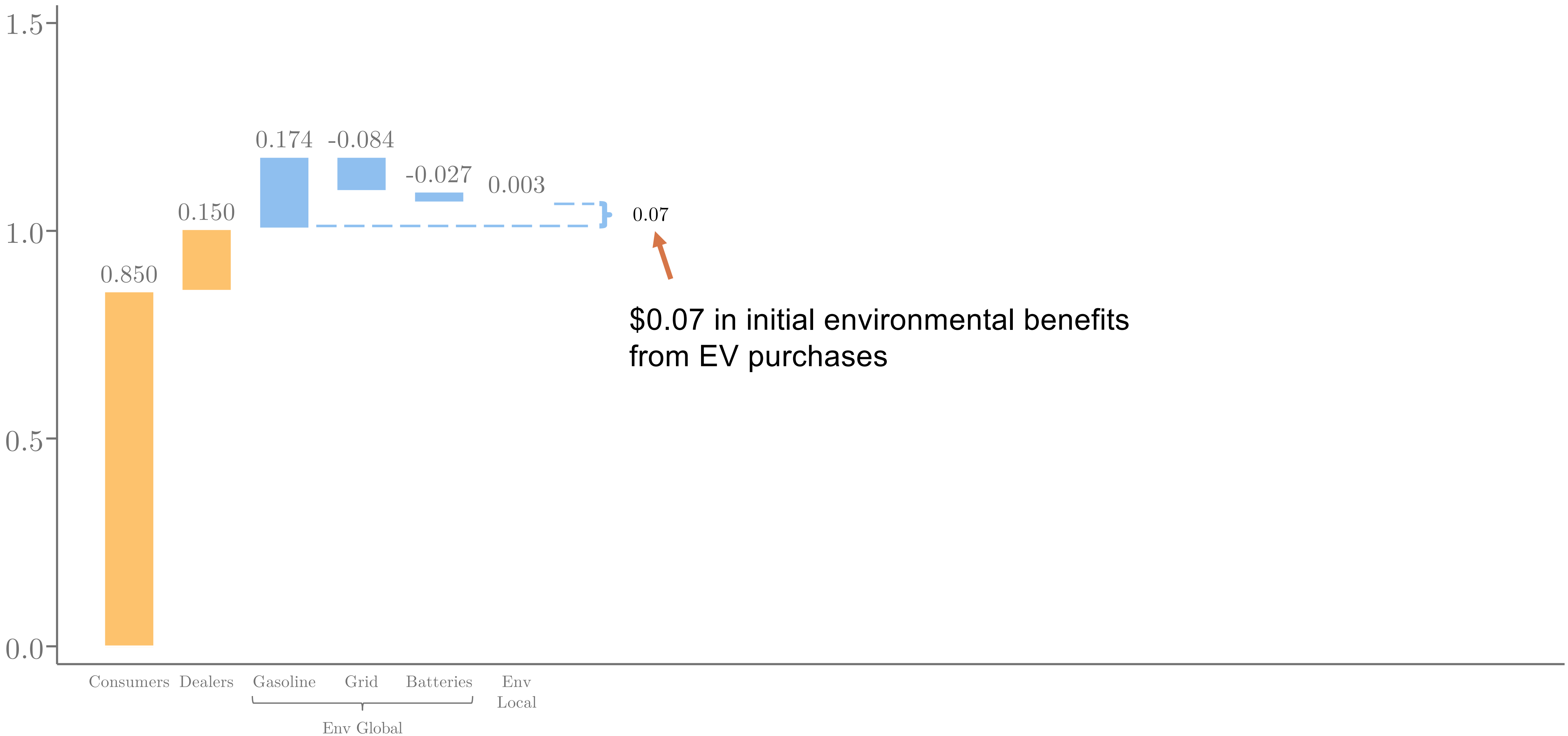
Electric Vehicles: Local Environmental Benefits



Local damages (gasoline minus grid externalities)

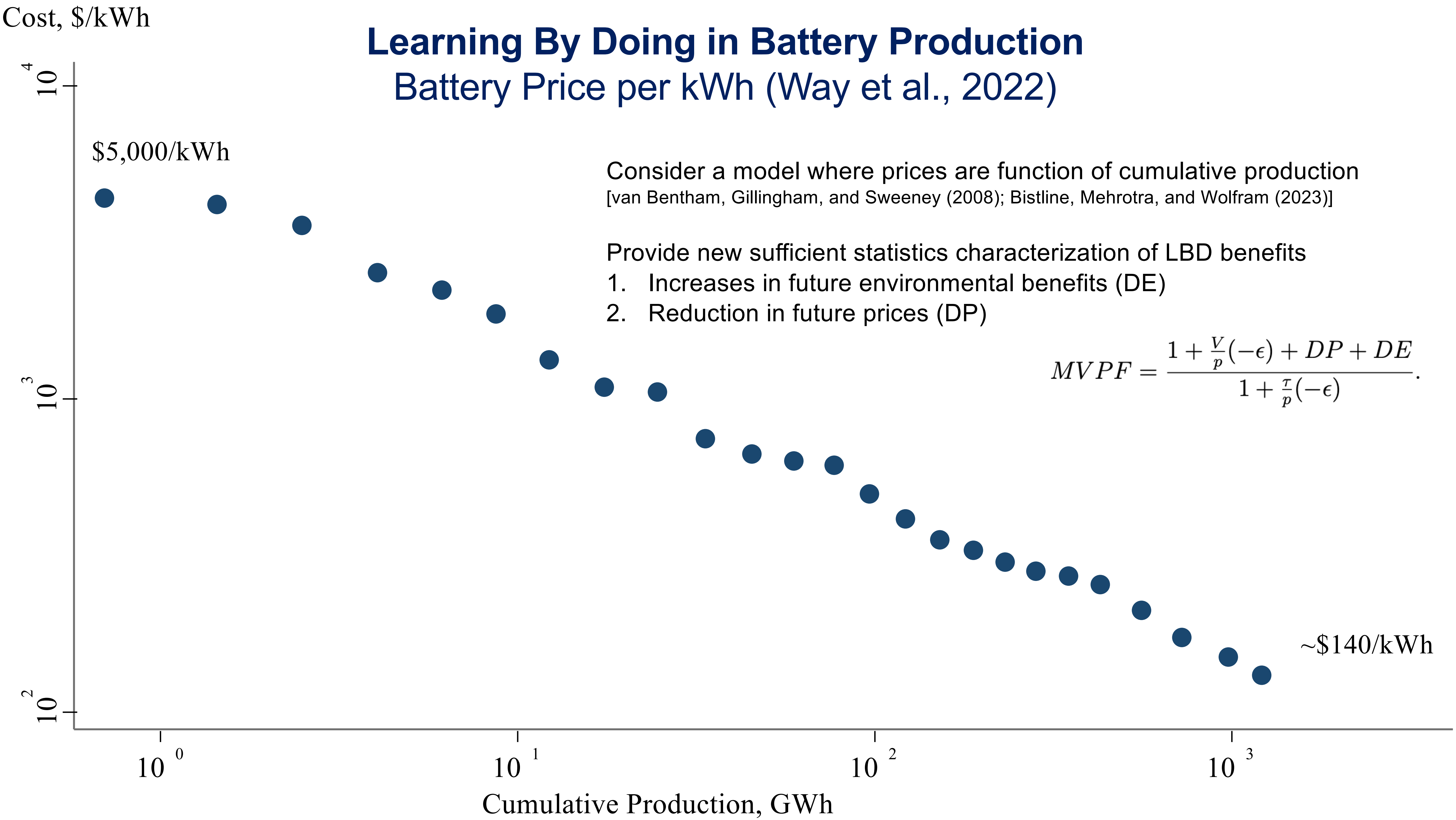
- NO_X, $PM_{2.5}$, HC, CO, SO_2, NH_3
- AVERT, EIA, Argonne National Lab, Jacobsen et al. (2023), and NEI
- AP3 for valuations (Tschofen, Azevedo, and Muller 2019)

Electric Vehicles: Total Environmental Benefits



Learning By Doing in Battery Production

Battery Price per kWh (Way et al., 2022)

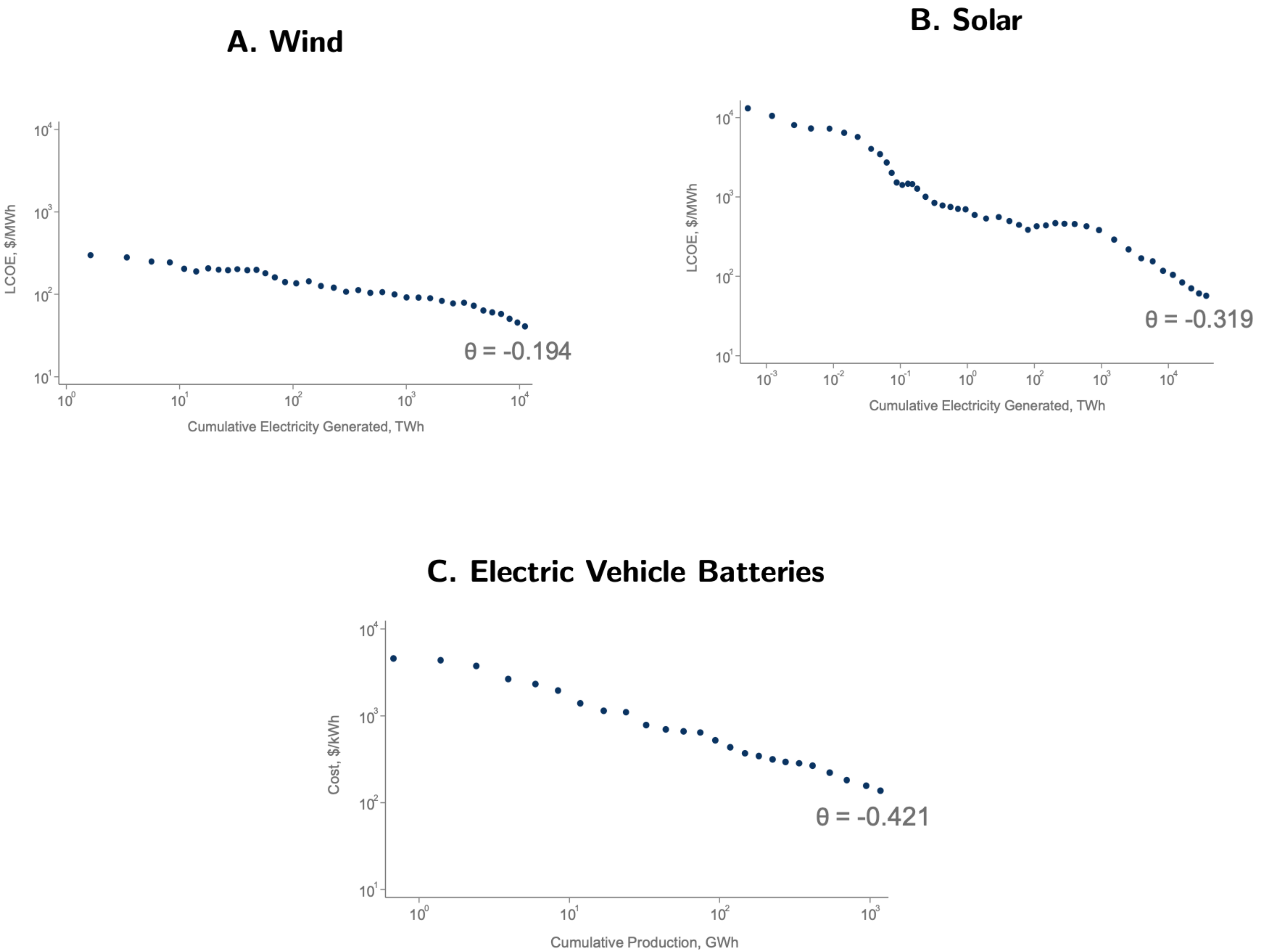


Consider a model where prices are function of cumulative production
[van Bentham, Gillingham, and Sweeney (2008); Bistline, Mehrotra, and Wolfram (2023)]

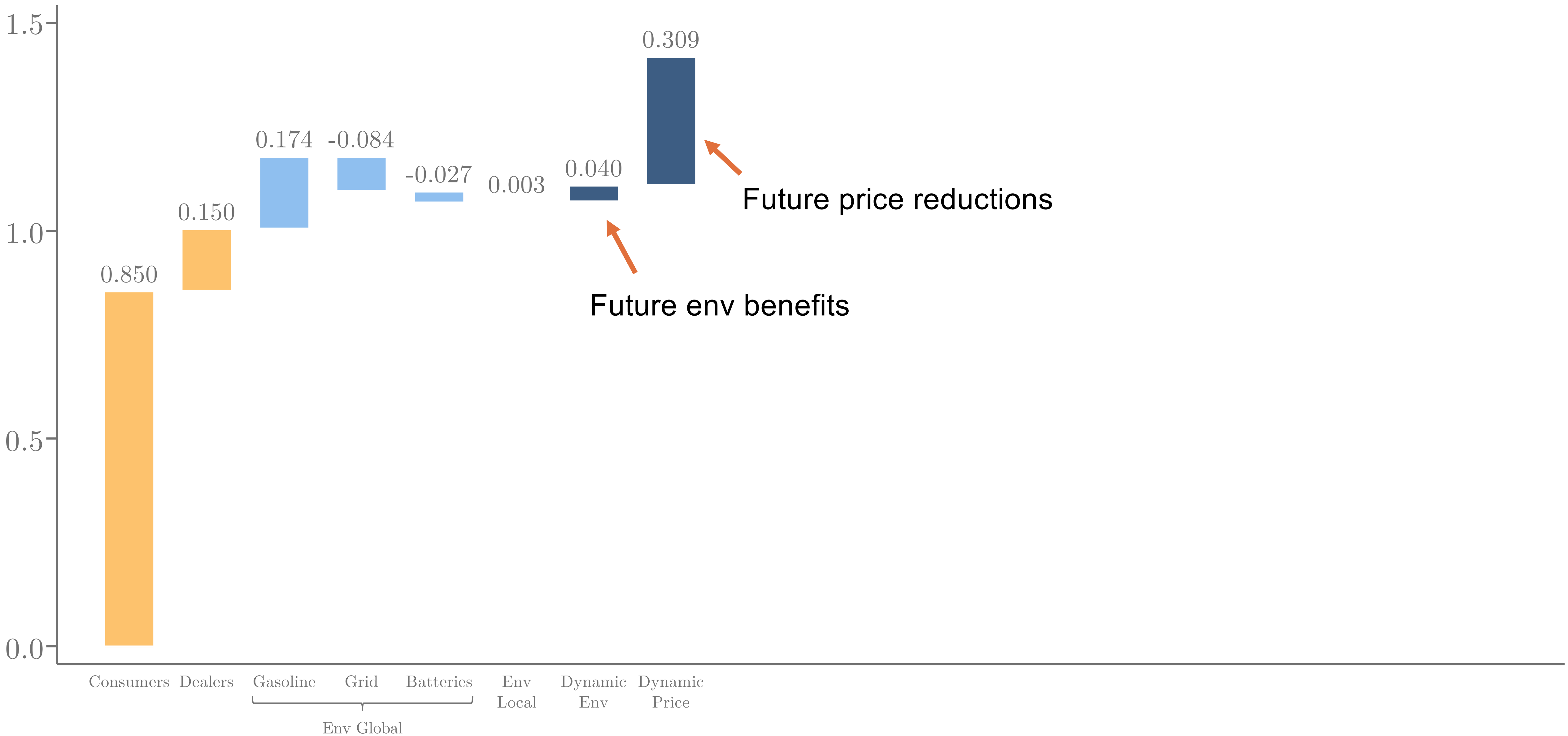
Provide new sufficient statistics characterization of LBD benefits

1. Increases in future environmental benefits (DE)
2. Reduction in future prices (DP)

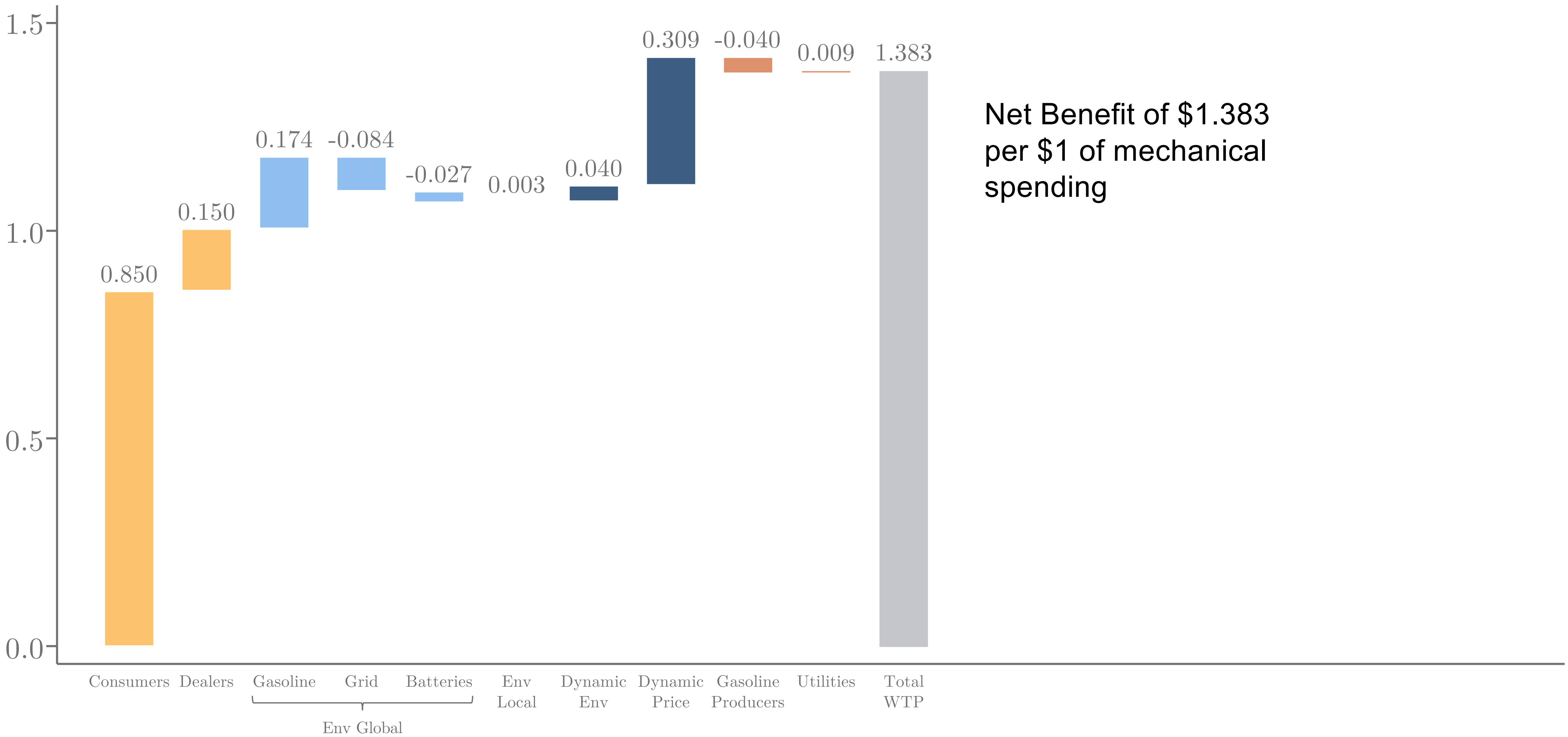
$$MVPF = \frac{1 + \frac{V}{p}(-\epsilon) + DP + DE}{1 + \frac{\tau}{p}(-\epsilon)}.$$


A. Wind
LCOE, $/MWh
Cumulative Electricity Generated, TWh
θ = -0.194
B. Solar
LCOE, $/MWh
Cumulative Electricity Generated, TWh
θ = -0.319
C. Electric Vehicle Batteries
Cost, $/kWh
Cumulative Production, GWh
θ = -0.421

Electric Vehicles: Learning by Doing Externalities

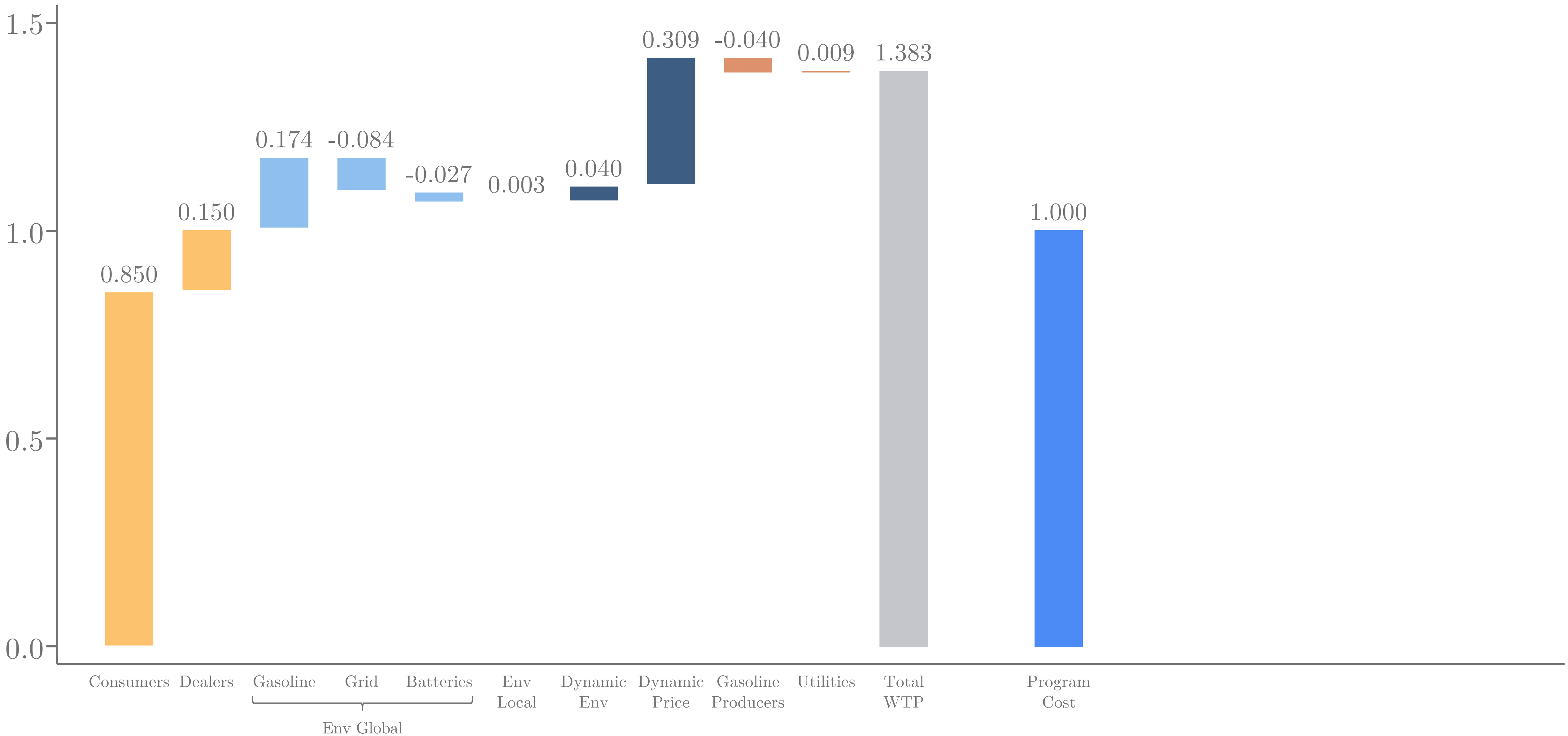


Electric Vehicles: Net WTP

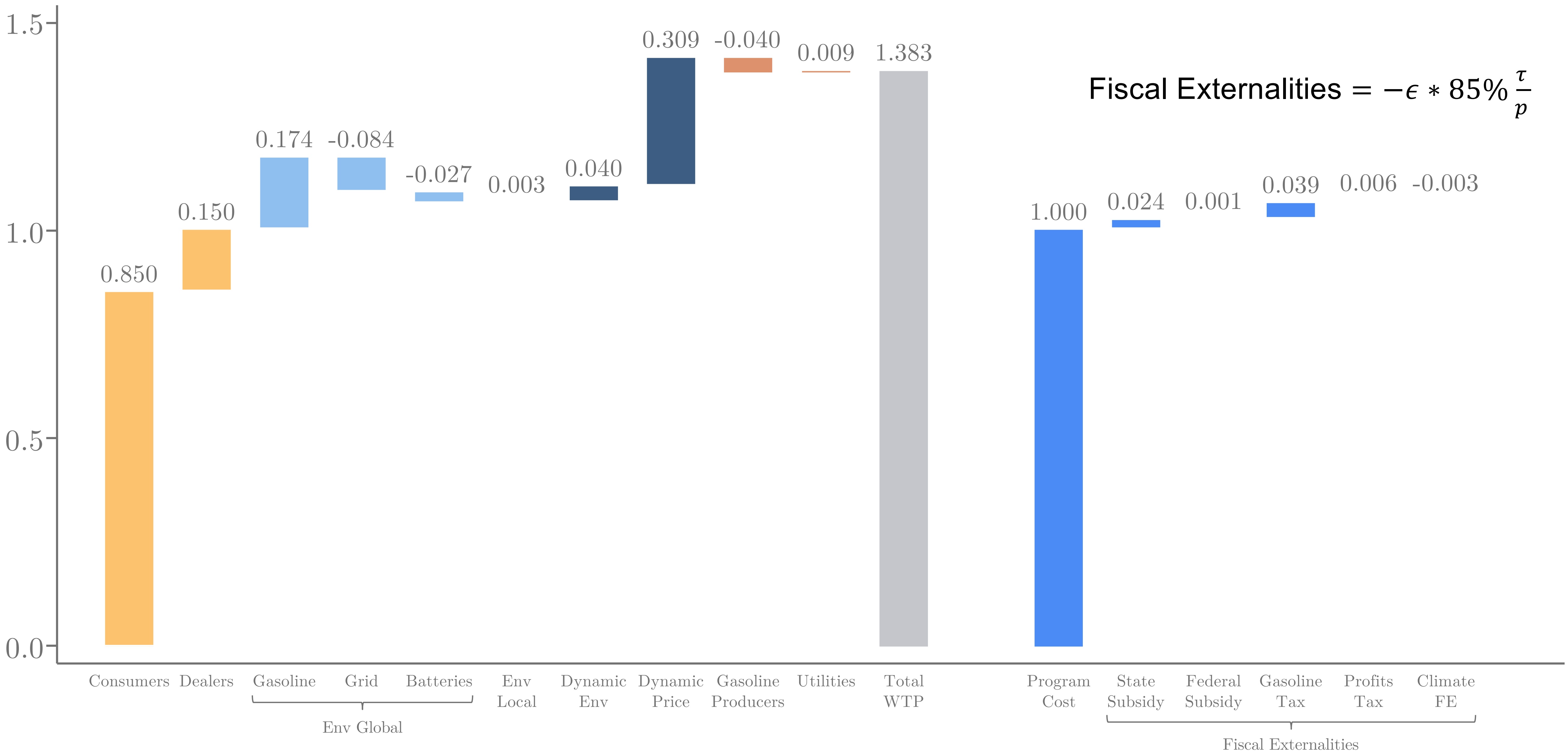


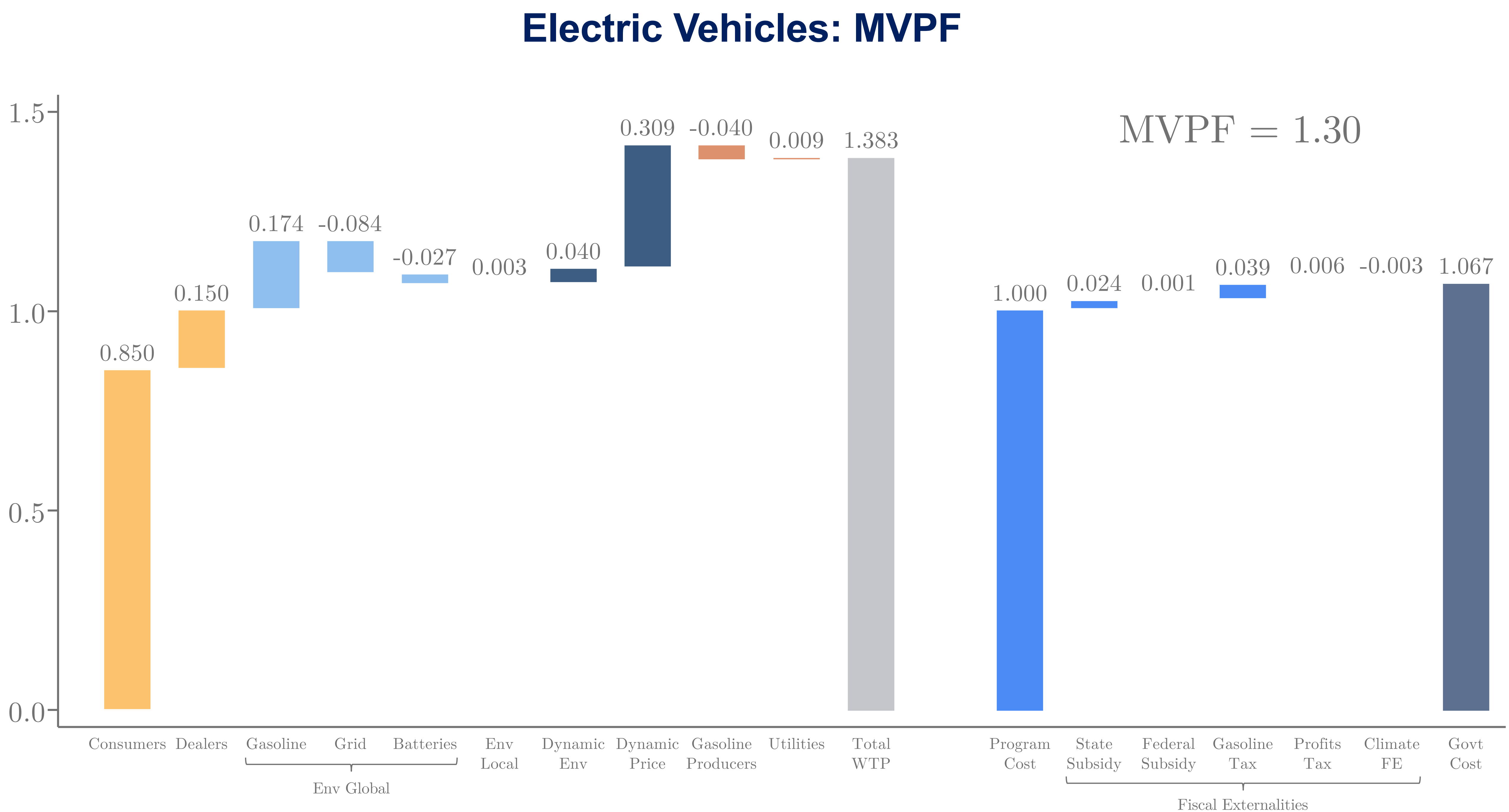
Net Benefit of $1.383 per $1 of mechanical spending

Electric Vehicles: Cost to Government

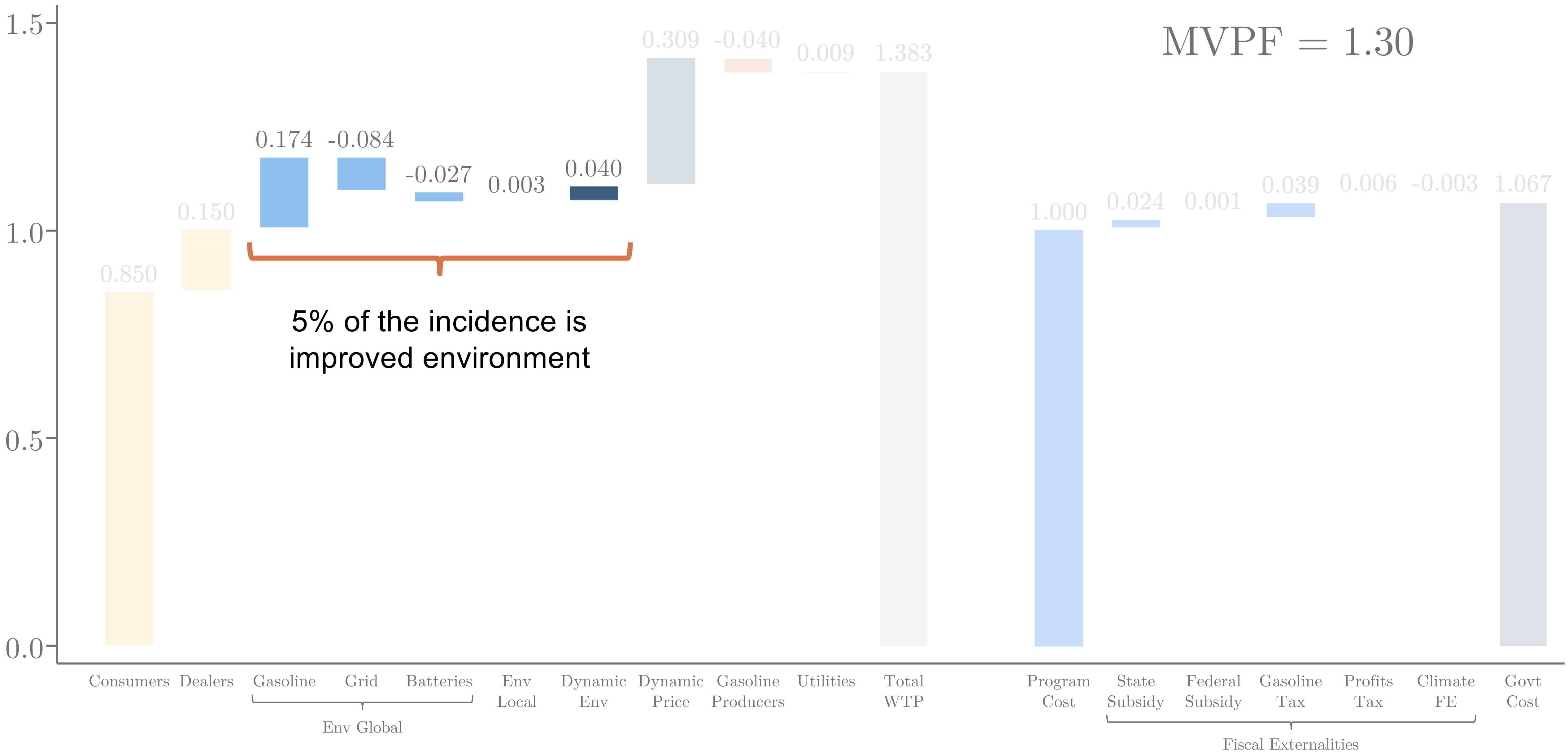


Electric Vehicles: Fiscal Externalities

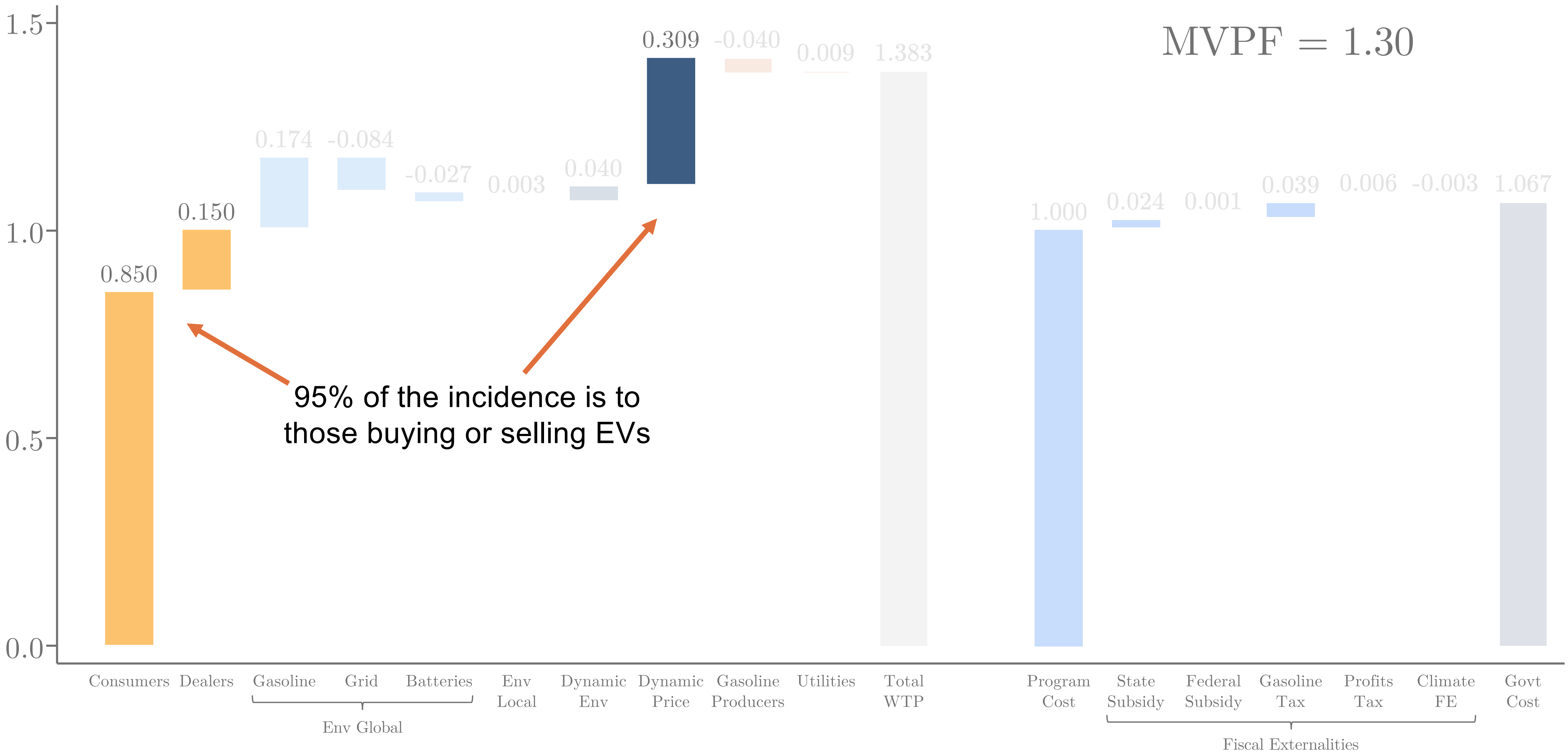



Electric Vehicles: MVPF
MVPF = 1.30
1.5
1.0
0.5
0.0
0.850
0.150
0.174
-0.084
-0.027
0.003
0.040
0.309
-0.040
0.009
1.383
1.000
0.024
0.001
0.039
0.006
-0.003
1.067
Consumers
Dealers
Gasoline
Grid
Batteries
Env Local
Dynamic Env
Dynamic Price
Gasoline Producers
Utilities
Total WTP
Program Cost
State Subsidy
Federal Subsidy
Gasoline Tax
Profits Tax
Climate FE
Govt Cost
Env Global
Fiscal Externalities

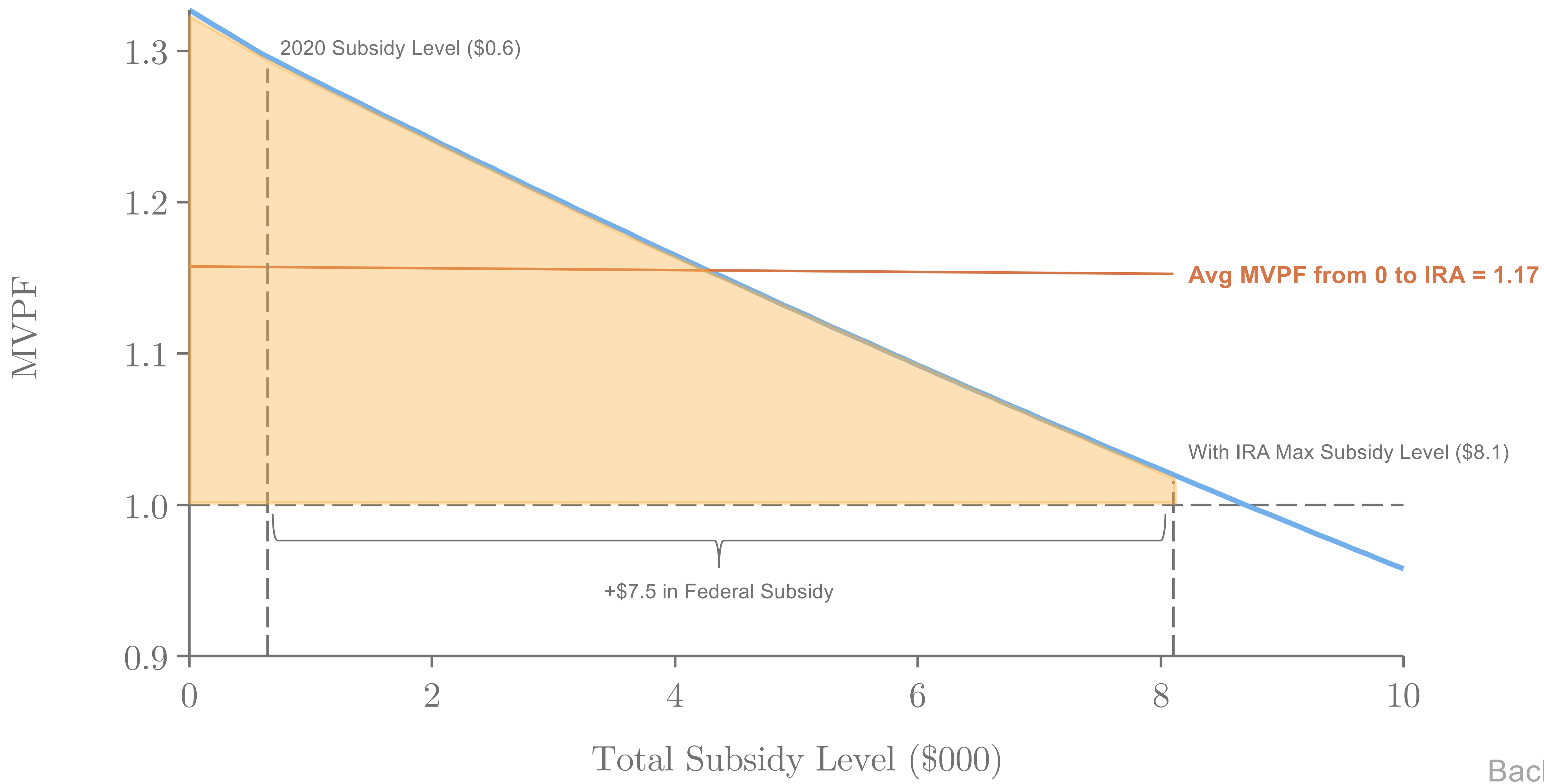
Electric Vehicles: MVPF



Electric Vehicles: MVPF



Electric Vehicles: Non-Marginal (Average) MVPF



Back

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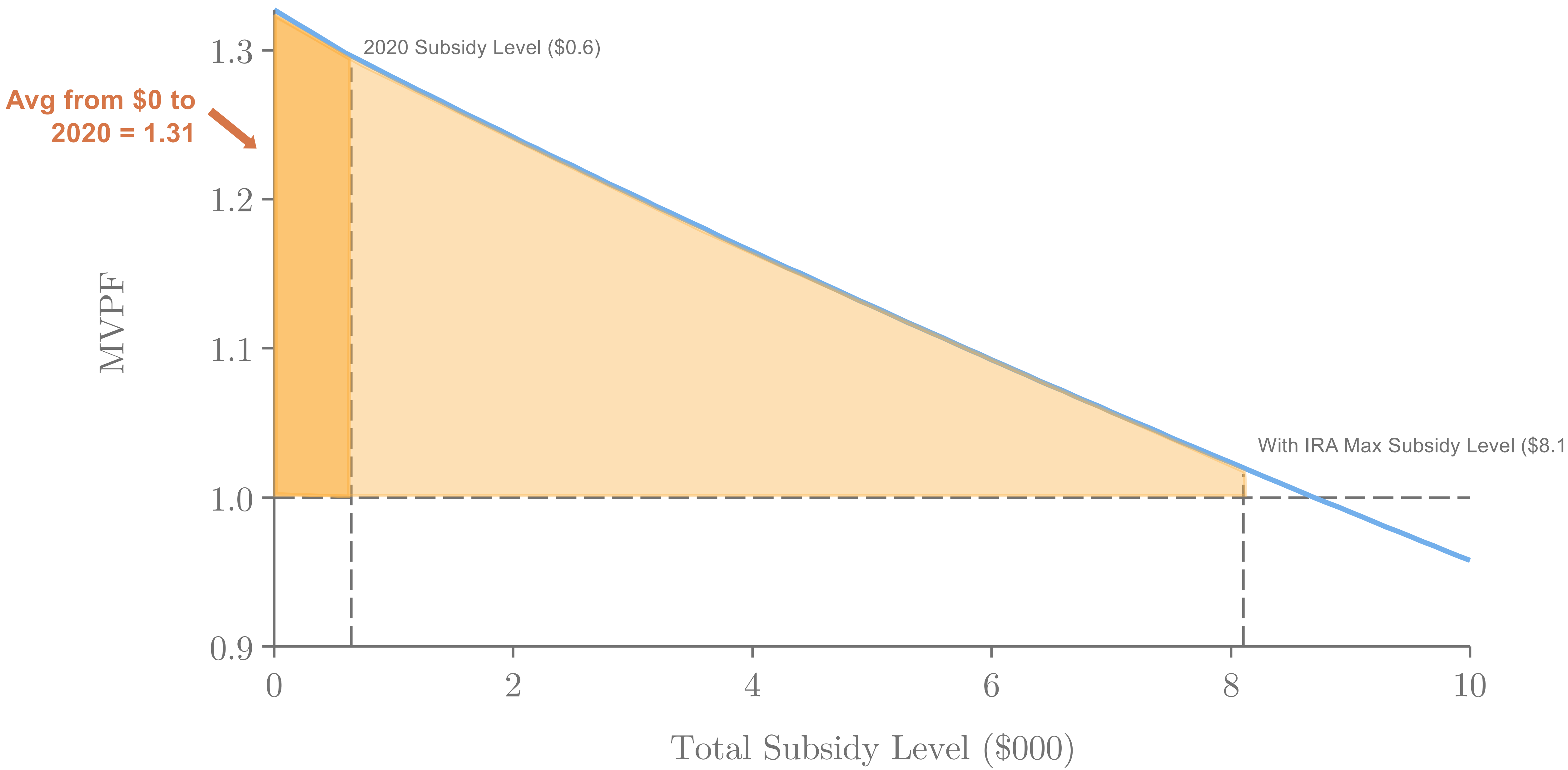
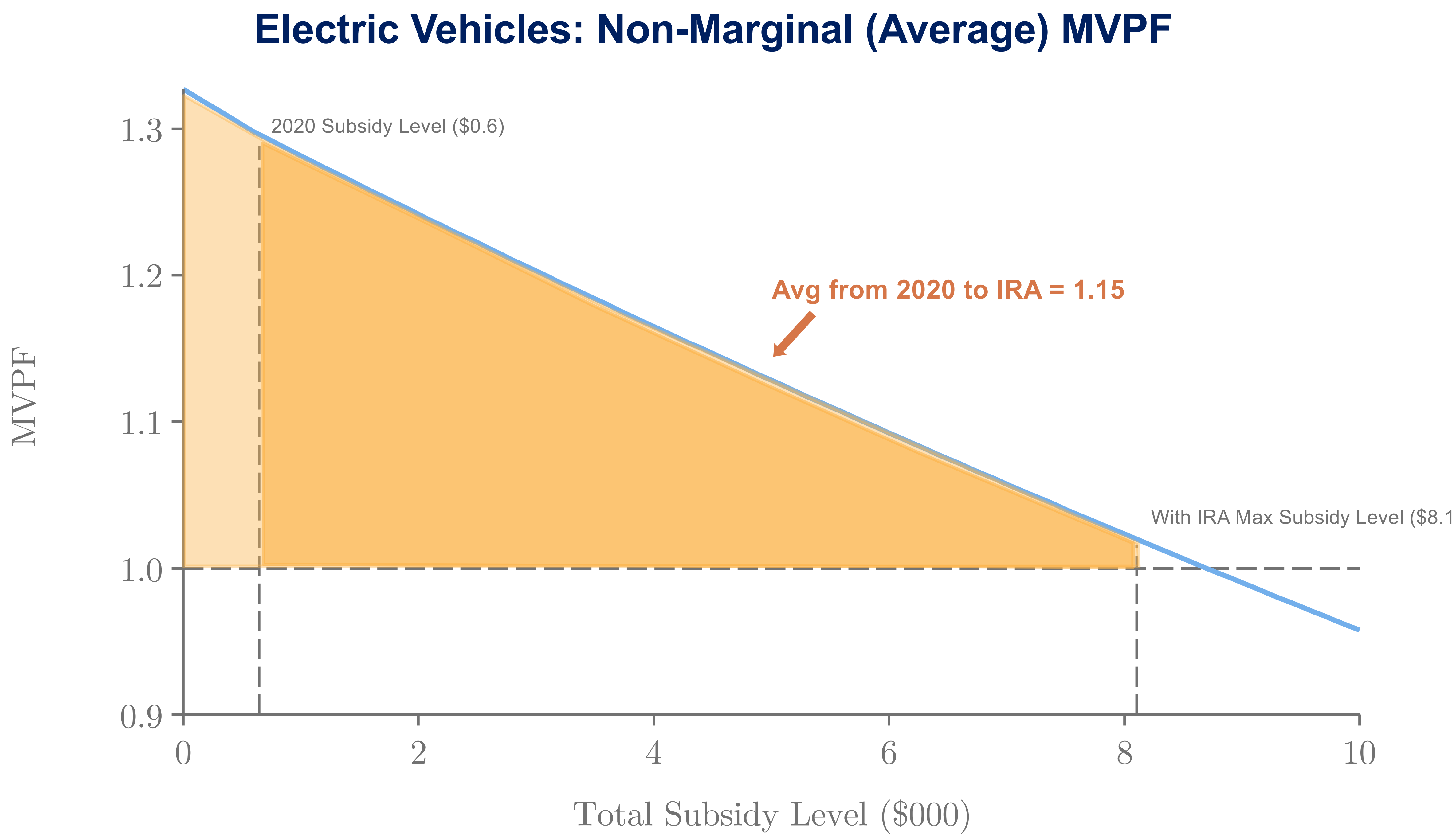
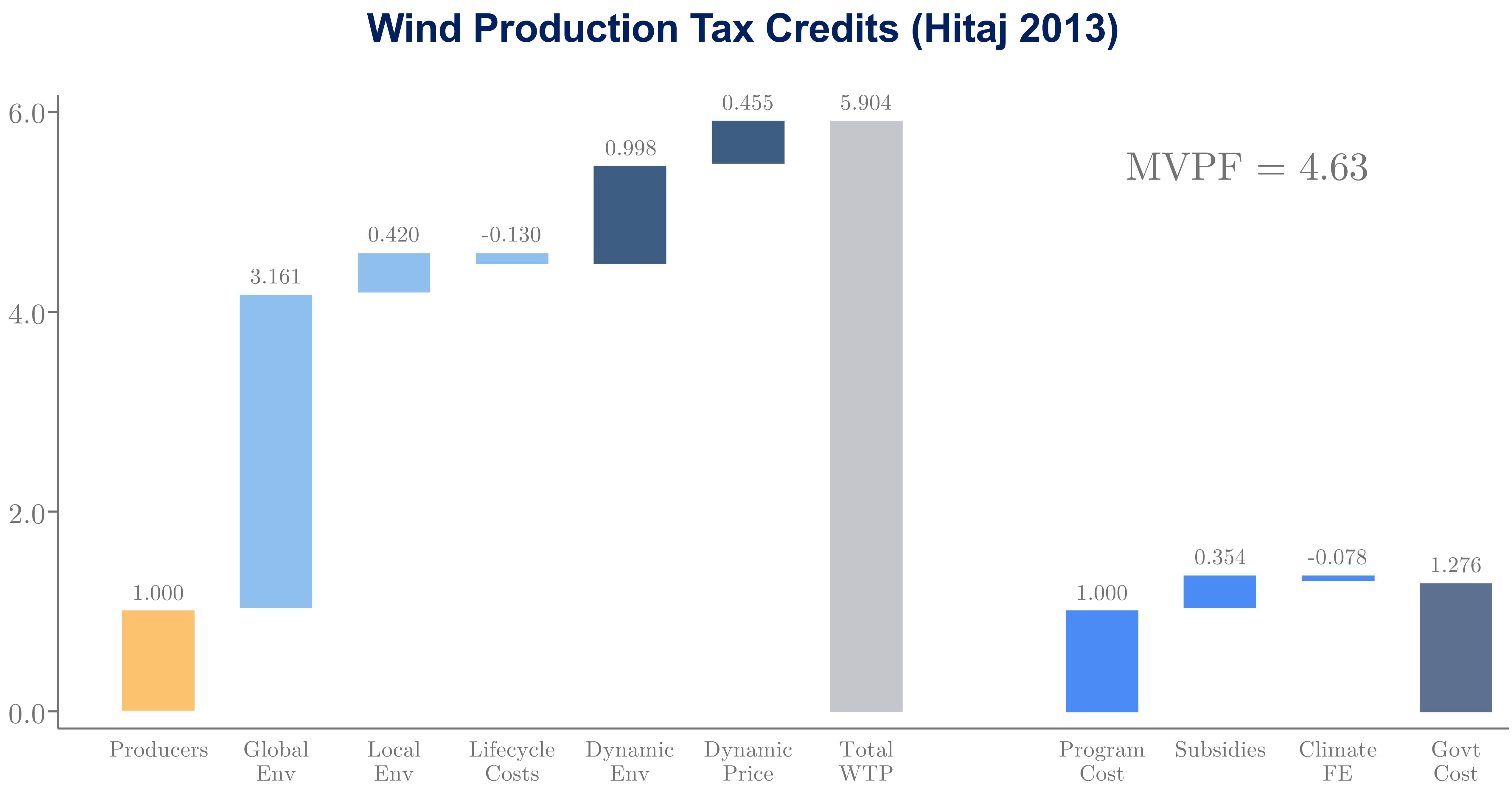
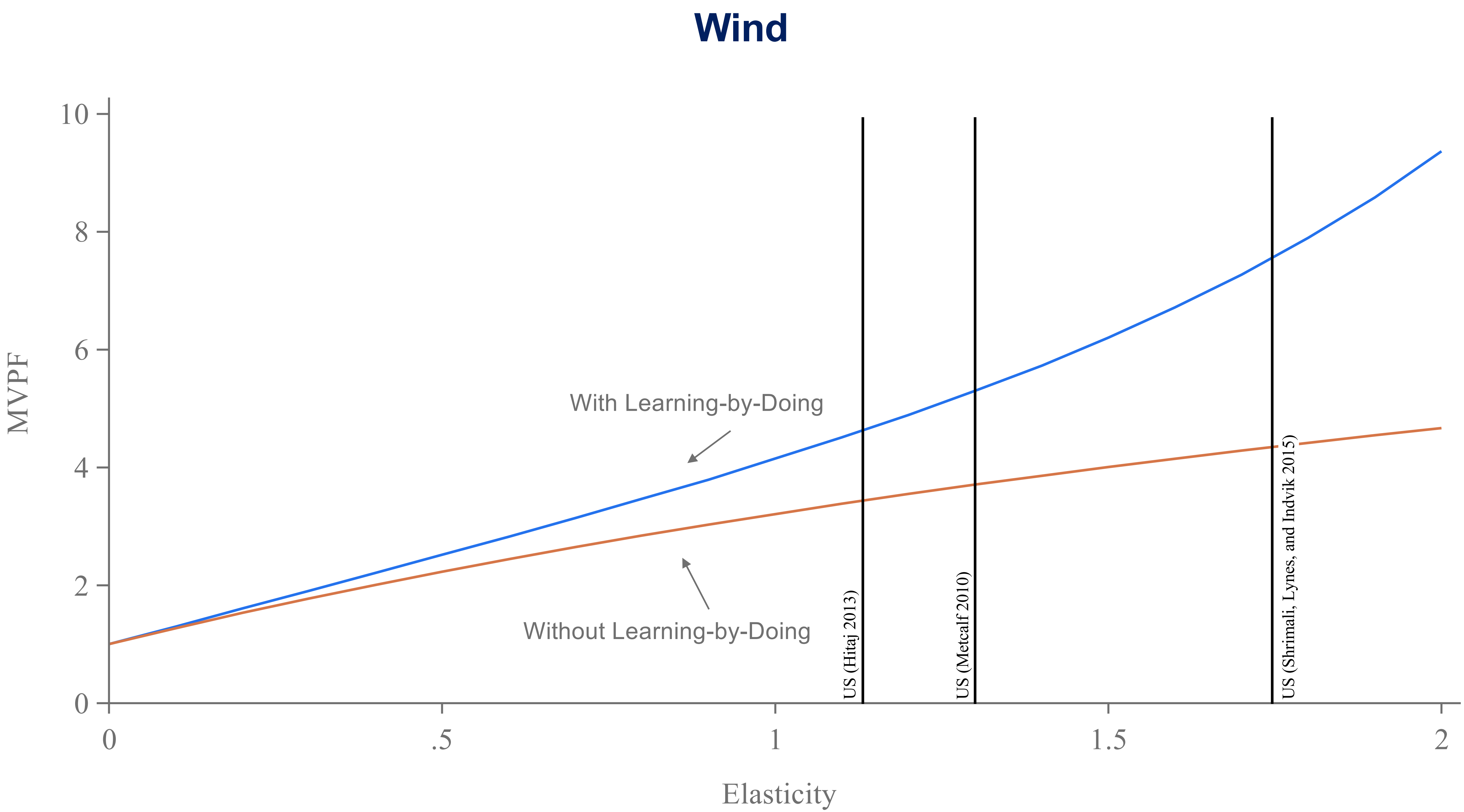


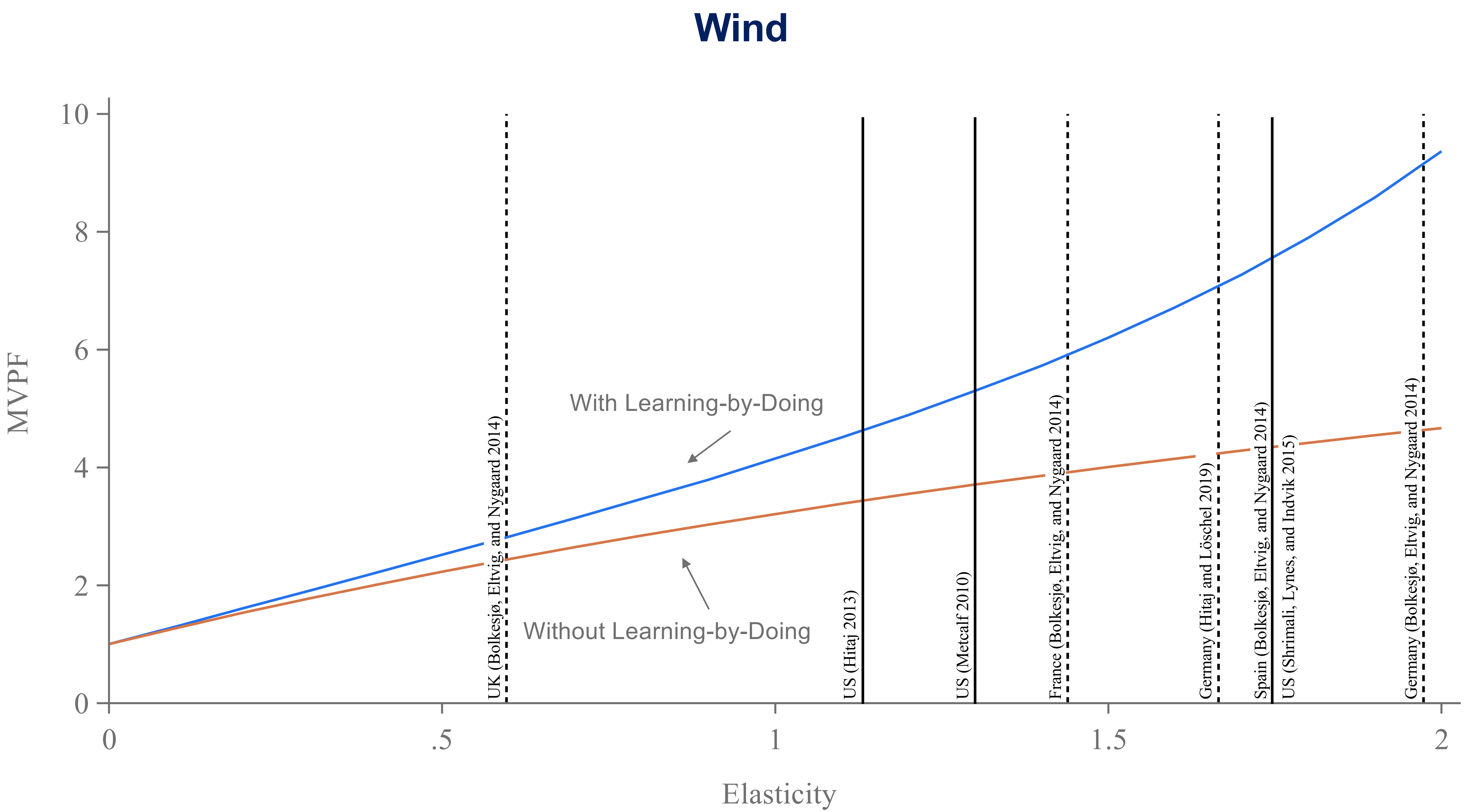

Electric Vehicles: Non-Marginal (Average) MVPF
2020 Subsidy Level ($0.6)
Avg from 2020 to IRA = 1.15
With IRA Max Subsidy Level ($8.1)
MVPF
1.3
1.2
1.1
1.0
0.9
0
2
4
6
8
10
Total Subsidy Level ($000)



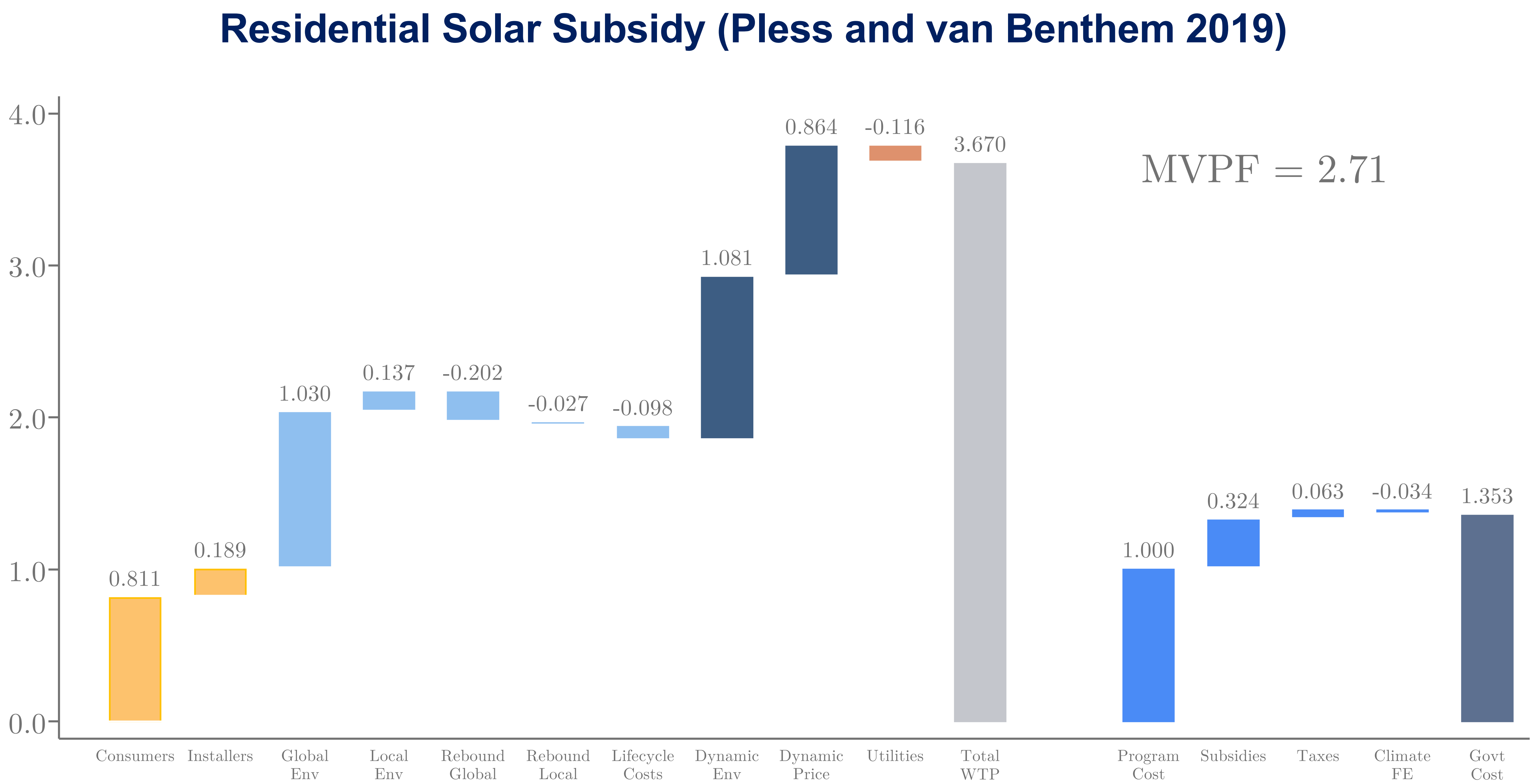
Wind Production Tax Credits (Hitaj 2013)
MVPF = 4.63
6.0
4.0
2.0
0.0
1.000
3.161
0.420
-0.130
0.998
0.455
5.904
1.000
0.354
-0.078
1.276
Producers
Global Env
Local Env
Lifecycle Costs
Dynamic Env
Dynamic Price
Total WTP
Program Cost
Subsidies
Climate FE
Govt Cost



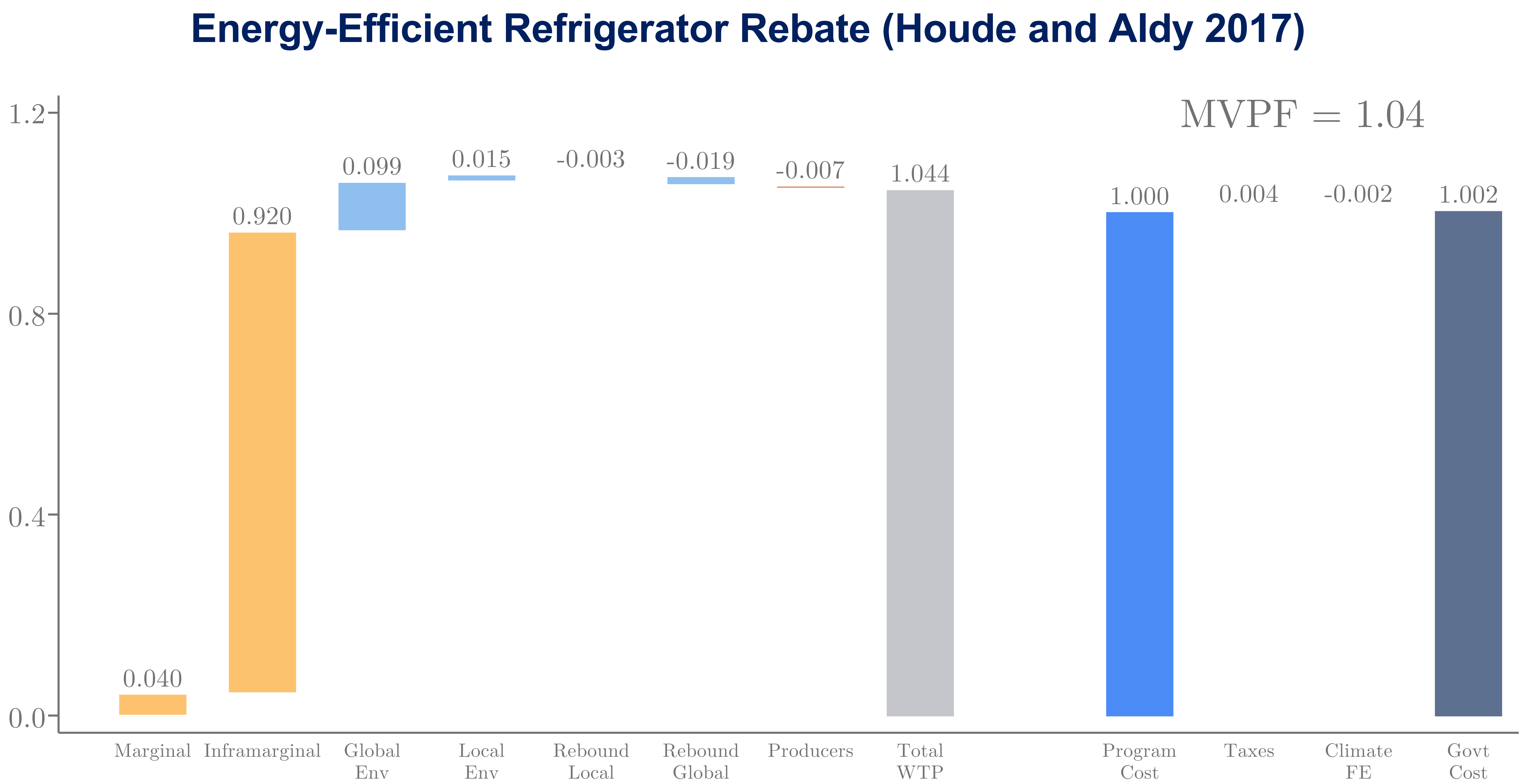
Wind
MVPF
10
8
6
4
2
0
0
.5
1
1.5
2
Elasticity
With Learning-by-Doing
Without Learning-by-Doing
US (Hitaj 2013)
US (Metcalf 2010)
US (Shrimali, Lynes, and Indvik 2015)



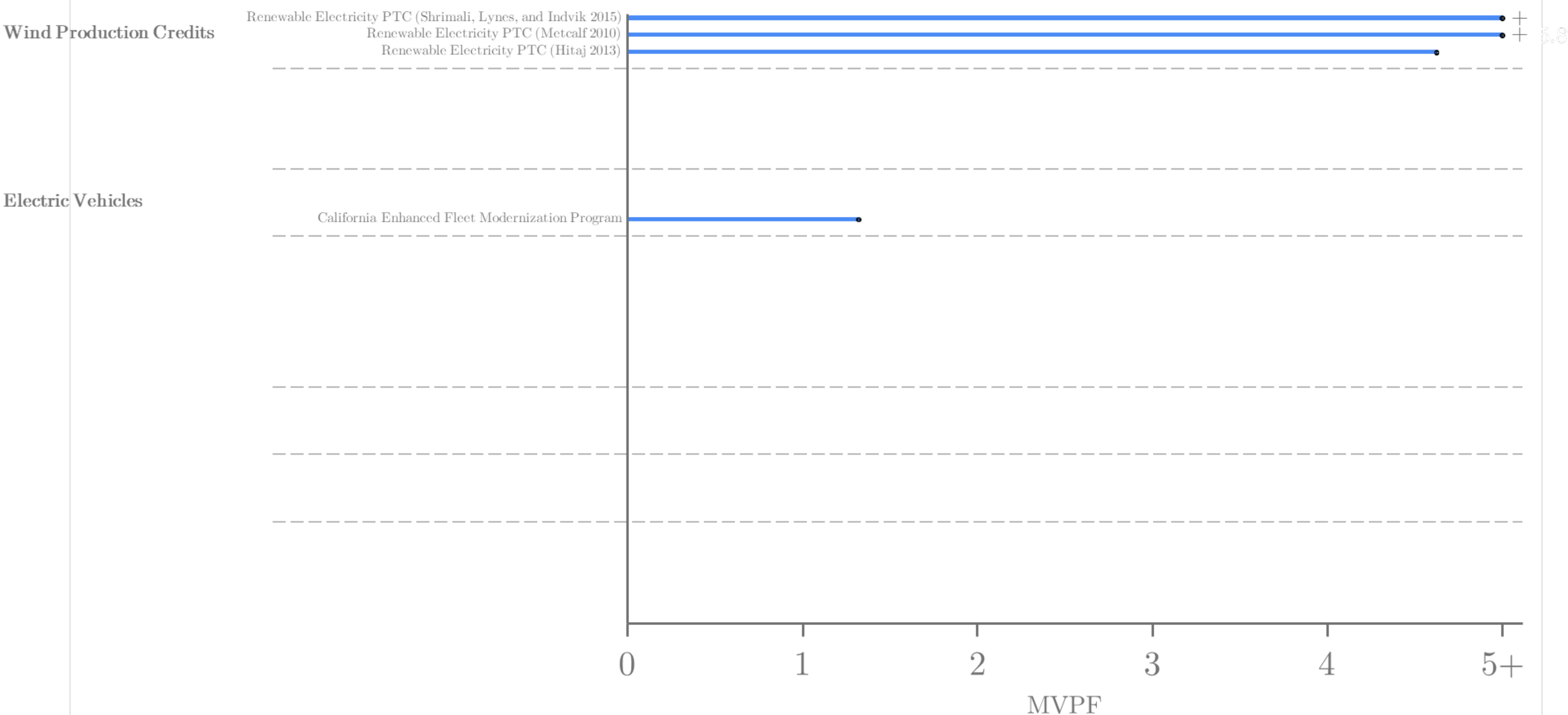
Wind
MVPF
10
8
6
4
2
0
0
.5
1
1.5
2
Elasticity
With Learning-by-Doing
Without Learning-by-Doing
UK (Bolkesjø, Eltvig, and Nygaard 2014)
US (Hitaj 2013)
US (Metcalf 2010)
France (Bolkesjø, Eltvig, and Nygaard 2014)
Germany (Hitaj and Löschel 2019)
Spain (Bolkesjø, Eltvig, and Nygaard 2014)
US (Shrimali, Lynes, and Indvik 2015)
Germany (Bolkesjø, Eltvig, and Nygaard 2014)



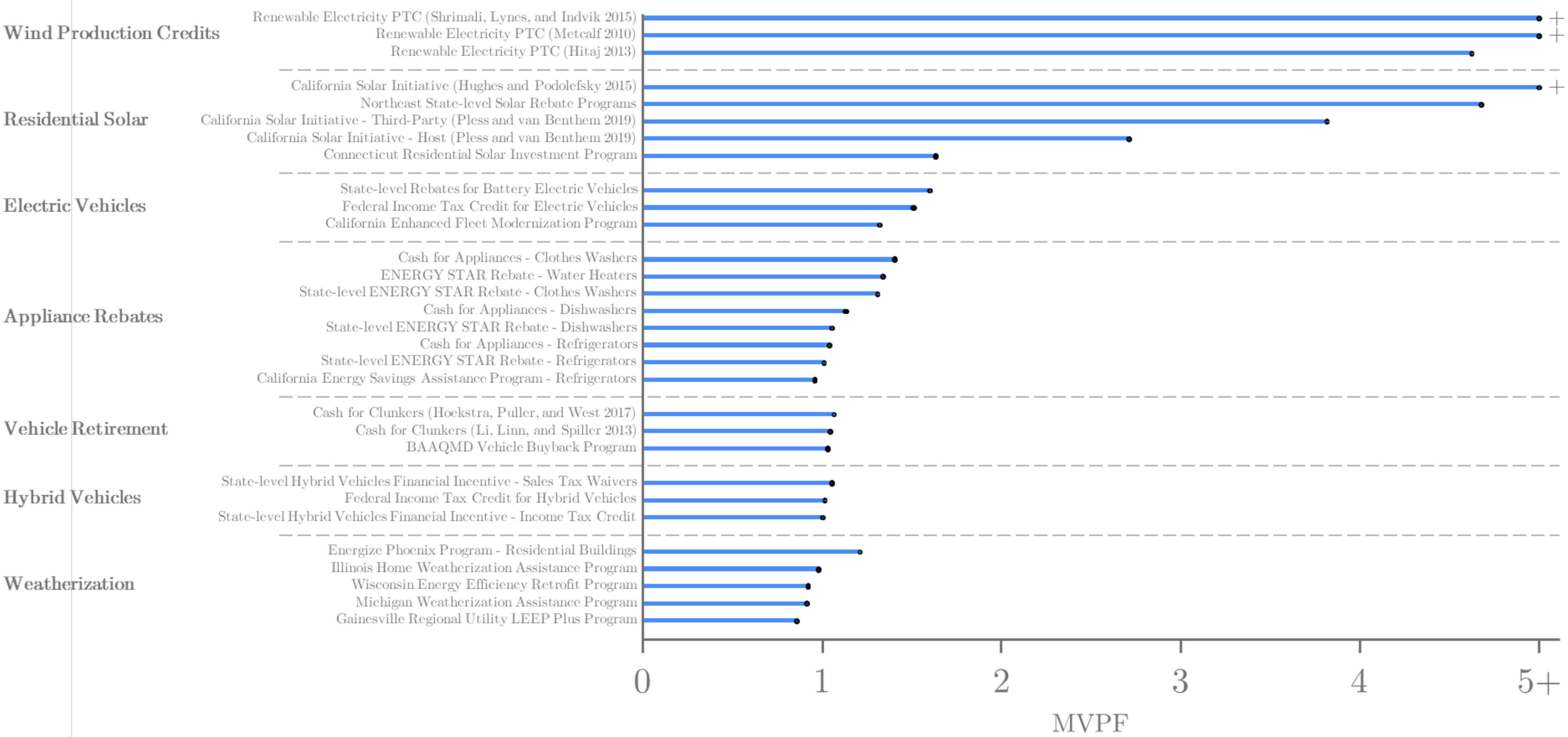
Residential Solar Subsidy (Pless and van Benthem 2019)
MVPF = 2.71
4.0
3.0
2.0
1.0
0.0
0.811
0.189
1.030
0.137
-0.202
-0.027
-0.098
1.081
0.864
-0.116
3.670
1.000
0.324
0.063
-0.034
1.353
Consumers
Installers
Global Env
Local Env
Rebound Global
Rebound Local
Lifecycle Costs
Dynamic Env
Dynamic Price
Utilities
Total WTP
Program Cost
Subsidies
Taxes
Climate FE
Govt Cost

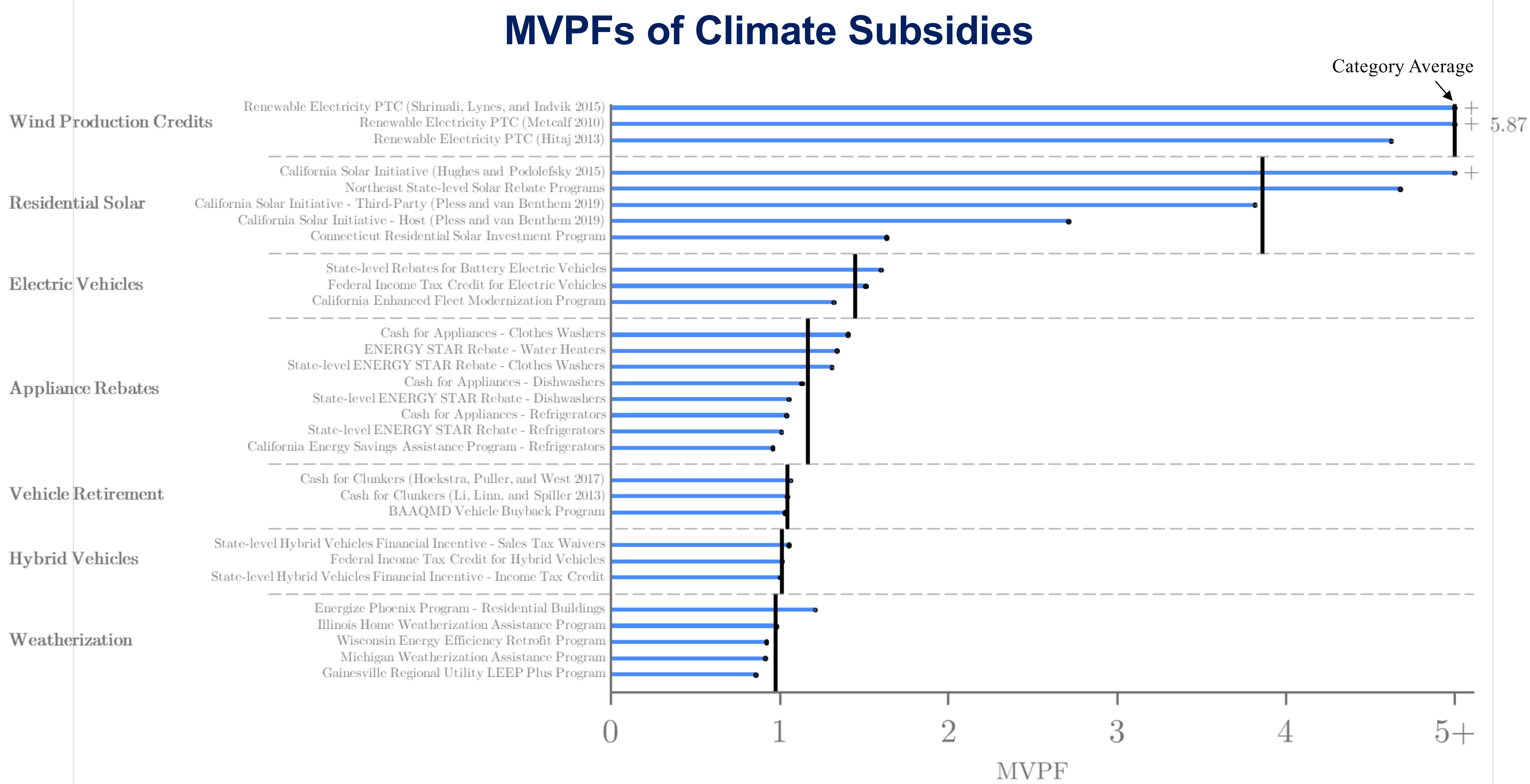

Energy-Efficient Refrigerator Rebate (Houde and Aldy 2017)
MVPF = 1.04
1.2
0.8
0.4
0.0
0.040
0.920
0.099
0.015
-0.003
-0.019
-0.007
1.044
1.000
0.004
-0.002
1.002
Marginal
Inframarginal
Global Env
Local Env
Rebound Local
Rebound Global
Producers
Total WTP
Program Cost
Taxes
Climate FE
Govt Cost

MVPFs of Climate Subsidies



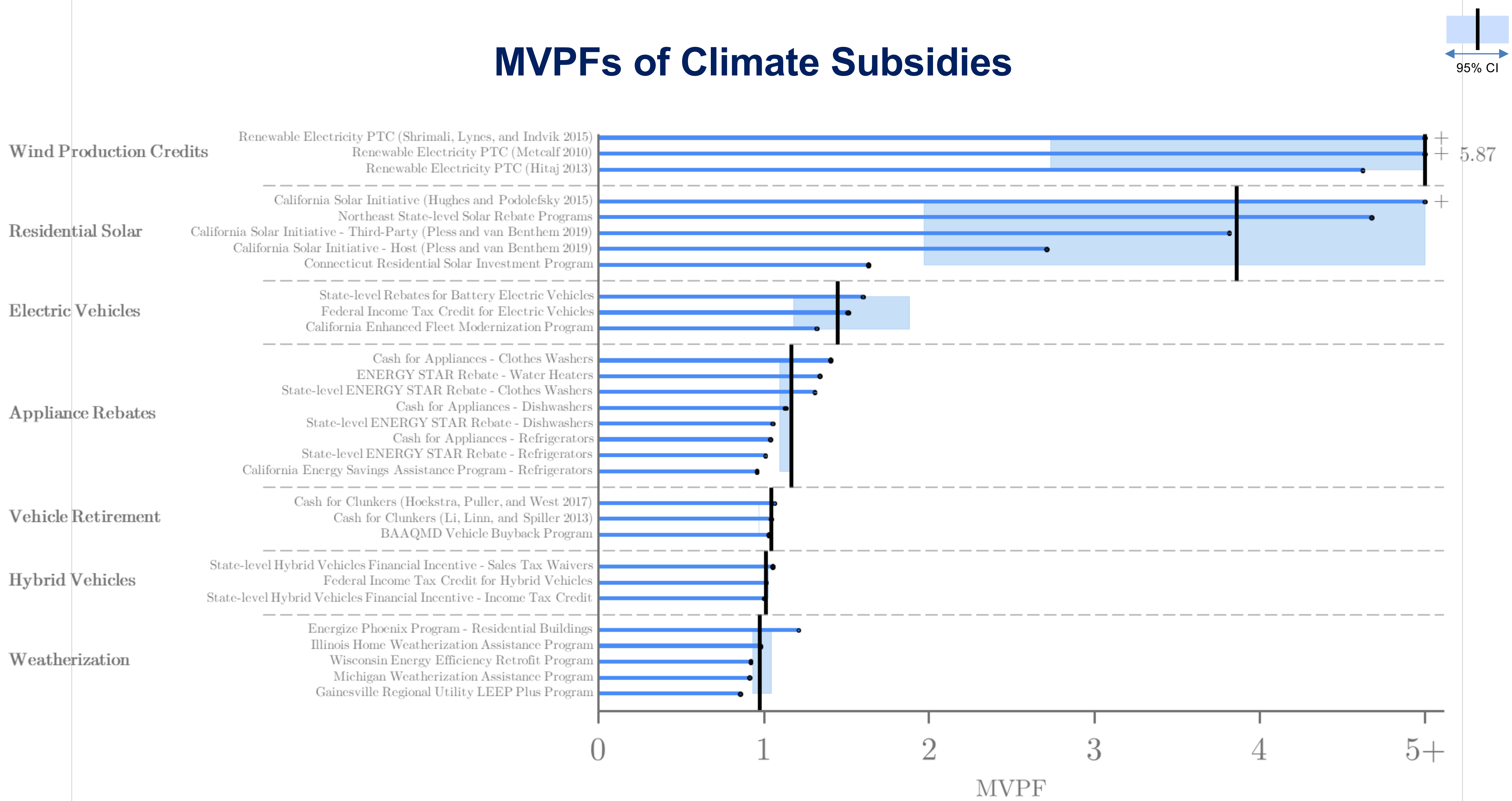
MVPFs of Climate Subsidies





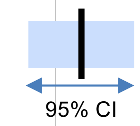
MVPFs of Climate Subsidies
Category Average
Wind Production Credits
Renewable Electricity PTC (Shrimali, Lynes, and Indvik 2015)
Renewable Electricity PTC (Metcalf 2010)
Renewable Electricity PTC (Hitaj 2013)
5.87
Residential Solar
California Solar Initiative (Hughes and Podolefsky 2015)
Northeast State-level Solar Rebate Programs
California Solar Initiative - Third-Party (Pless and van Benthem 2019)
California Solar Initiative - Host (Pless and van Benthem 2019)
Connecticut Residential Solar Investment Program
Electric Vehicles
State-level Rebates for Battery Electric Vehicles
Federal Income Tax Credit for Electric Vehicles
California Enhanced Fleet Modernization Program
Appliance Rebates
Cash for Appliances - Clothes Washers
ENERGY STAR Rebate - Water Heaters
State-level ENERGY STAR Rebate - Clothes Washers
Cash for Appliances - Dishwashers
State-level ENERGY STAR Rebate - Dishwashers
Cash for Appliances - Refrigerators
State-level ENERGY STAR Rebate - Refrigerators
California Energy Savings Assistance Program - Refrigerators
Vehicle Retirement
Cash for Clunkers (Hoekstra, Puller, and West 2017)
Cash for Clunkers (Li, Linn, and Spiller 2013)
BAAQMD Vehicle Buyback Program
Hybrid Vehicles
State-level Hybrid Vehicles Financial Incentive - Sales Tax Waivers
Federal Income Tax Credit for Hybrid Vehicles
State-level Hybrid Vehicles Financial Incentive - Income Tax Credit
Weatherization
Energize Phoenix Program - Residential Buildings
Illinois Home Weatherization Assistance Program
Wisconsin Energy Efficiency Retrofit Program
Michigan Weatherization Assistance Program
Gainesville Regional Utility LEEP Plus Program
0
1
2
3
4
5+
MVPF

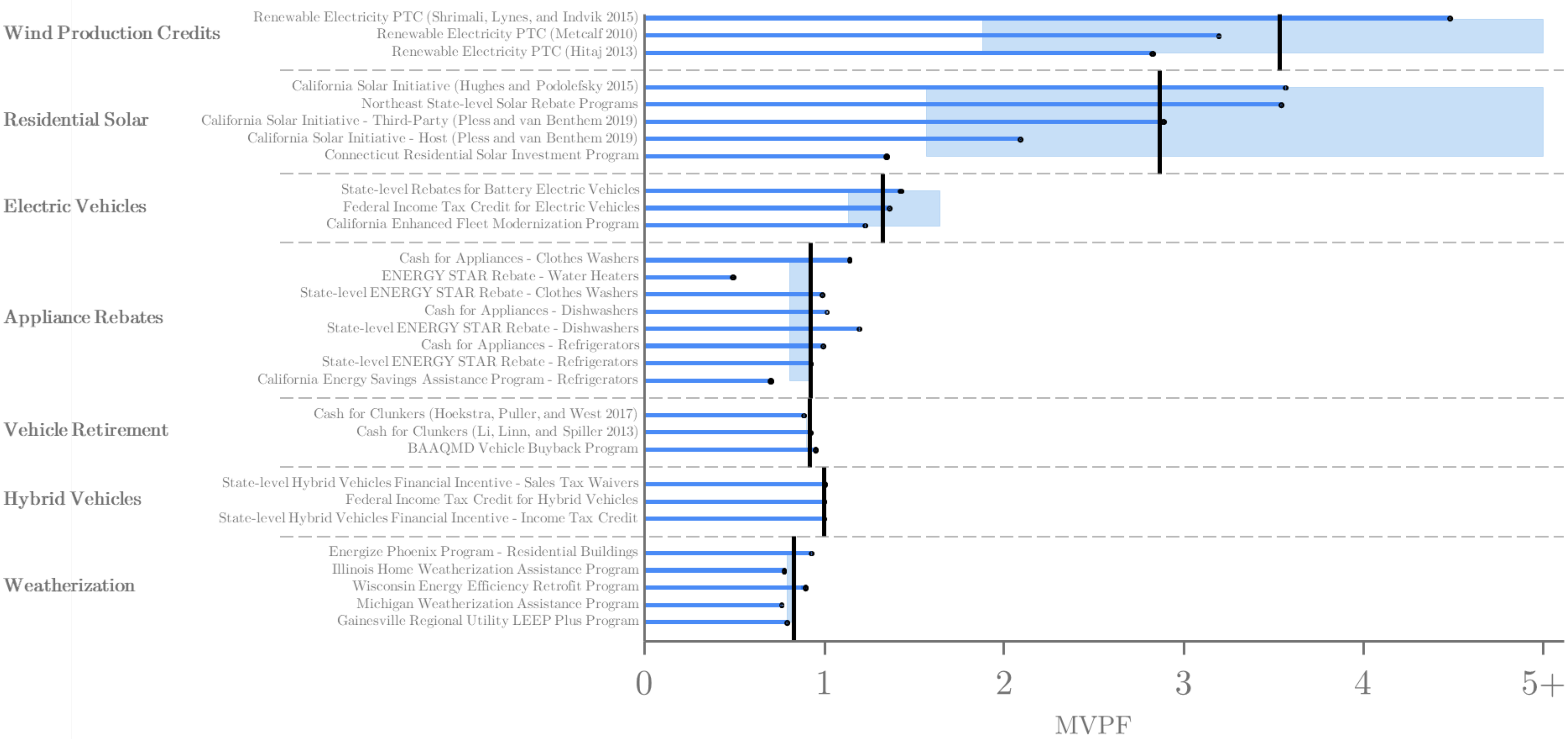
MVPFs of Climate Subsidies



SCC $76 SCC $337 No LBD US vs RoW No Profits Energy Savings In Context Non-Marginal

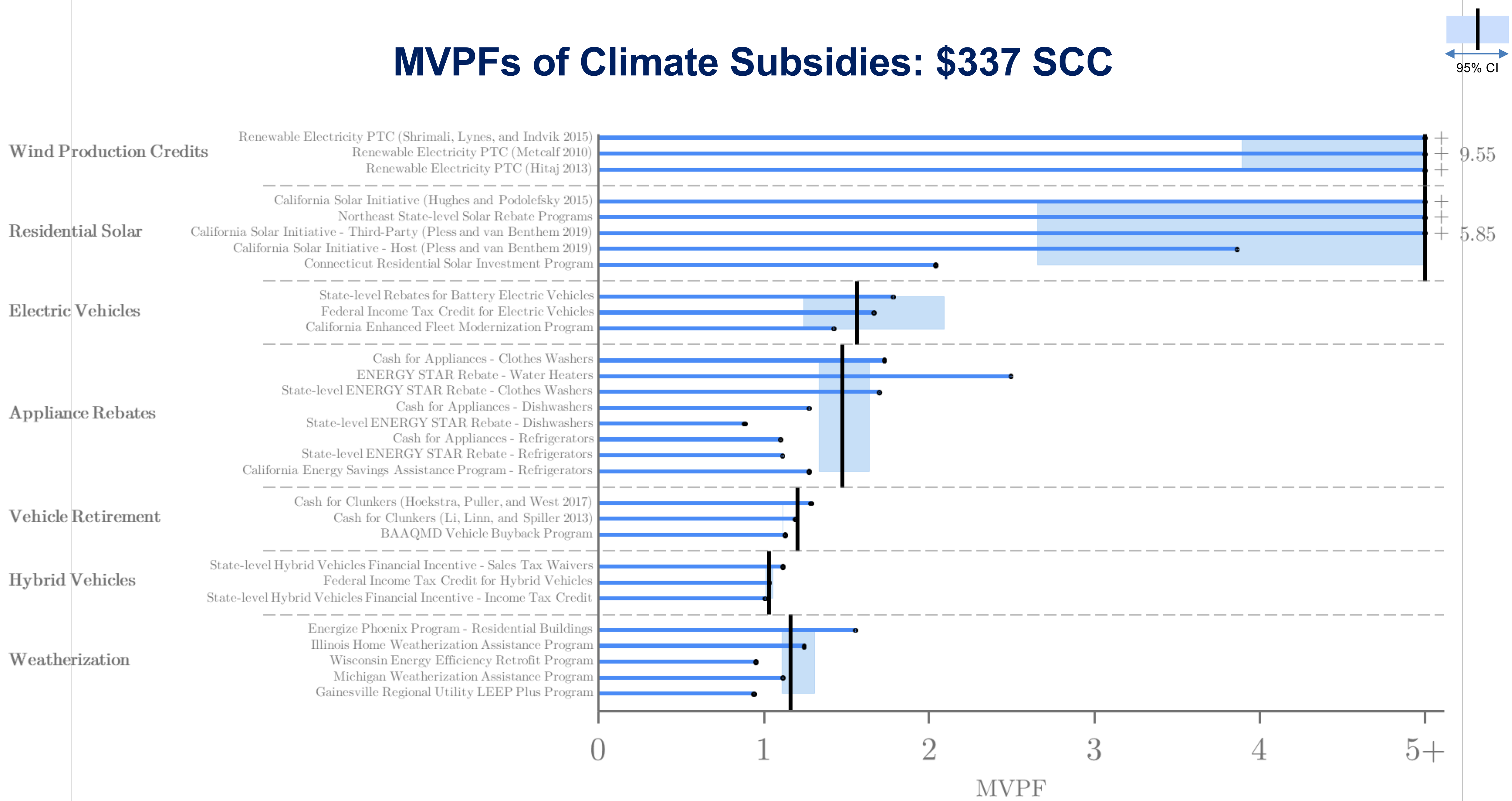
MVPFs of Climate Subsidies: $76 SCC





Back

MVPFs of Climate Subsidies: $337 SCC



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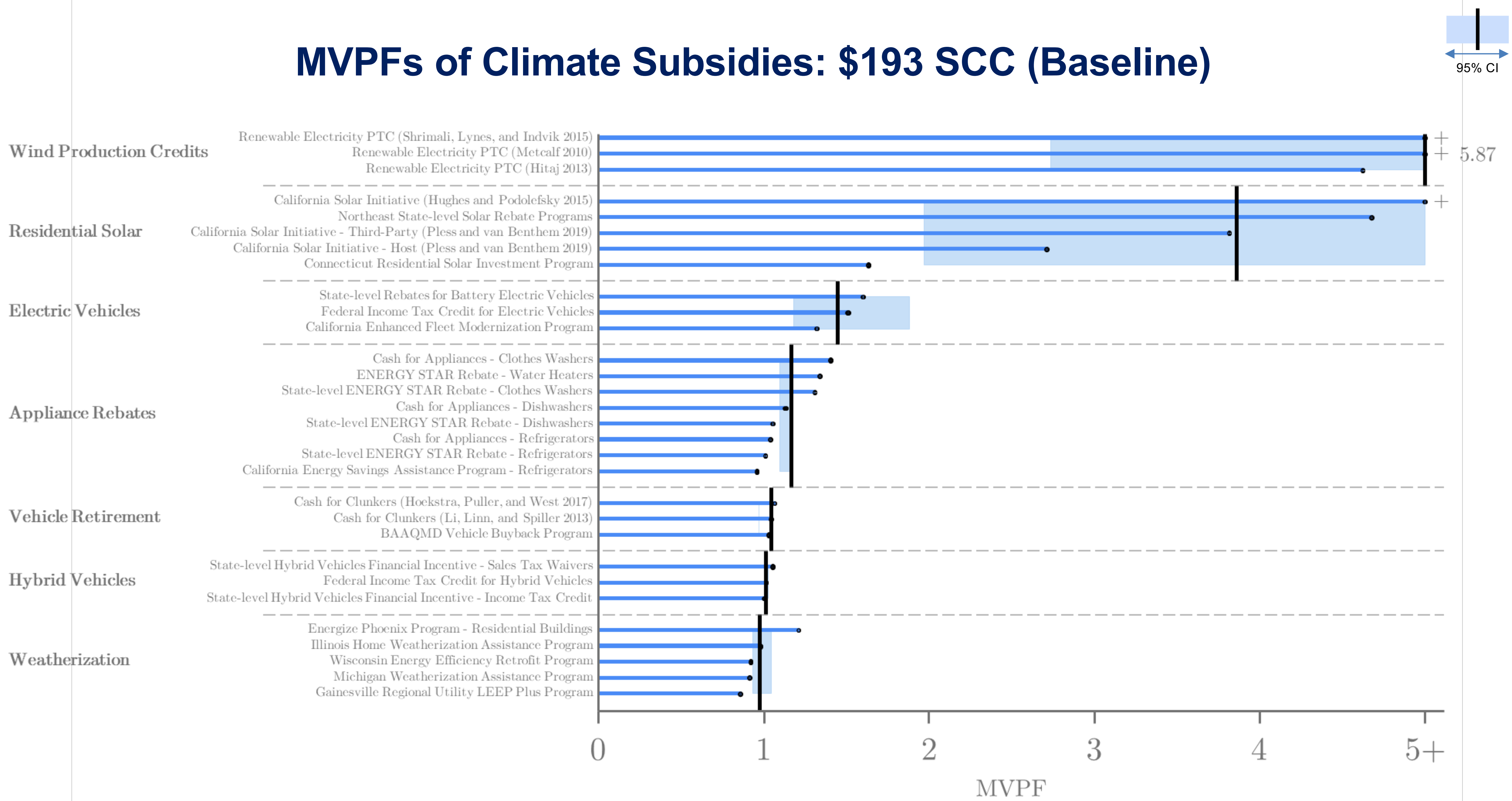
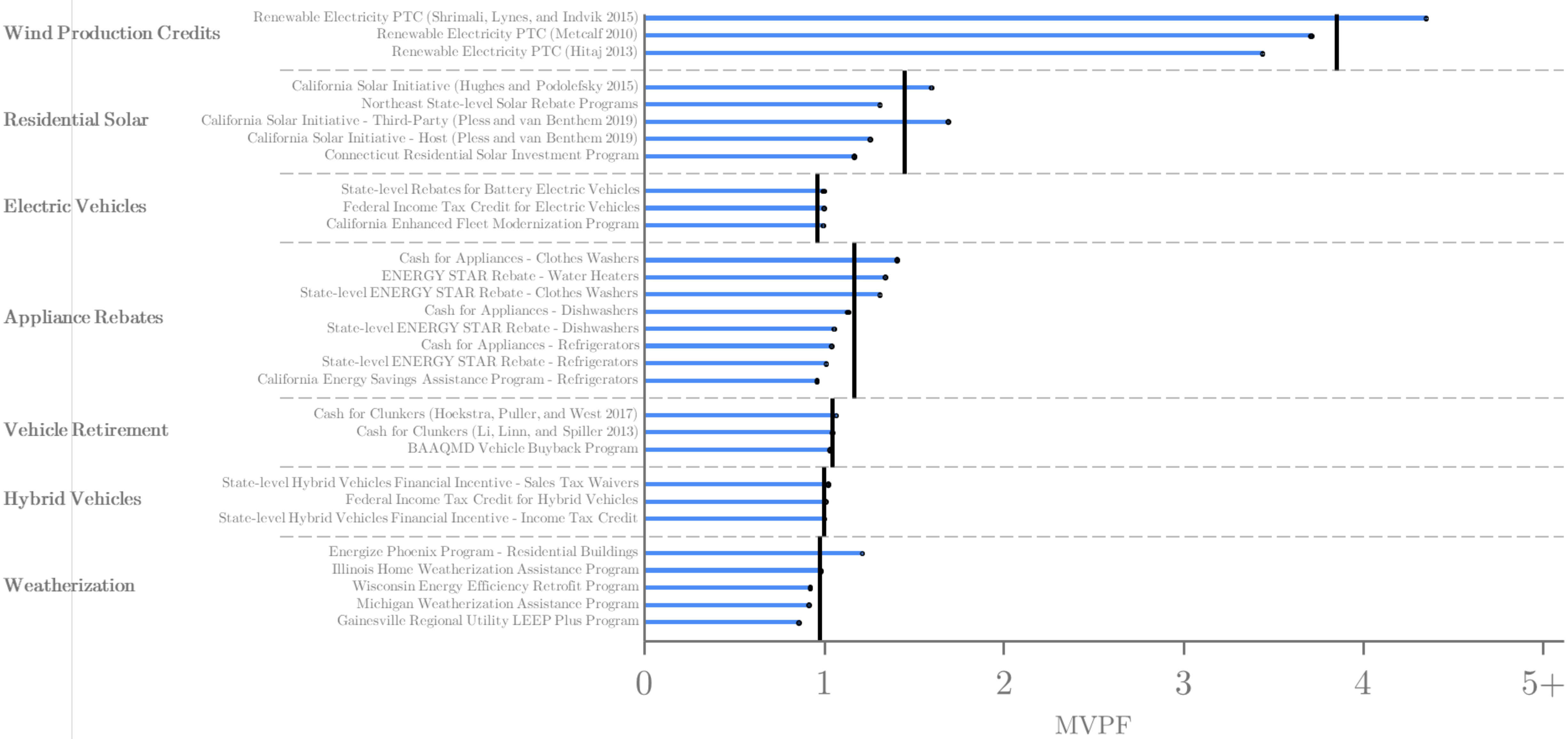
MVPFs of Climate Subsidies: $193 SCC (Baseline)



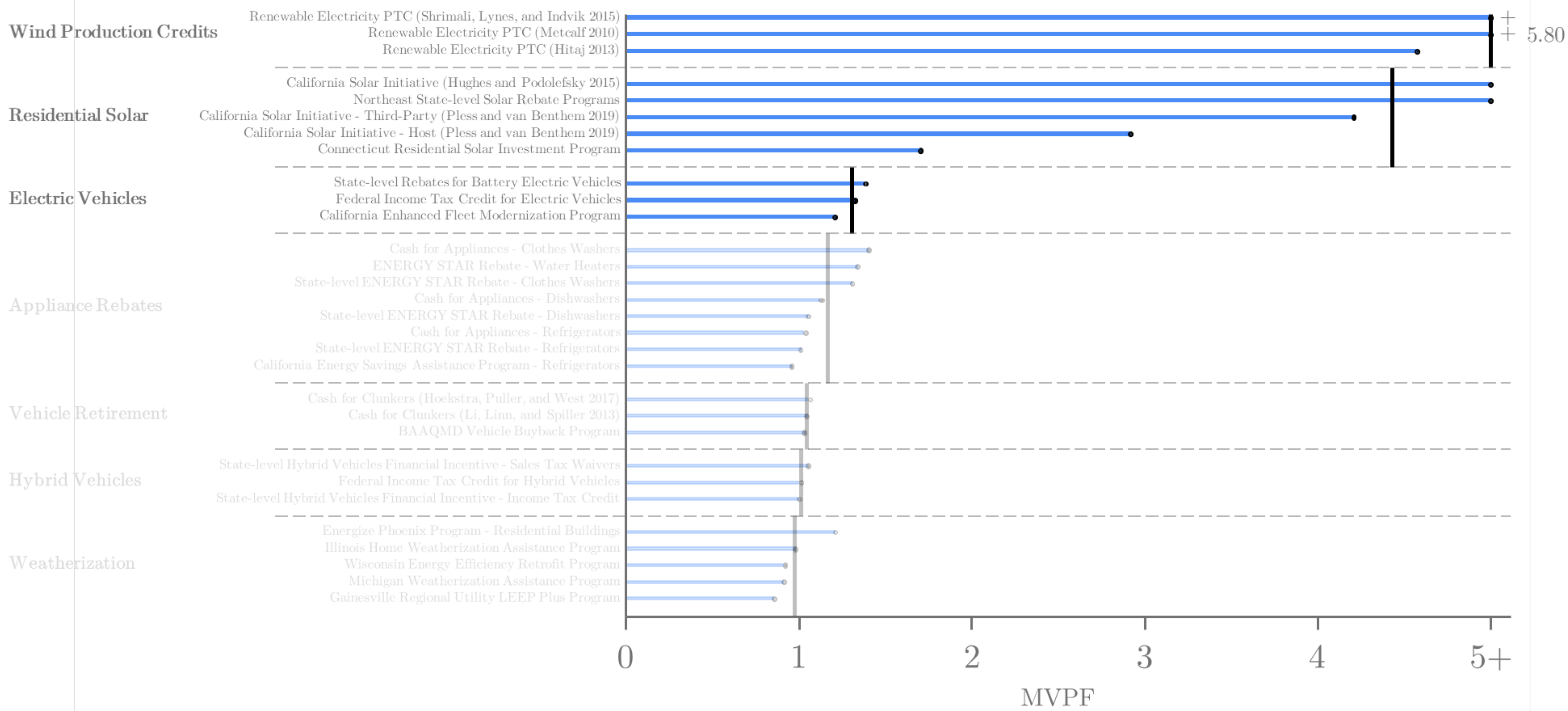
Back

MVPFs of Climate Subsidies: Excluding Learning by Doing



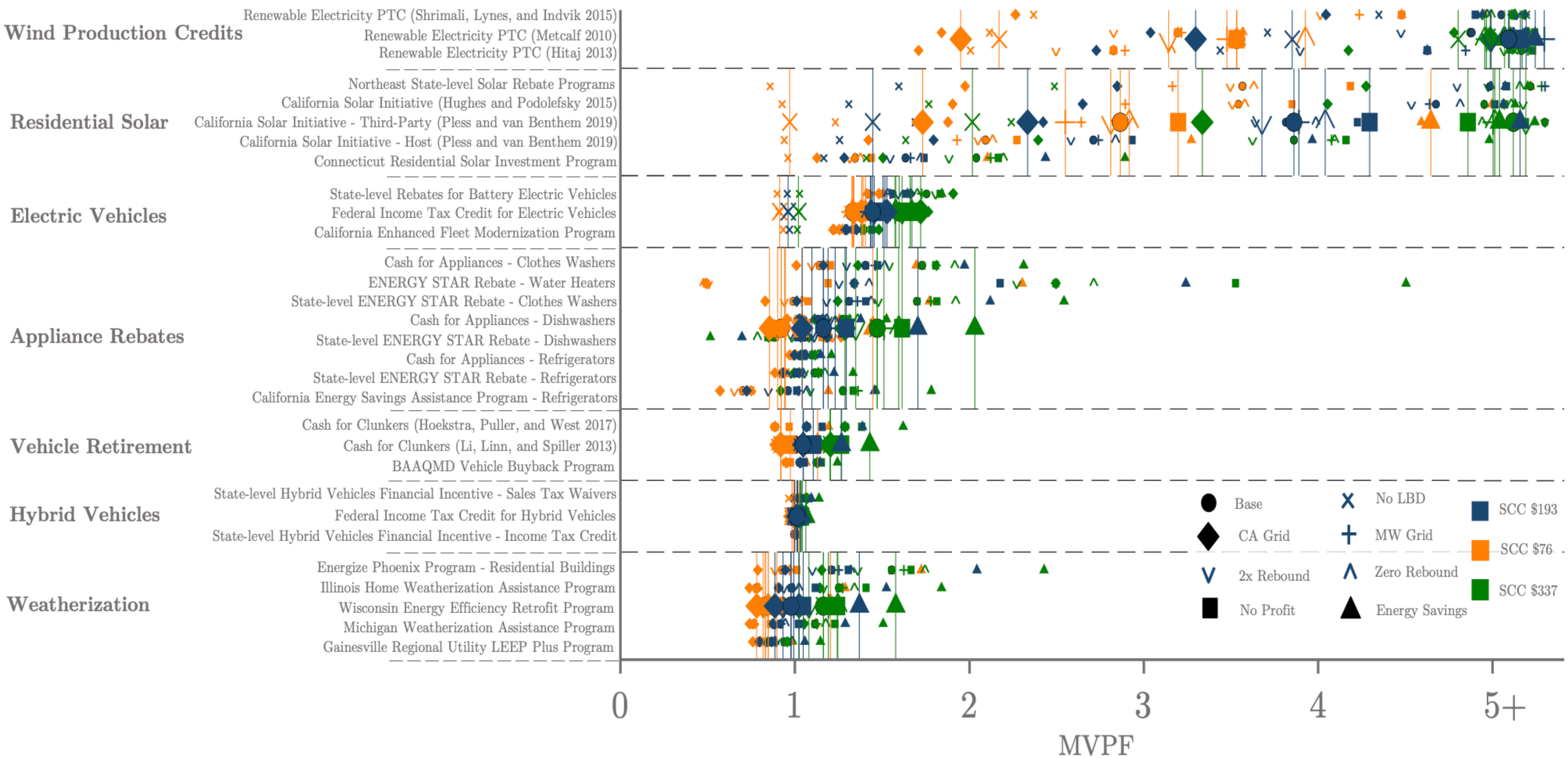
Back

MVPFs of Climate Subsidies: IRA levels

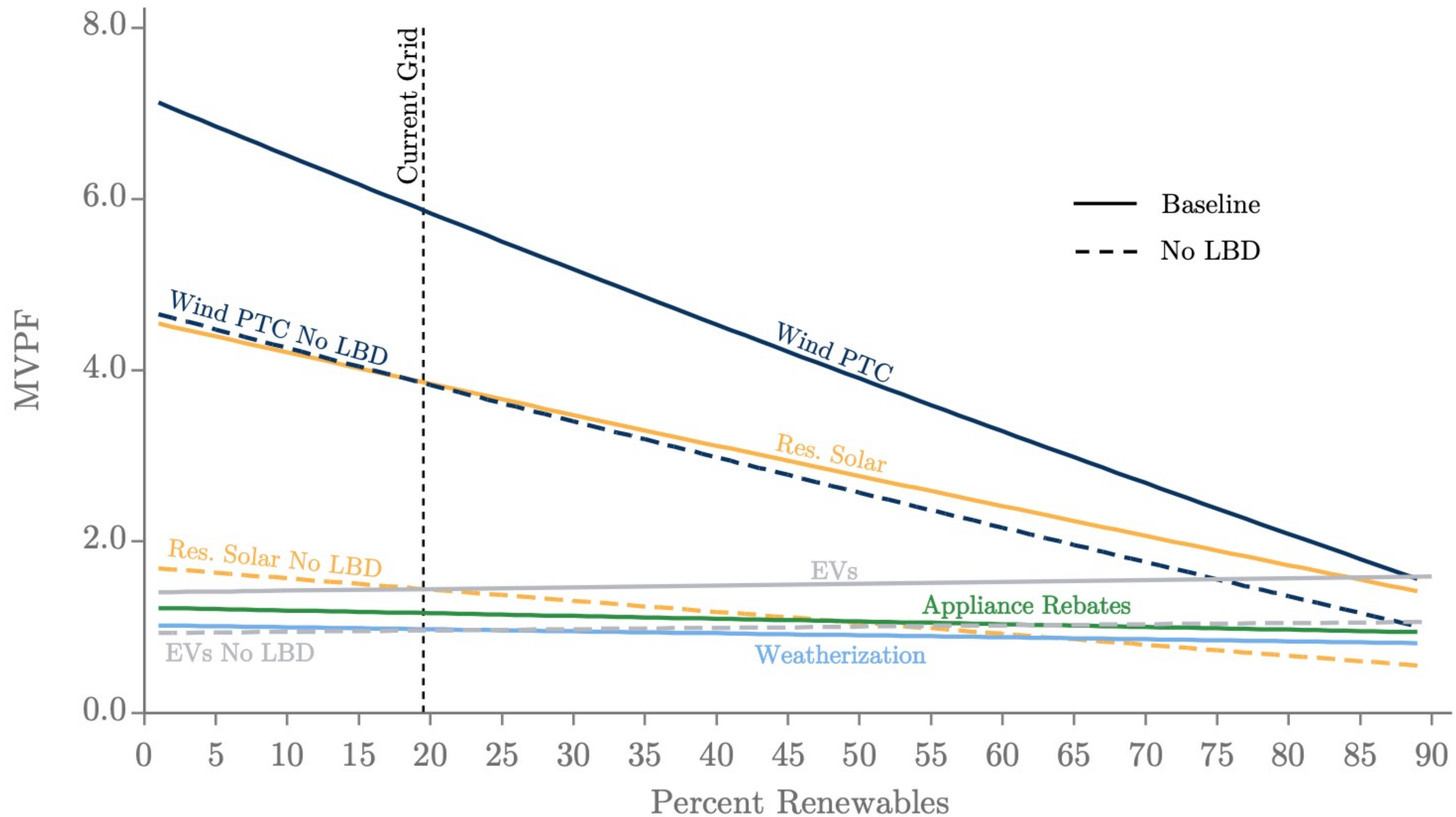


Back

A. MVPFs Under Varying Specifications



B. MVPFs with a Changing Grid

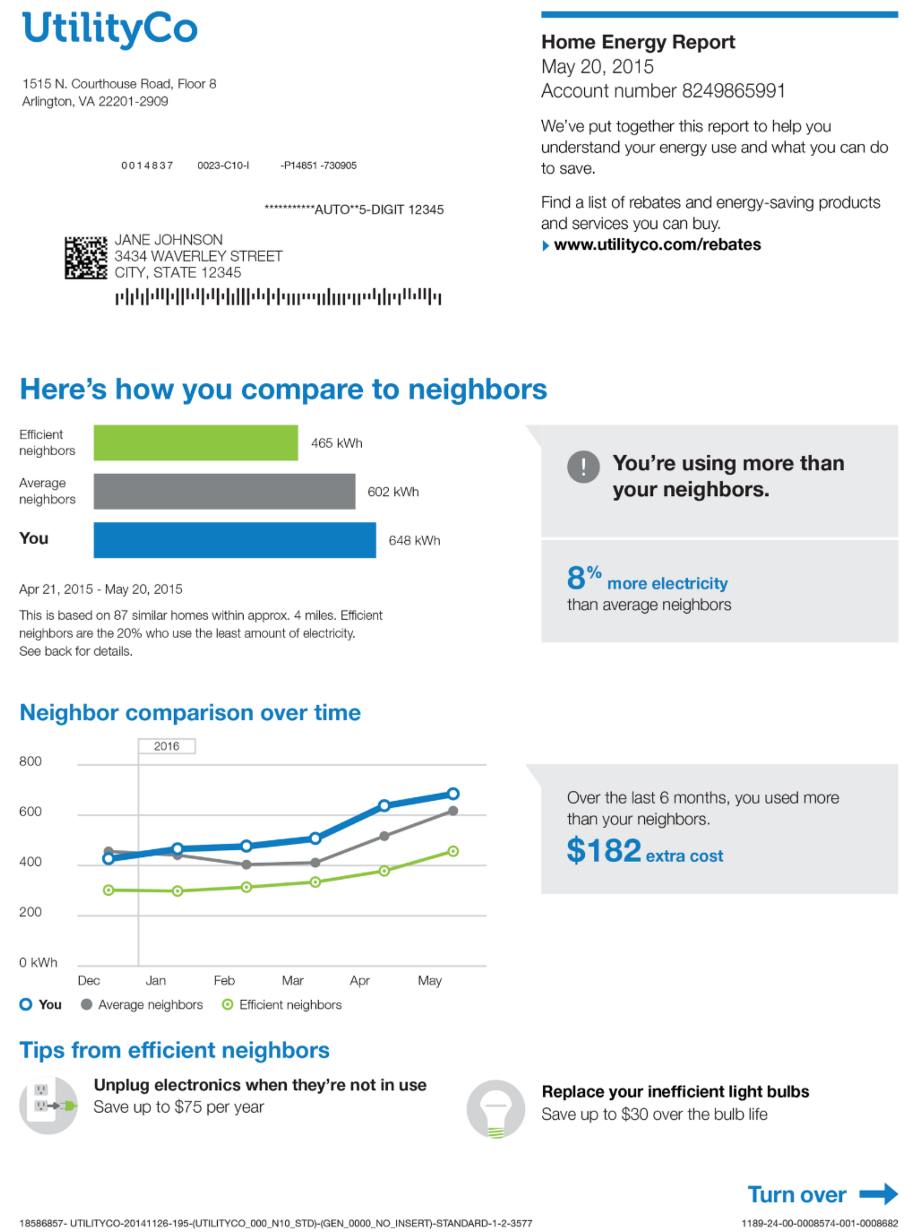


Results Roadmap

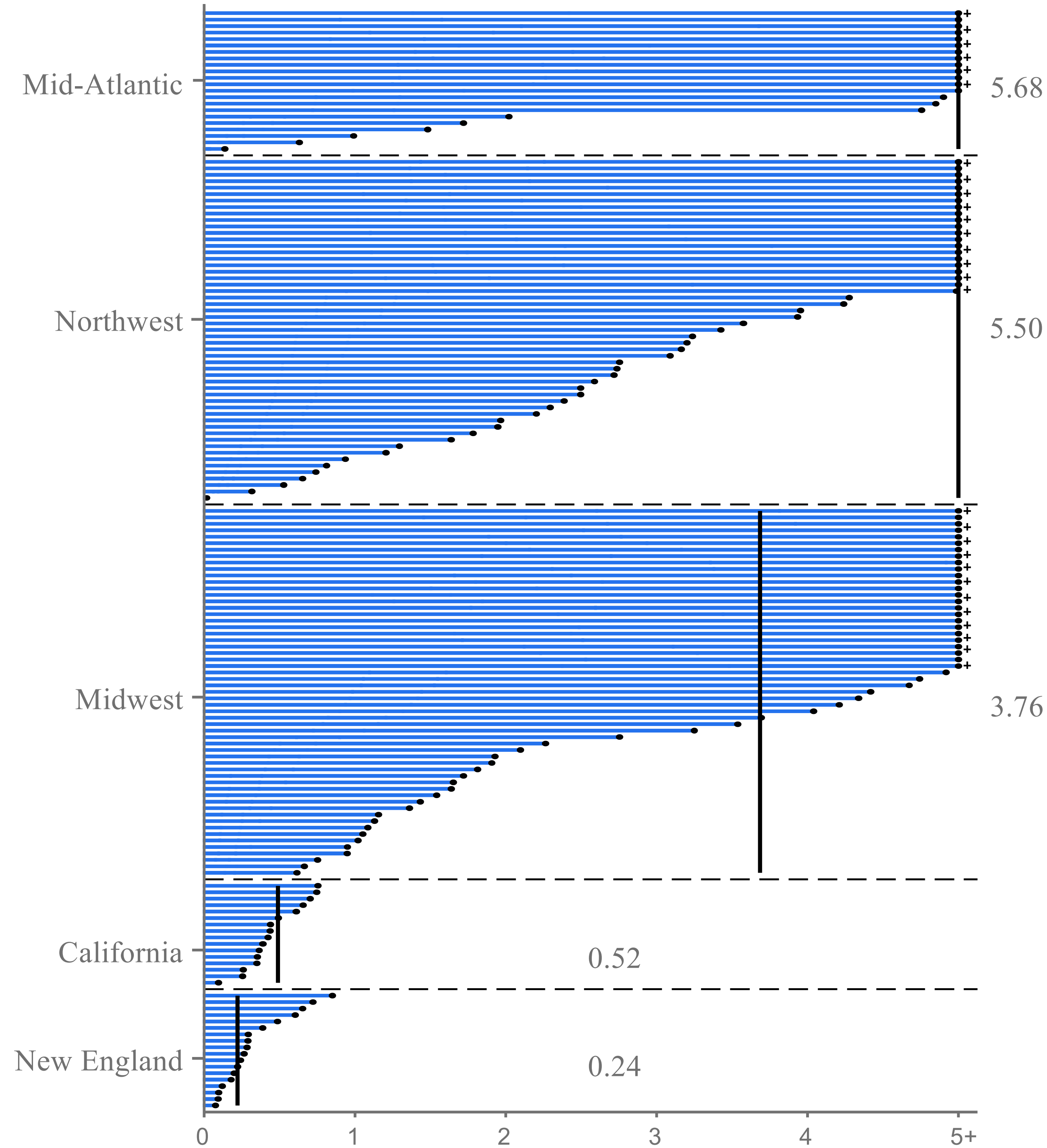
1. Subsidies
2. **Nudges**
3. Revenue Raisers
4. International Policies
5. Comparison to Cost per Ton Metrics

MVPFs of 243 RCTs of Home Energy Reports

- Consider Home Energy Reports (HERs) developed by Opower
- Focus on regional variation in MVPF due to differences in grid emissions



MVPFs of HERs by Region



With Savings

Results Roadmap

1. Subsidies
2. Nudges
3. **Revenue Raisers**
4. International Policies
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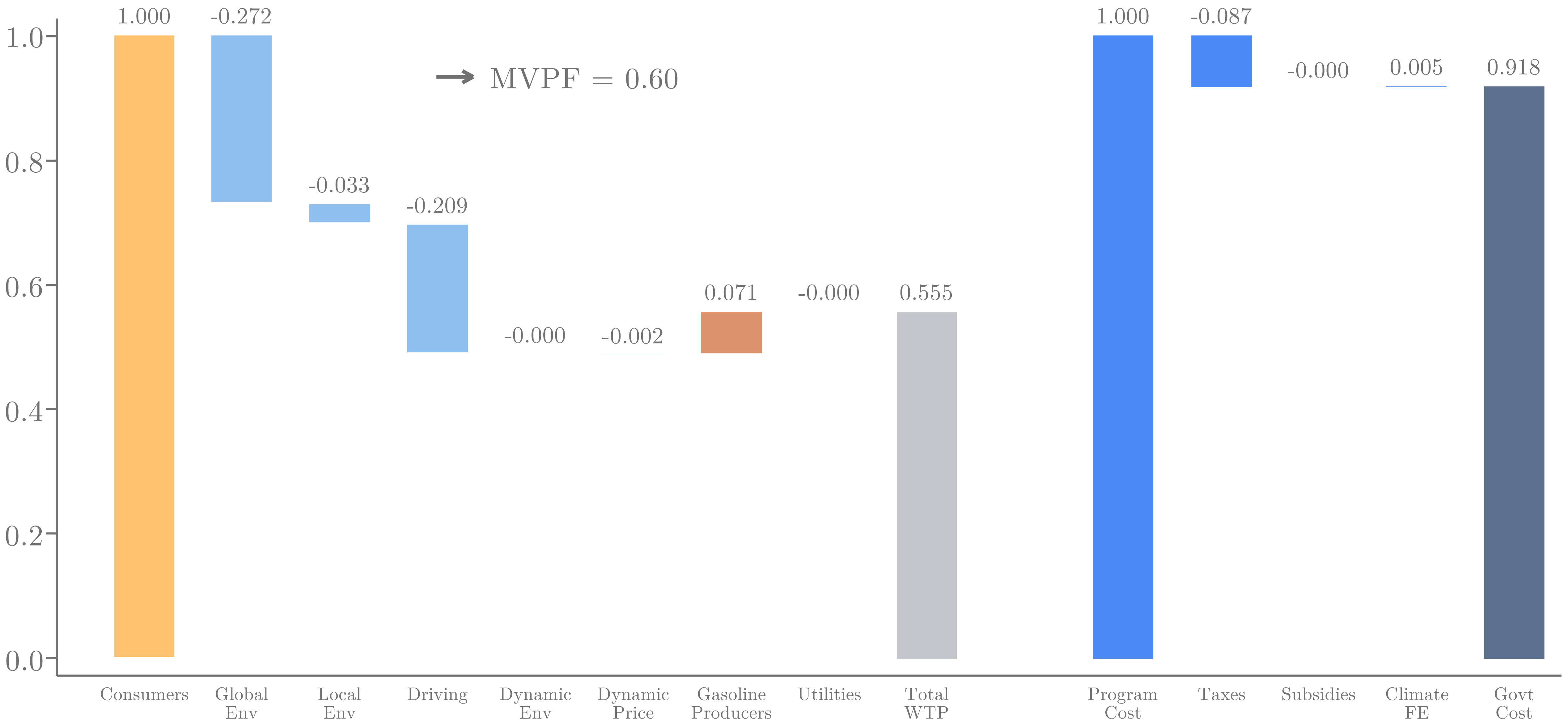
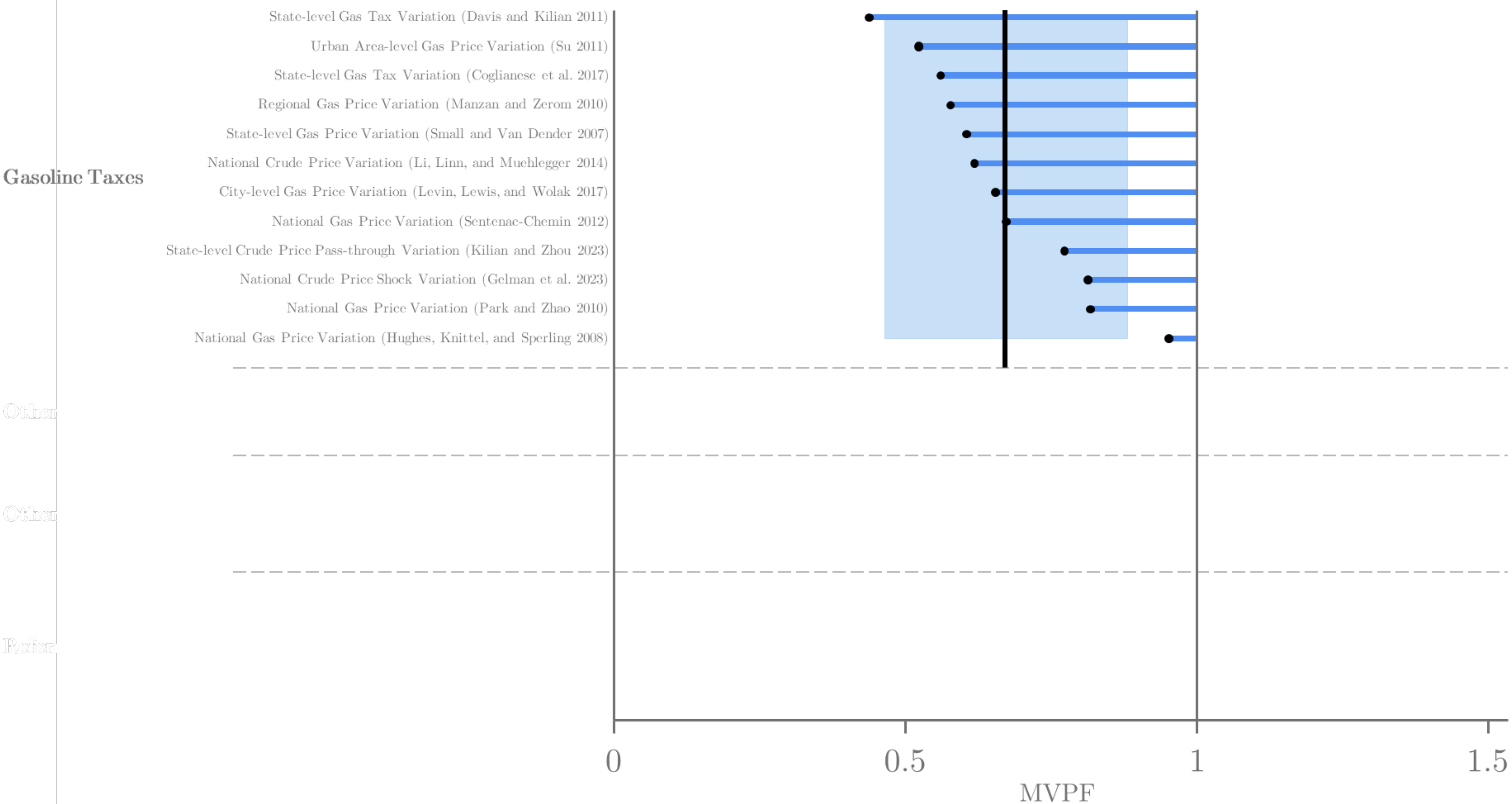
Gasoline Tax MVPF - Price Elasticity from Small and Van Dender (2007)



MVPFs of Revenue Raisers (National 2020)



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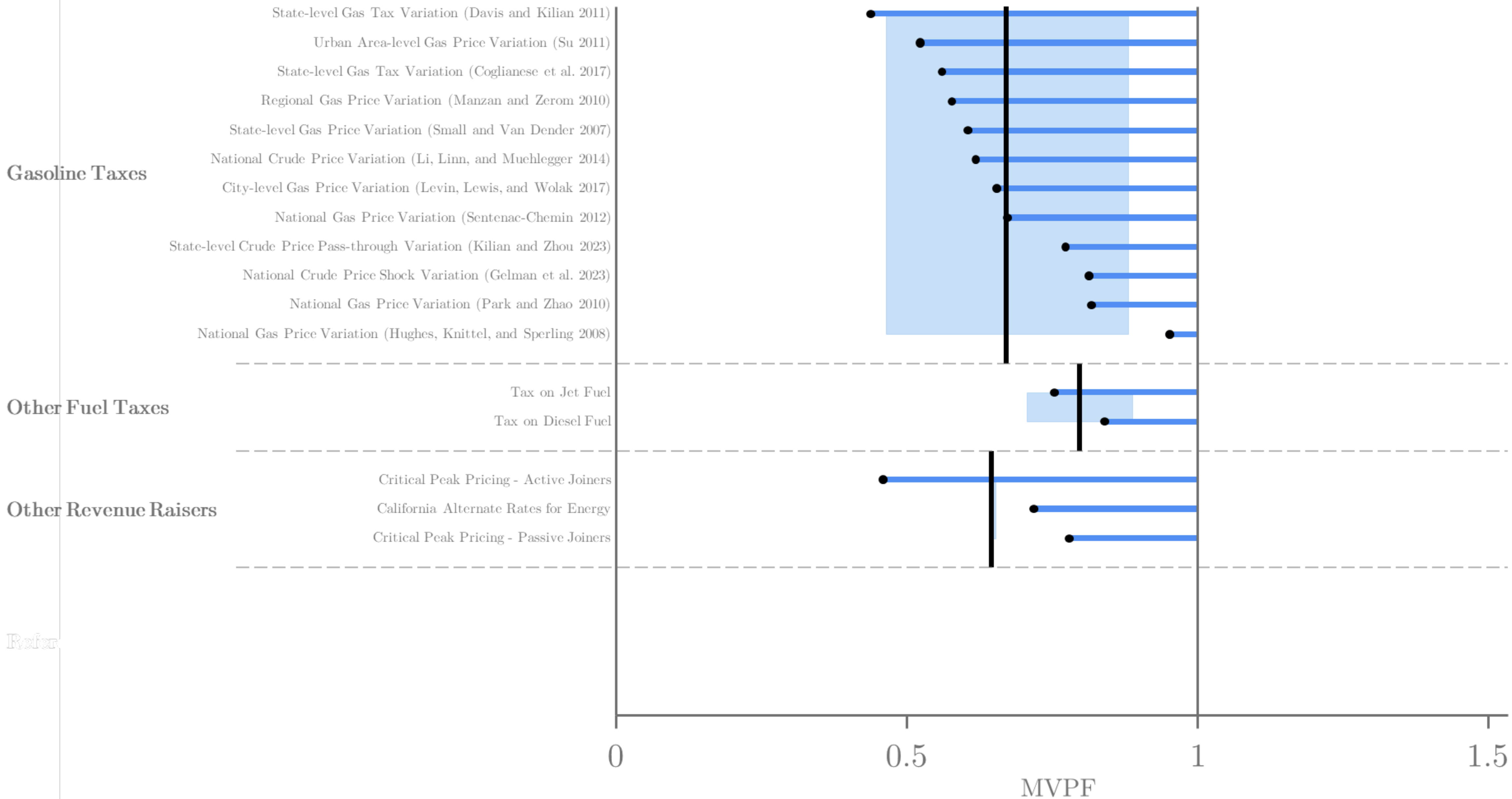

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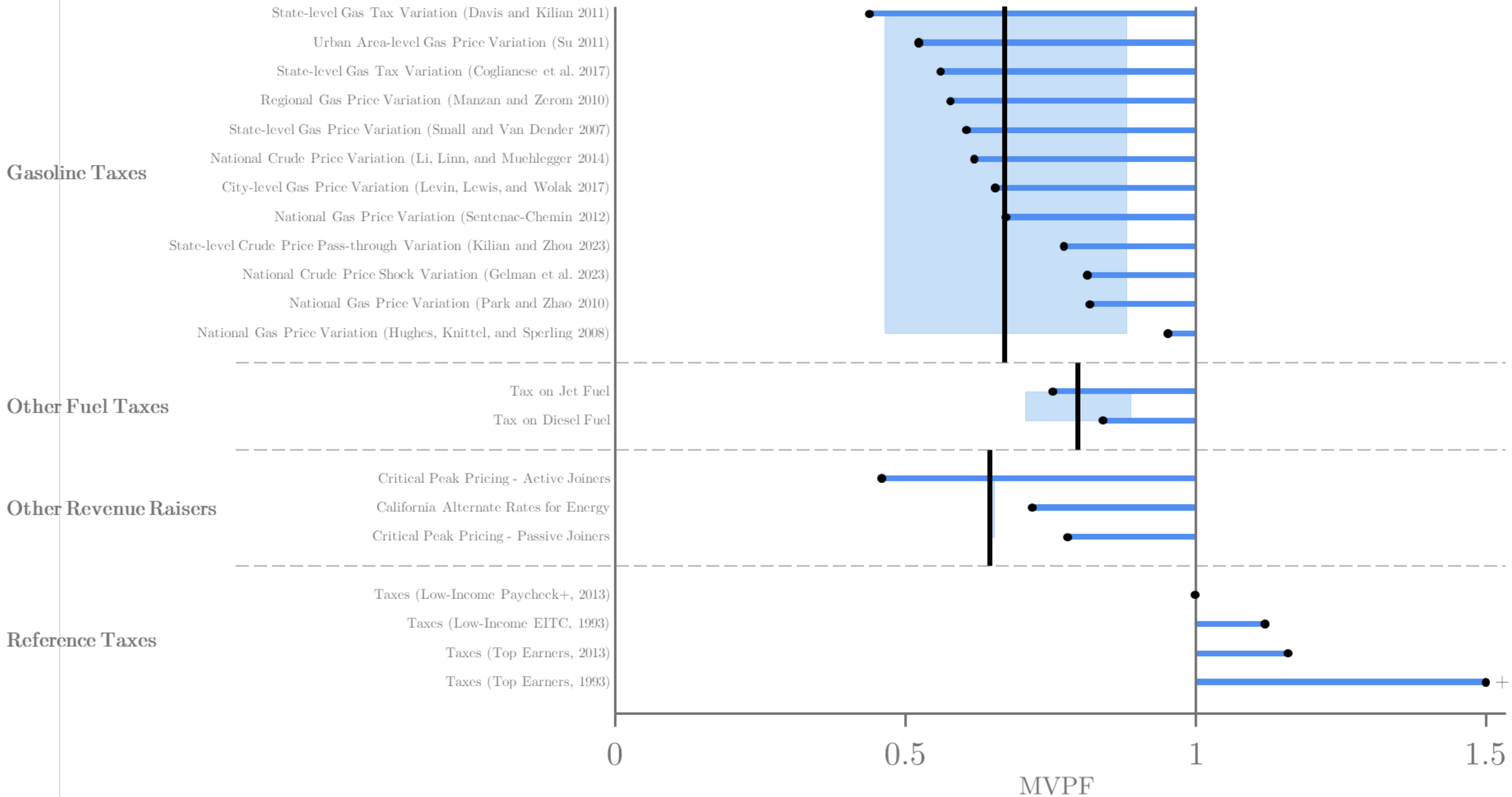

Implications for weighting and the double dividend

Weighting

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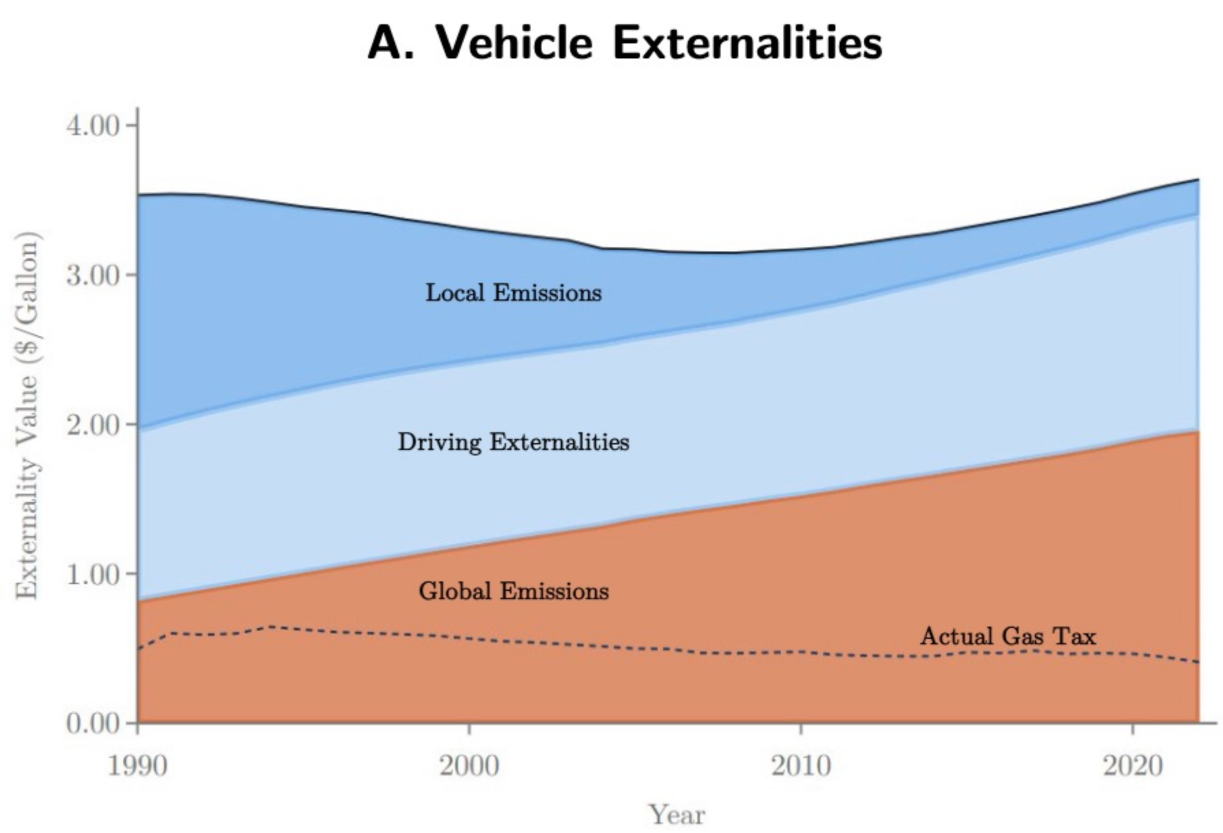

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- The Federal gas tax has not increased since 1993.
  - Ignore all the environmental effects of gasoline but only consider the effect of gas taxes on accidents and congestion, our estimates suggest an MVPF of 0.95 associated with the gas tax.
  - This is 14% lower than the MVPF around 1.1 typically observed for tax changes on low-income individuals (Hendren & Sprung-Keyser 2020).

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Double dividend

- Can tax pollution and can offset other non-distortionary taxes, although pollution taxes are smaller and more narrow

The MVPF of Cap and Trade

- Examine cap and trade policies in the context (time and place) where they were implemented.

- Consider the effect of a reduction in permits auctioned

$$MVPF = \frac{-x\frac{dp}{dx} + V(1-L)}{-x\frac{dp}{dx} - p}.$$

- First term: firms' WTP to avoid the increase in permit prices induced by a reduction in permit supply. This is offset by the environmental damages avoided, $V(1-L)$, due to a one-unit change in the number of permits auctioned.
- On the cost side, the government receives the mechanical revenue from the higher prices, $-xdp/dx > 0$, but also loses p in revenue from the forgone permit no longer auctioned.
- p does not appear in the numerator due to the envelope theorem: the marginal firm holding a permit has a marginal abatement cost equal to the permit price.

- Examine Regional Greenhouse Gas Initiative (RGGI). Find permit reductions raised revenue while also producing net benefits for individuals
  - Formally, the MVPF < 0 in this context

- Estimates align with those from the European Emission Trading System (ETS)

Results Roadmap

1. Subsidies
2. Nudges
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5. Comparison to Cost per Ton Metrics

Cookstoves in Kenya: Berkouwer and Dean (2022)

- Berkouwer and Dean (2022) study subsidies for “improved” cookstoves in Kenya
  - Paper finds each \$30 subsidy removes 7 tons of CO_2

FIGURE 1: THE KENYAN CERAMIC JIKO AND THE IMPROVED JIKOKOA

Two-thirds of Kenyan households still use a traditional stove as their primary cooking technology. Displayed here is the ‘Kenyan ceramic jiko’ (KCJ), a mid-tier charcoal cookstove (left). The Jikokoa (right) is a modern charcoal cookstove sold in East Africa produced by Burn Manufacturing.

Source: Burn Manufacturing (2021)

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  - "US-only" MVPF of 4.91; Global MVPF of 50

International MVPFs International MVPFs – US Only

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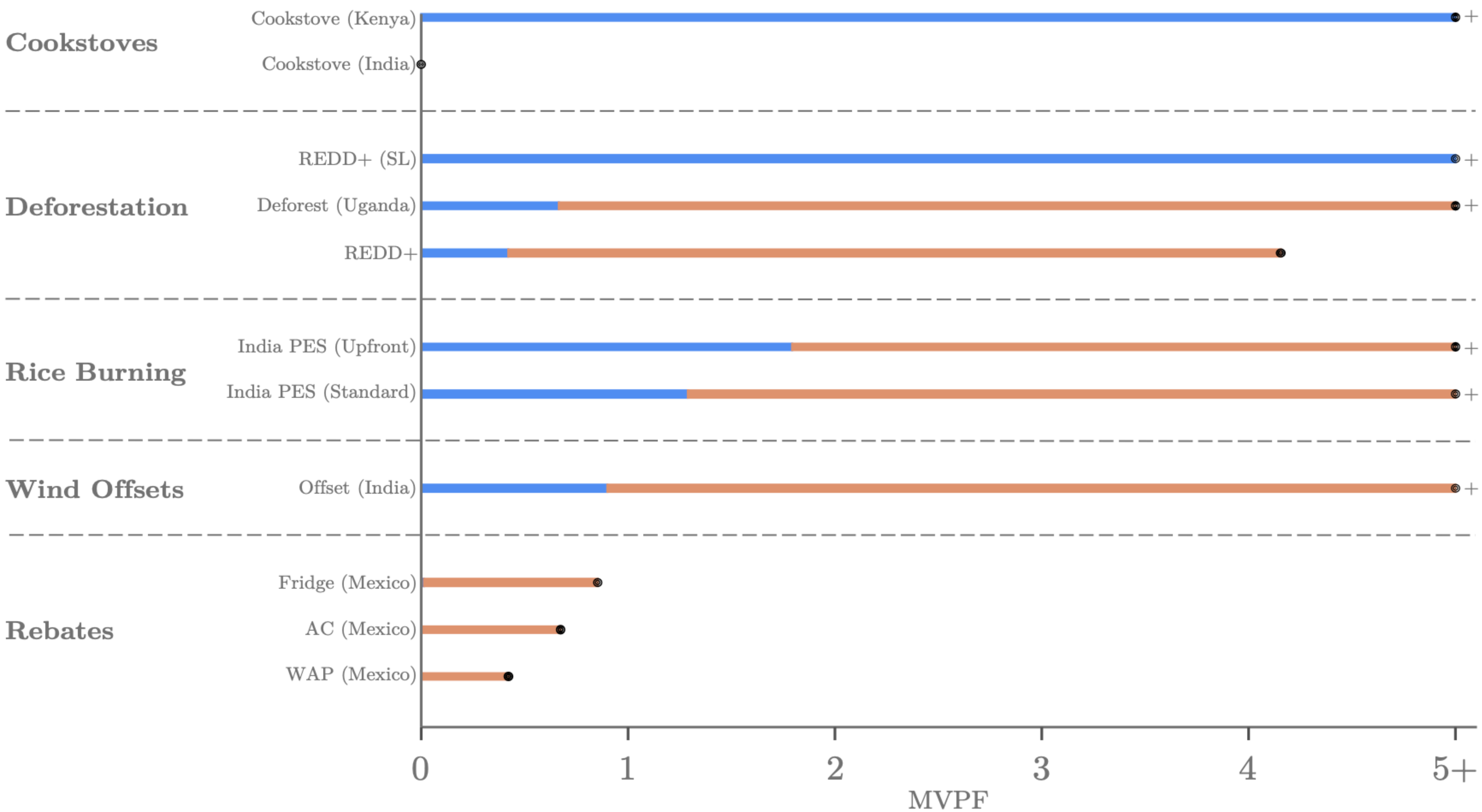
- However, large variation in estimates of the effect of cookstoves and other international subsidies

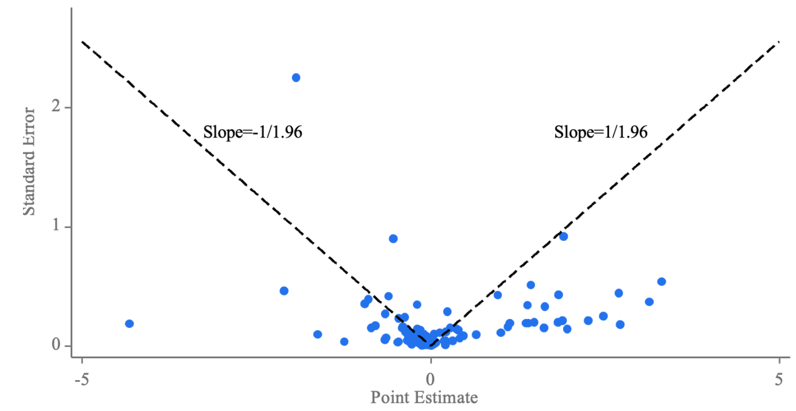
International MVPFs International MVPFs – US Only

FIGURE 8: Baseline MVPFs of International Policies



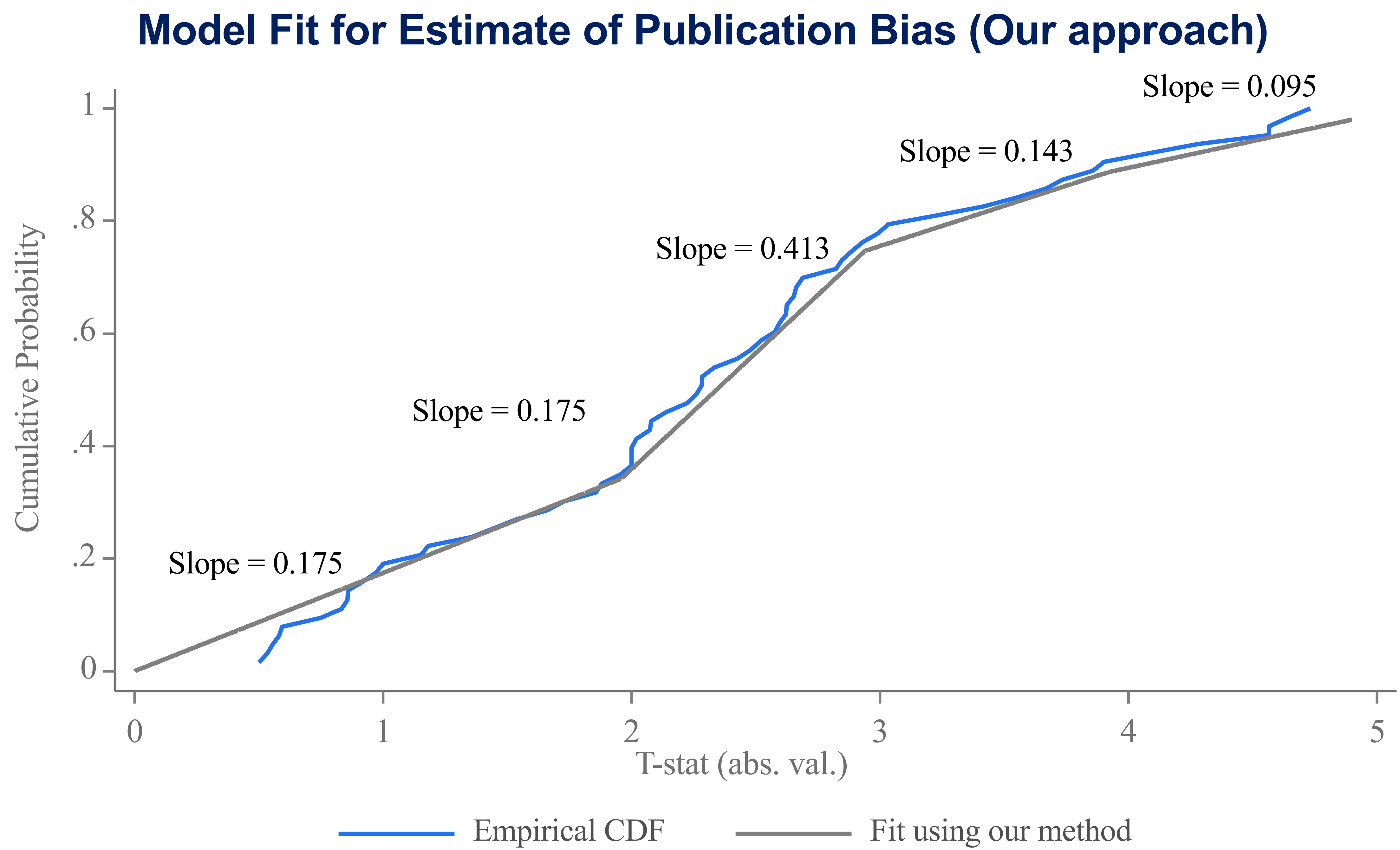
Additional Analyses in the Paper

- **Distributional Incidence**
  - Excluding non-US benefits → MVPFs near 1 for most US-based subsidies
  - Subsidies and taxes disproportionately affect the rich

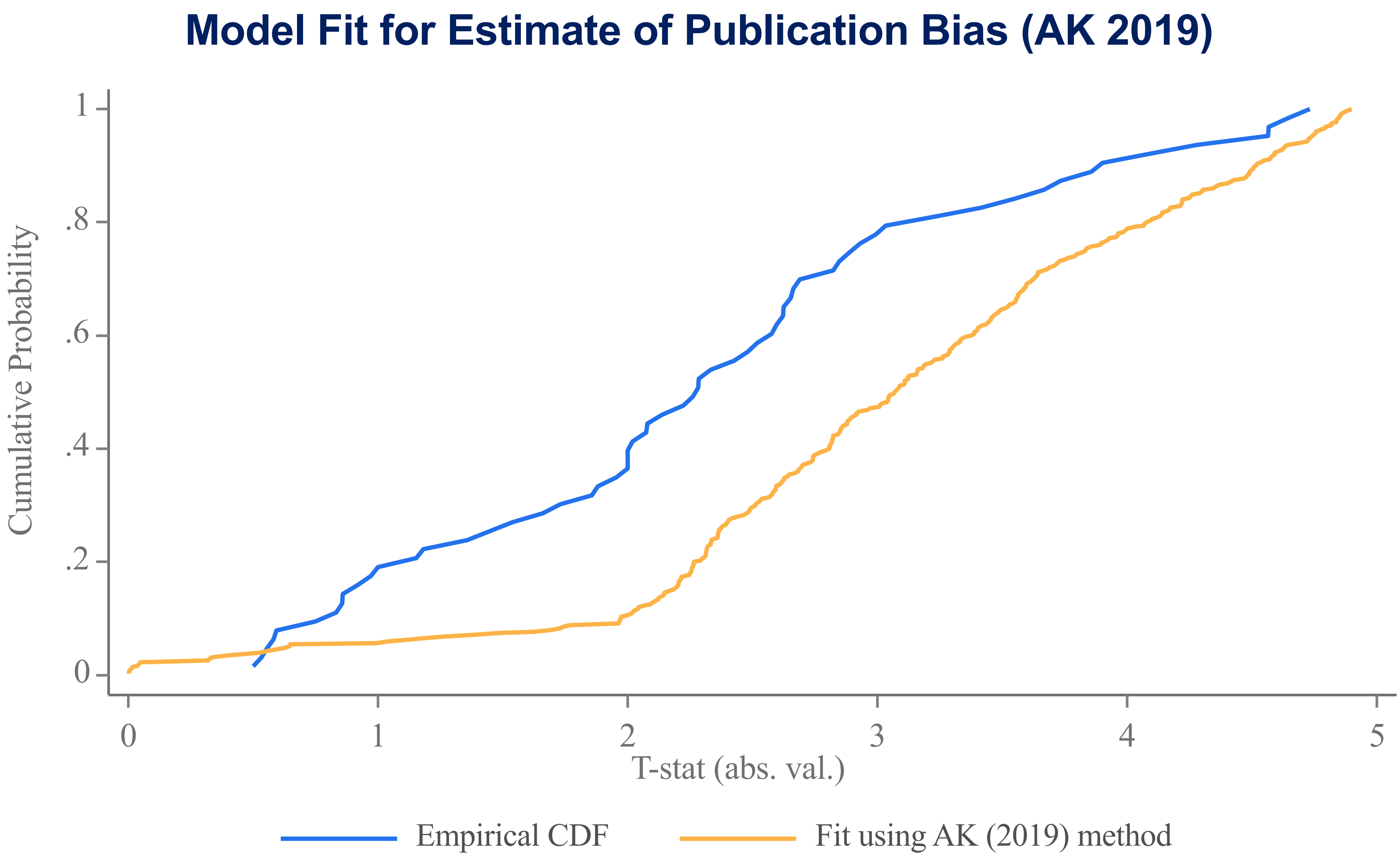


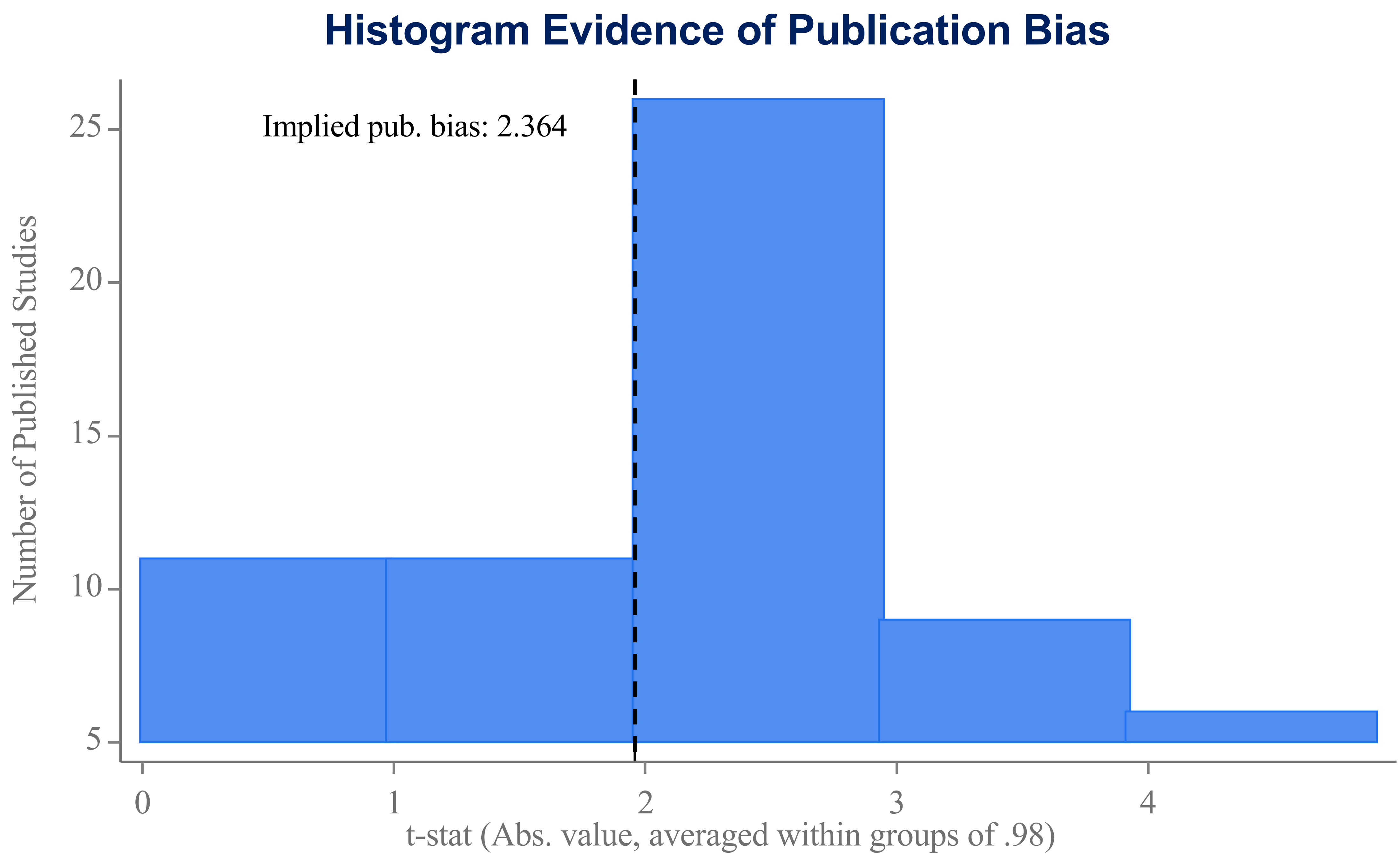
- **Publication Bias**
  - Papers with t-stats > 1.96 are 2X more likely to be published
  - Adjusting for this using Andrews and Kasy (2019) does not meaningfully affect conclusions

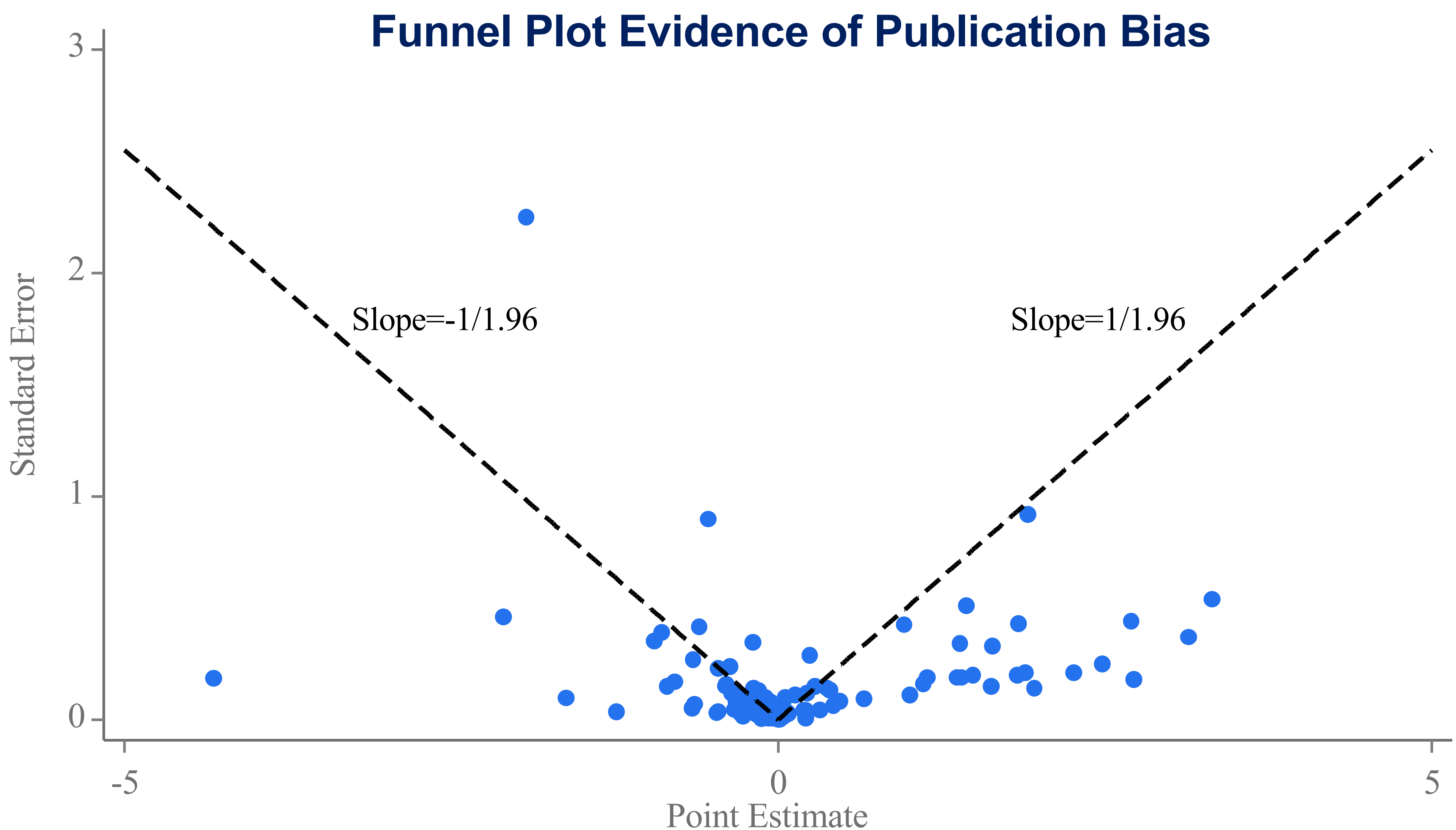
- **Non-Marginal analysis**
  - Evaluate how MVPF varies for 1st vs. last dollar of subsidy/tax and consider non-marginal policy changes corresponding to EV, Residential Solar and Wind policies under the IRA
  - Relative orderings and broad magnitudes remain unchanged



Model Fit for Estimate of Publication Bias (Our approach)
Slope = 0.095
Slope = 0.143
Slope = 0.413
Slope = 0.175
Slope = 0.175
Cumulative Probability
1
.8
.6
.4
.2
0
0
1
2
3
4
5
T-stat (abs. val.)
Empirical CDF
Fit using our method


Model Fit for Estimate of Publication Bias (AK 2019)
Cumulative Probability
0
.2
.4
.6
.8
1
0
1
2
3
4
5
T-stat (abs. val.)
Empirical CDF
Fit using AK (2019) method

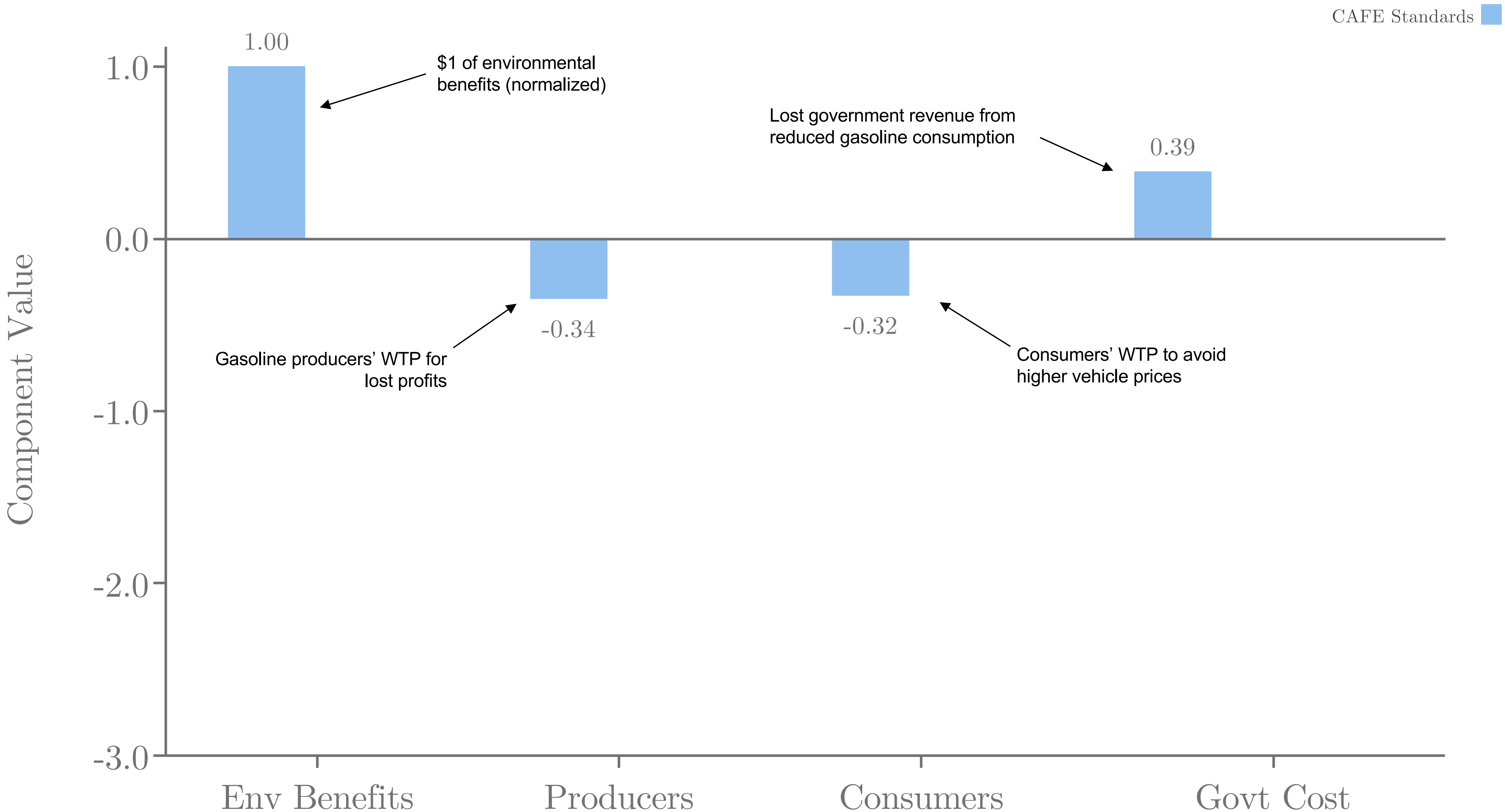

Histogram Evidence of Publication Bias
Implied pub. bias: 2.364
Number of Published Studies
t-stat (Abs. value, averaged within groups of .98)
5
10
15
20
25
0
1
2
3
4



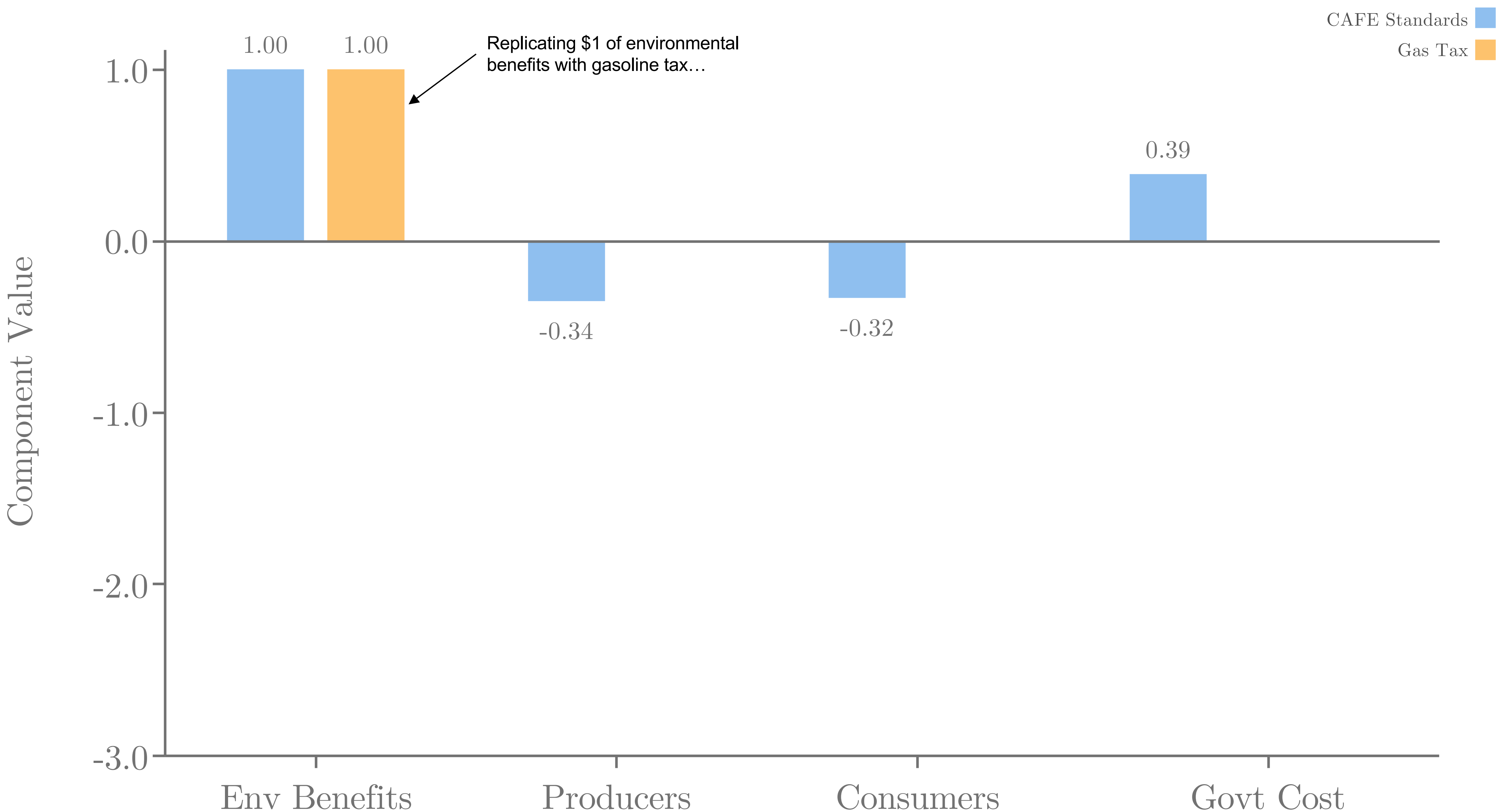
Funnel Plot Evidence of Publication Bias
Standard Error
Point Estimate
Slope=-1/1.96
Slope=1/1.96
3
2
1
0
-5
0
5

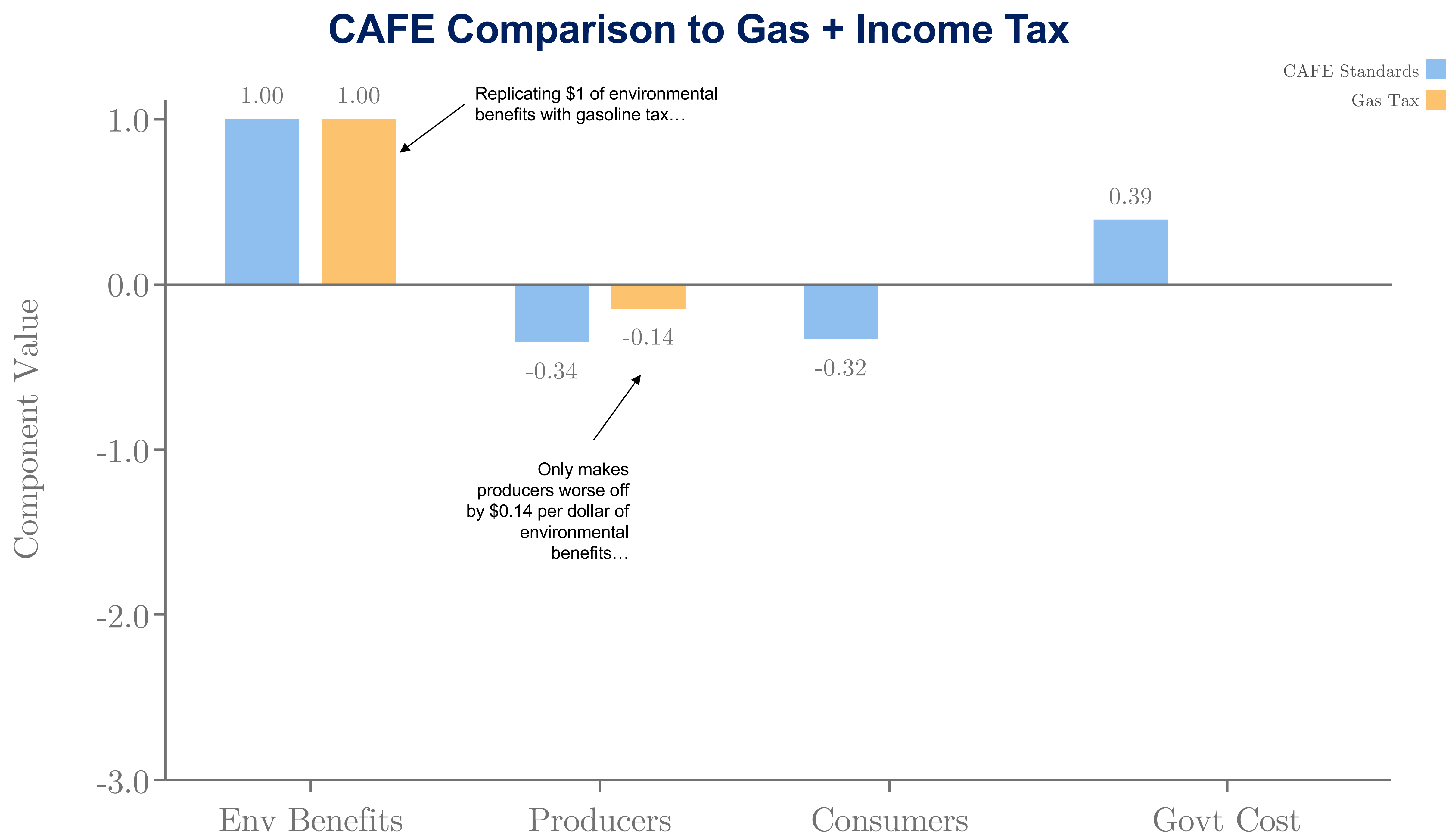
Regulation

CAFE Comparison to Gas + Income Tax (Leard and McConnell 2017)

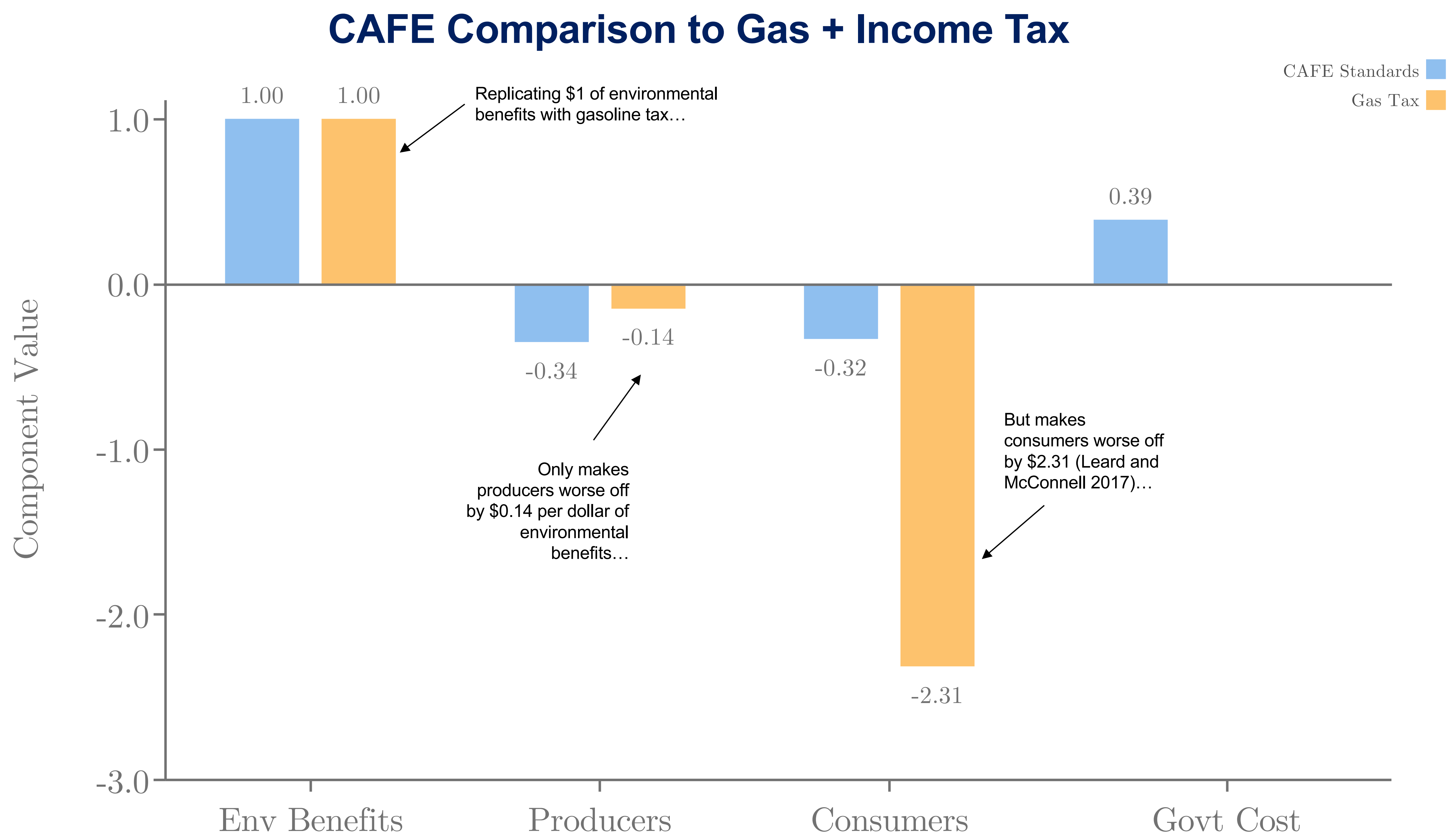


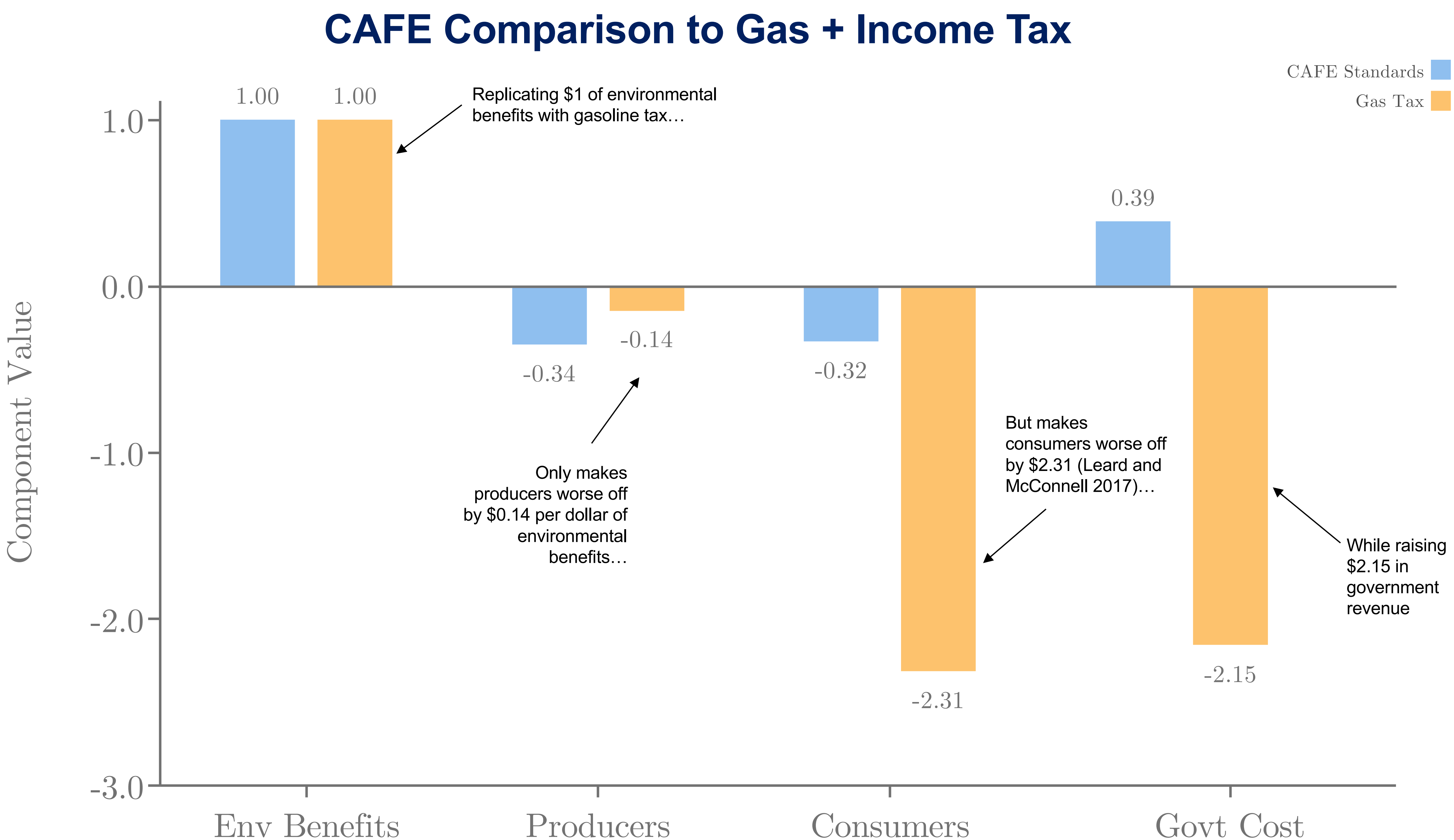
CAFE Comparison to Gas + Income Tax

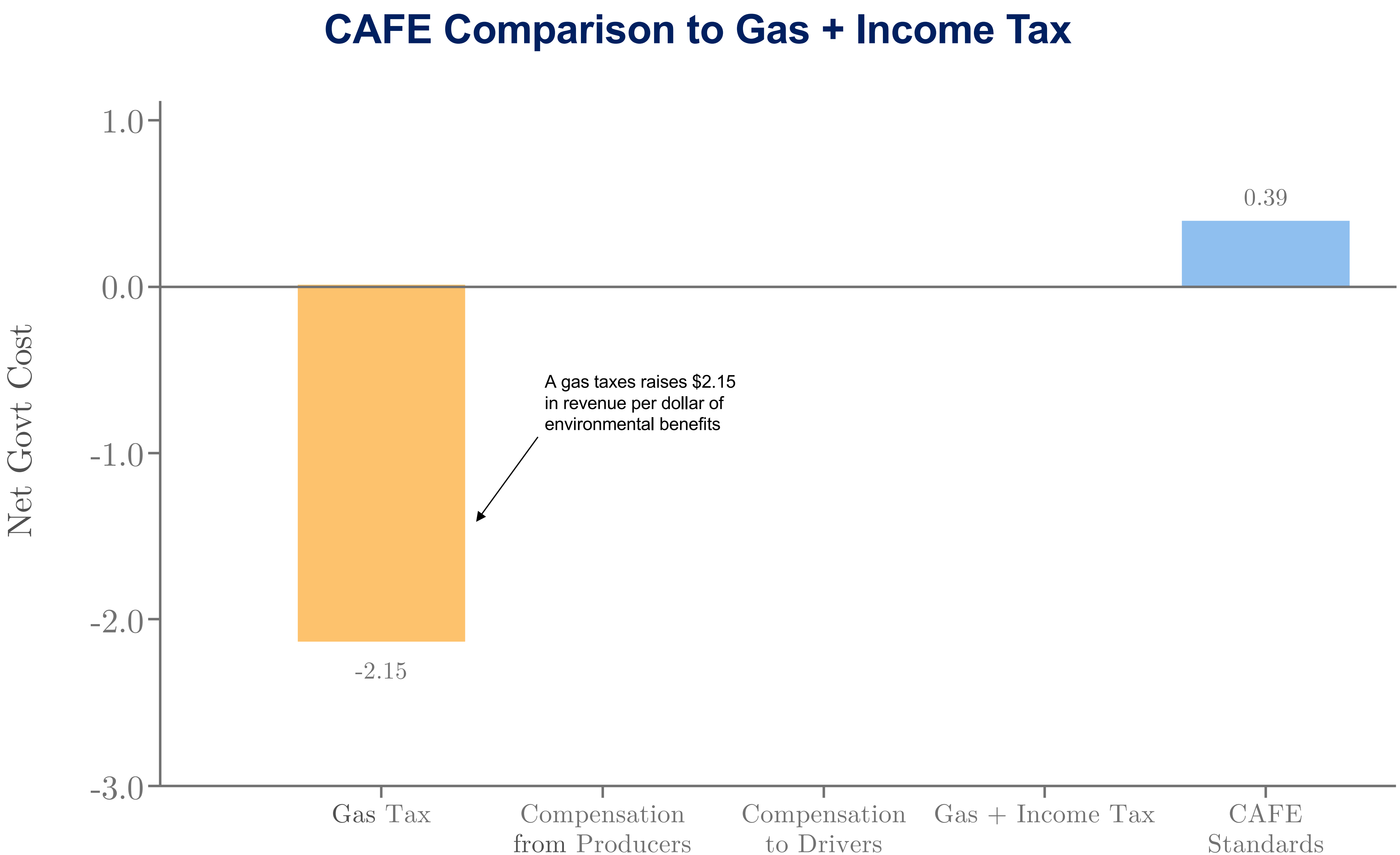




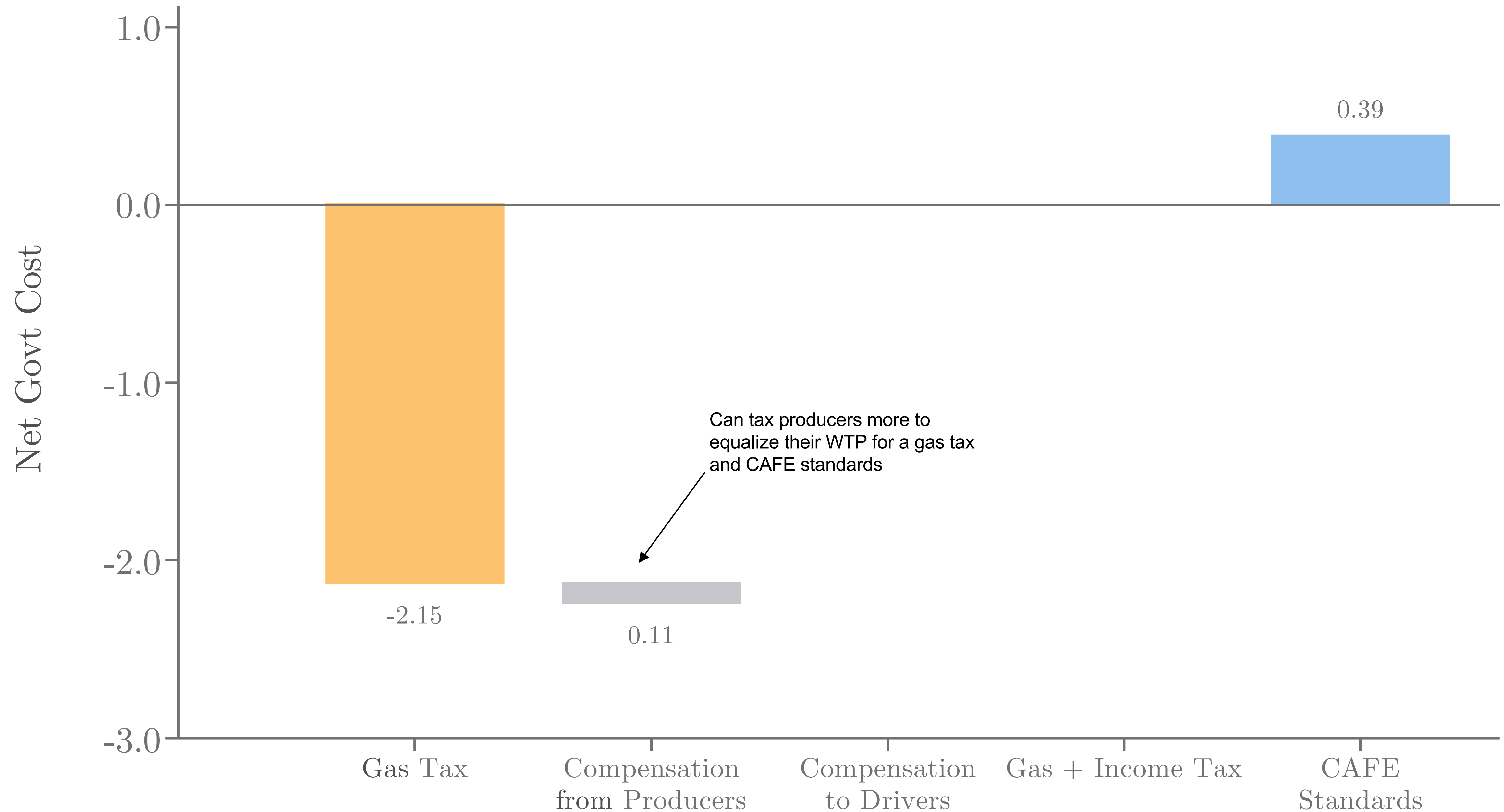
CAFE Comparison to Gas + Income Tax
CAFE Standards
Gas Tax
1.00
1.00
Replicating $1 of environmental benefits with gasoline tax…
0.39
-0.34
-0.14
-0.32
Only makes producers worse off by $0.14 per dollar of environmental benefits…
Component Value
1.0
0.0
-1.0
-2.0
-3.0
Env Benefits
Producers
Consumers
Govt Cost

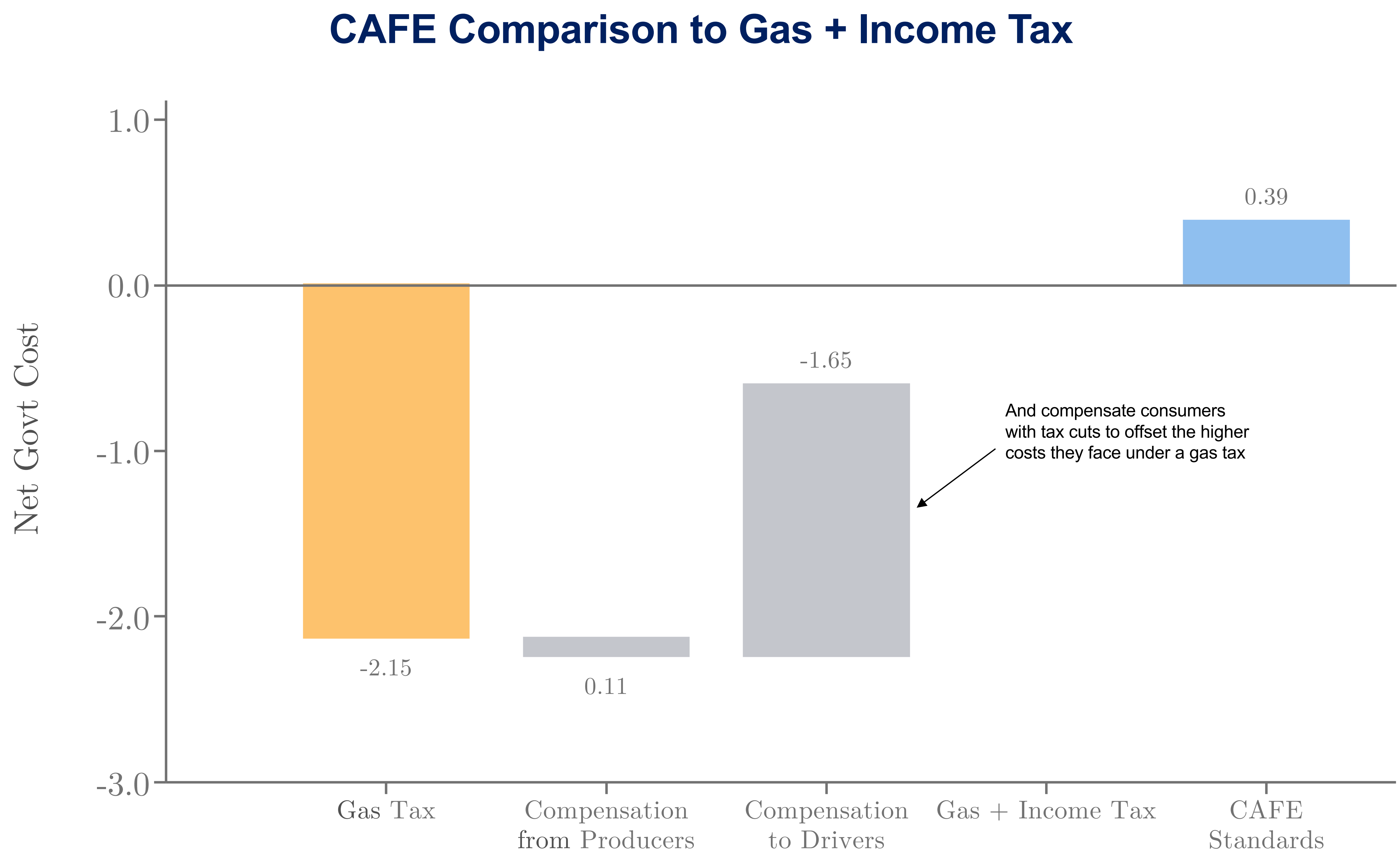

CAFE Comparison to Gas + Income Tax
CAFE Standards
Gas Tax
Component Value
1.0
0.0
-1.0
-2.0
-3.0
1.00
1.00
Replicating $1 of environmental benefits with gasoline tax…
-0.34
-0.14
-0.32
-2.31
0.39
Only makes producers worse off by $0.14 per dollar of environmental benefits…
But makes consumers worse off by $2.31 (Leard and McConnell 2017)…
Env Benefits
Producers
Consumers
Govt Cost


CAFE Comparison to Gas + Income Tax
CAFE Standards
Gas Tax
Component Value
1.0
0.0
-1.0
-2.0
-3.0
1.00
1.00
-0.34
-0.14
-0.32
-2.31
0.39
-2.15
Replicating $1 of environmental benefits with gasoline tax…
Only makes producers worse off by $0.14 per dollar of environmental benefits…
But makes consumers worse off by $2.31 (Leard and McConnell 2017)…
While raising $2.15 in government revenue
Env Benefits
Producers
Consumers
Govt Cost

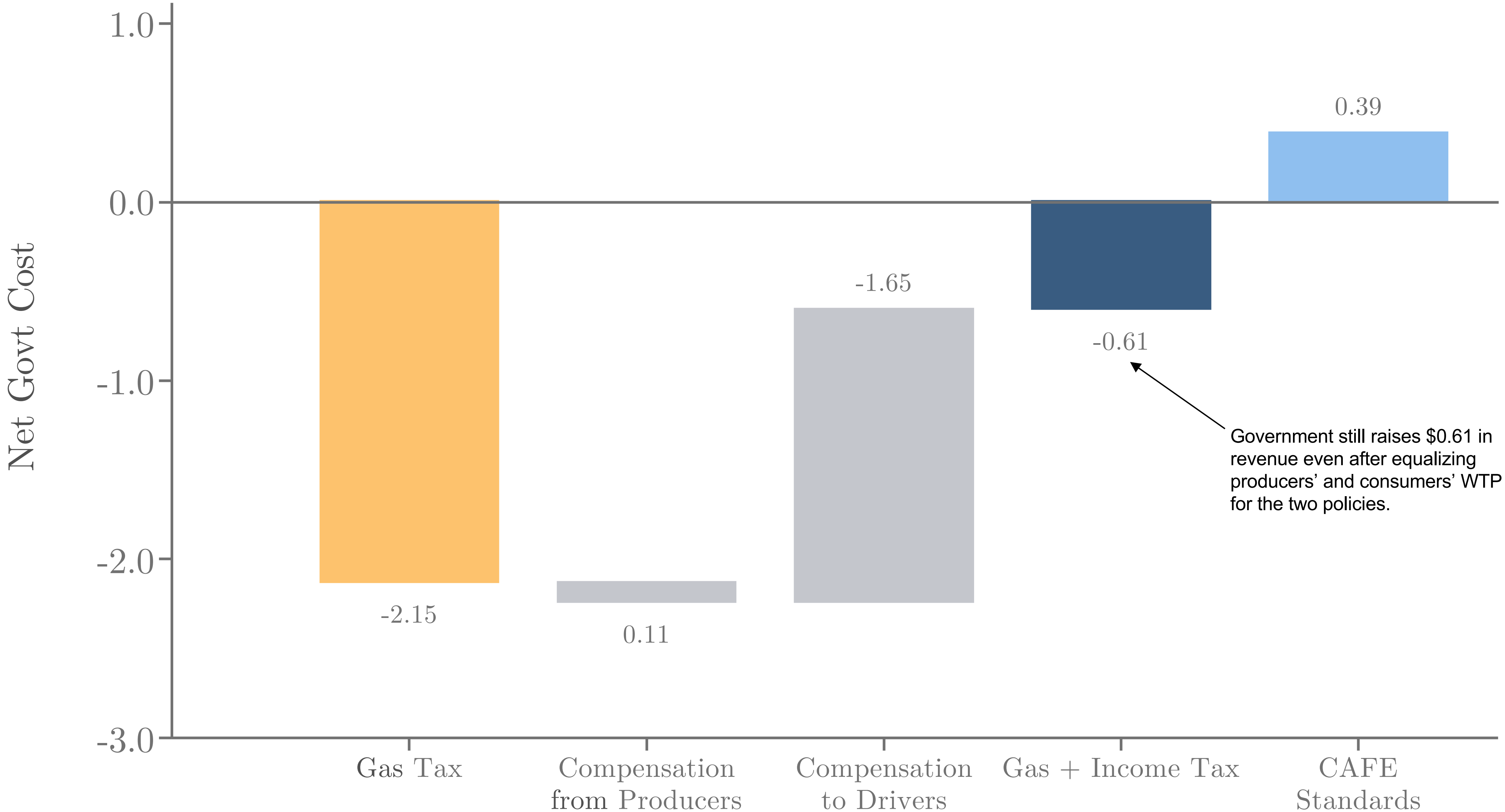

CAFE Comparison to Gas + Income Tax
Net Govt Cost
1.0
0.0
-1.0
-2.0
-3.0
0.39
-2.15
A gas taxes raises $2.15 in revenue per dollar of environmental benefits
Gas Tax
Compensation from Producers
Compensation to Drivers
Gas + Income Tax
CAFE Standards

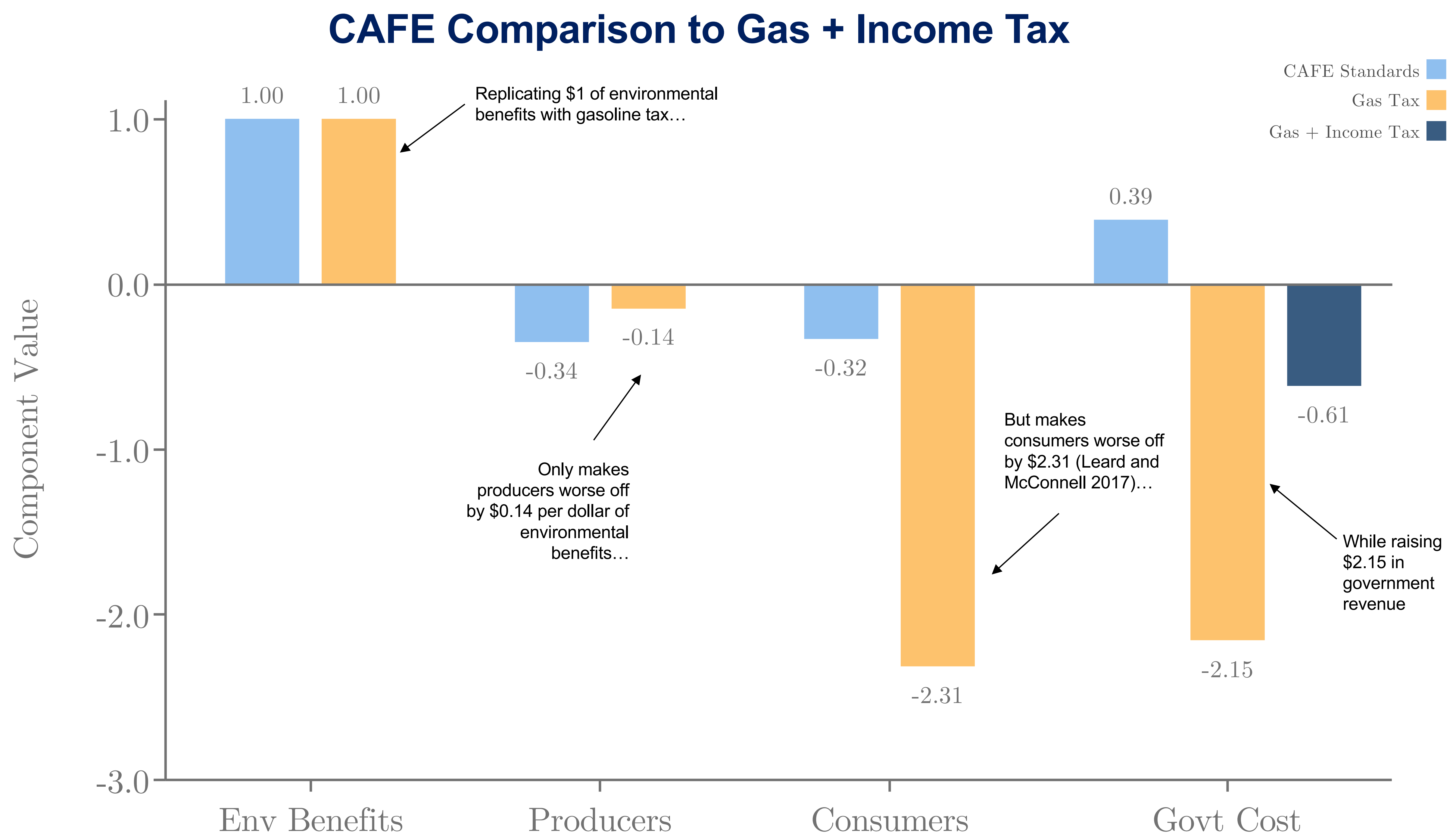
CAFE Comparison to Gas + Income Tax




CAFE Comparison to Gas + Income Tax
Net Govt Cost
1.0
0.0
-1.0
-2.0
-3.0
-2.15
0.11
-1.65
0.39
And compensate consumers with tax cuts to offset the higher costs they face under a gas tax
Gas Tax
Compensation from Producers
Compensation to Drivers
Gas + Income Tax
CAFE Standards

CAFE Comparison to Gas + Income Tax




CAFE Comparison to Gas + Income Tax
CAFE Standards
Gas Tax
Gas + Income Tax
Component Value
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0.0
-1.0
-2.0
-3.0
1.00
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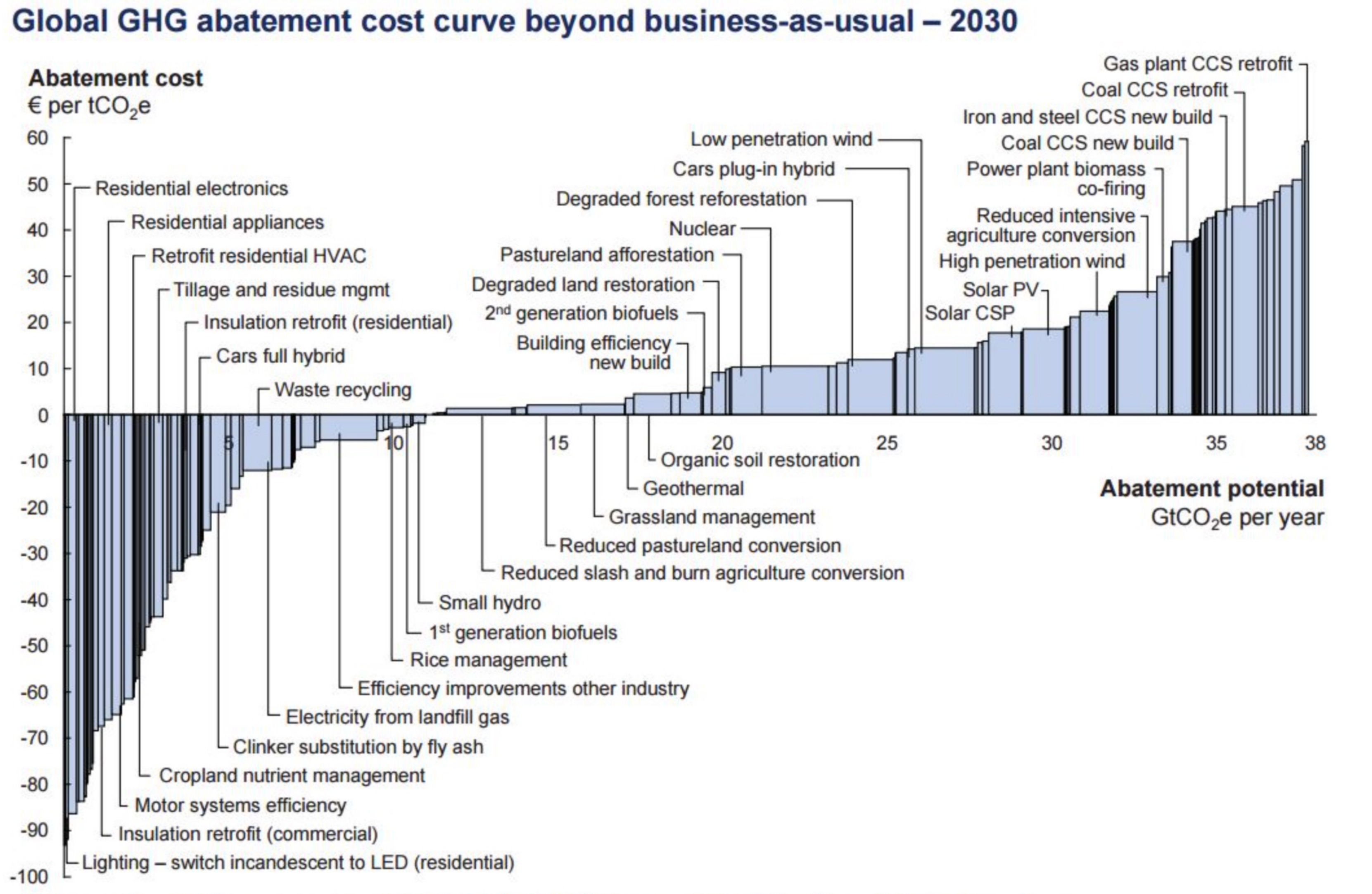
5. **Comparison to Cost per Ton Metrics**

Cost Per Ton Metrics

Resource Cost Per Ton

- Measure public and private resource expenditures

- Focuses on products rather than policies
- Omits cost to government of inframarginal transfers



Note: The curve presents an estimate of the maximum potential of all technical GHG abatement measures below €60 per tCO_2e if each lever was pursued aggressively. It is not a forecast of what role different abatement measures and technologies will play.
Source: Global GHG Abatement Cost Curve v2.0

Source: McKinsey (2007)

Cost Per Ton Metrics

Resource Cost Per Ton

- Measure public and private resource expenditures

- Focuses on products rather than policies
- Omits cost to government of inframarginal transfers

Government Cost Per Ton

- Focus on government cost (inclusive of FE)

- Includes costs but ignores benefits of inframarginal transfers
- Omitted benefits prevent SCC comparison

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Government Cost Per Ton

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Social Cost Per Ton

- Social cost = government cost – private benefits – non-CO_2 social benefits

- Ignores opportunity cost of inframarginal transfers
- Independent of policy take-up (just like resource costs per ton)

Example

MVPF Versus Cost Per Ton

	MVPF	Cost Per Ton		
		Resource	Government	Social
Subsidies				
Wind Production Credits	5.870	-103	46	-32
Residential Solar	3.862	-77	90	-67
Electric Vehicles	1.445	-458	1,356	-415
Appliance Rebates	1.164	-2	474	111
Vehicle Retirement	1.047	987	876	148
Hybrid Vehicles	1.012	577	5,892	-38
Weatherization	0.978	194	779	207
Nudges and Marketing				
Opower Elec. (166 RCTs)	2.548	-41	77	70
Revenue Raisers				
Gasoline Taxes	0.671	-104	-770	-64

No LBD MCF

MVPF Versus Cost Per Ton

	MVPF	Cost Per Ton		
		Resource	Government	Social
Subsidies				
Wind Production Credits	5.870	-103	46	-32
Residential Solar	3.862	-77	90	-67
Electric Vehicles	1.445	-458	1,356	-415
Appliance Rebates	1.164	-2	474	111
Vehicle Retirement	1.047	987	876	148
Hybrid Vehicles	1.012	577	5,892	-38
Weatherization	0.978	194	779	207
Nudges and Marketing				
Opower Elec. (166 RCTs)	2.548	-41	77	70
Revenue Raisers				
Gasoline Taxes	0.671	-104	-770	-64

No LBD MCF

MVPF Versus Cost Per Ton

	MVPF	Cost Per Ton		
		Resource	Government	Social
Subsidies				
Wind Production Credits	5.870	-103	46	-32
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Gasoline Taxes	0.671	-104	-770	-64

No LBD MCF

Conclusion

1. Investments that directly displace dirty electricity production have highest MVPFs (5+ for wind PTCs; 3-4 for residential solar; 1.5 for EVs; others ~1)

2. Nudges to reduce electricity use have high MVPFs (3+) in places with dirty grids, but lower (<1) in clean grid areas (e.g. CA and Northeast)

3. Taxes on polluting goods (e.g., gas taxes) are relatively efficient (MVPFs < 0.7)

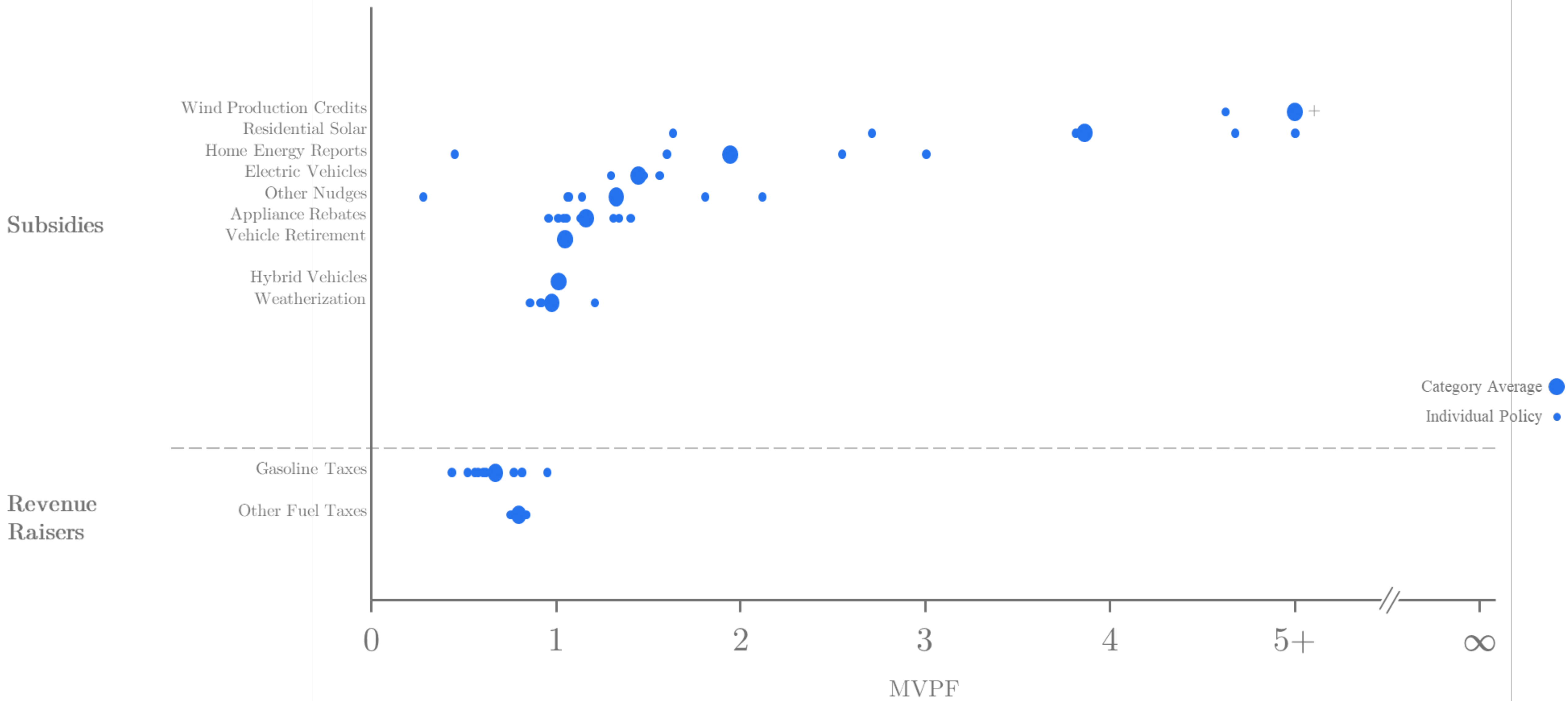
4. Spending on international policies can deliver the largest MVPFs in our sample, even considering only US-benefits and costs

5. Common cost per ton metrics do not fully capture these lessons and often yield different rankings across definitions

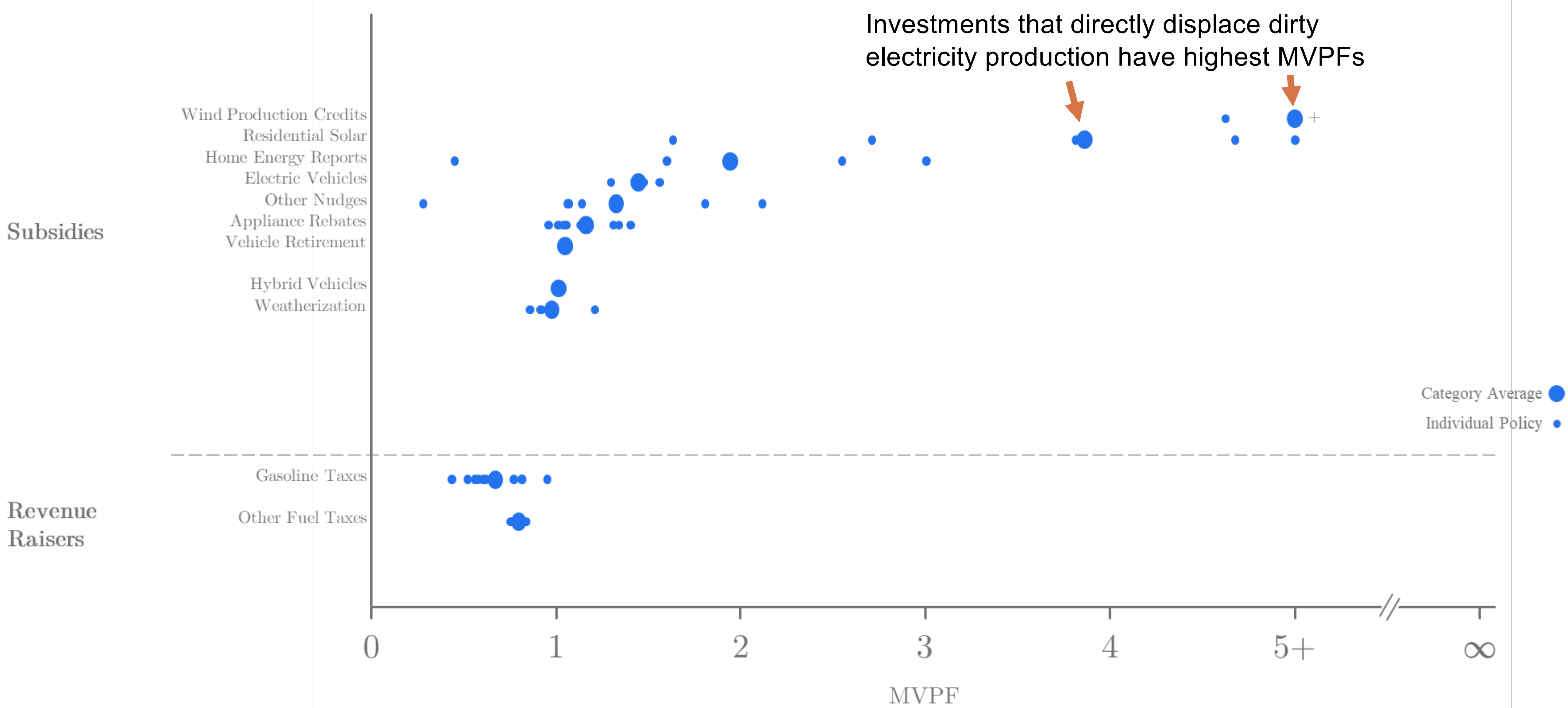
Why does this all matter?

	ARRA Spending (2022 Prices)	IRA Spending			MVPF (Our Estimates)
		CBO Estimate	Goldman Sachs	Penn Wharton Model	
Clean Energy	$67.9bn	$192bn	$274bn	$263bn	Wind – 5.87 Solar – 3.86
EVs	$8.3bn	$14bn	$393bn	$393bn	1.3
Energy Efficiency	$23.0bn	$2bn	$44bn	$28bn	~1

MVPFs of Environmental Policies Versus Other Policy Categories



MVPFs of Environmental Policies Versus Other Policy Categories



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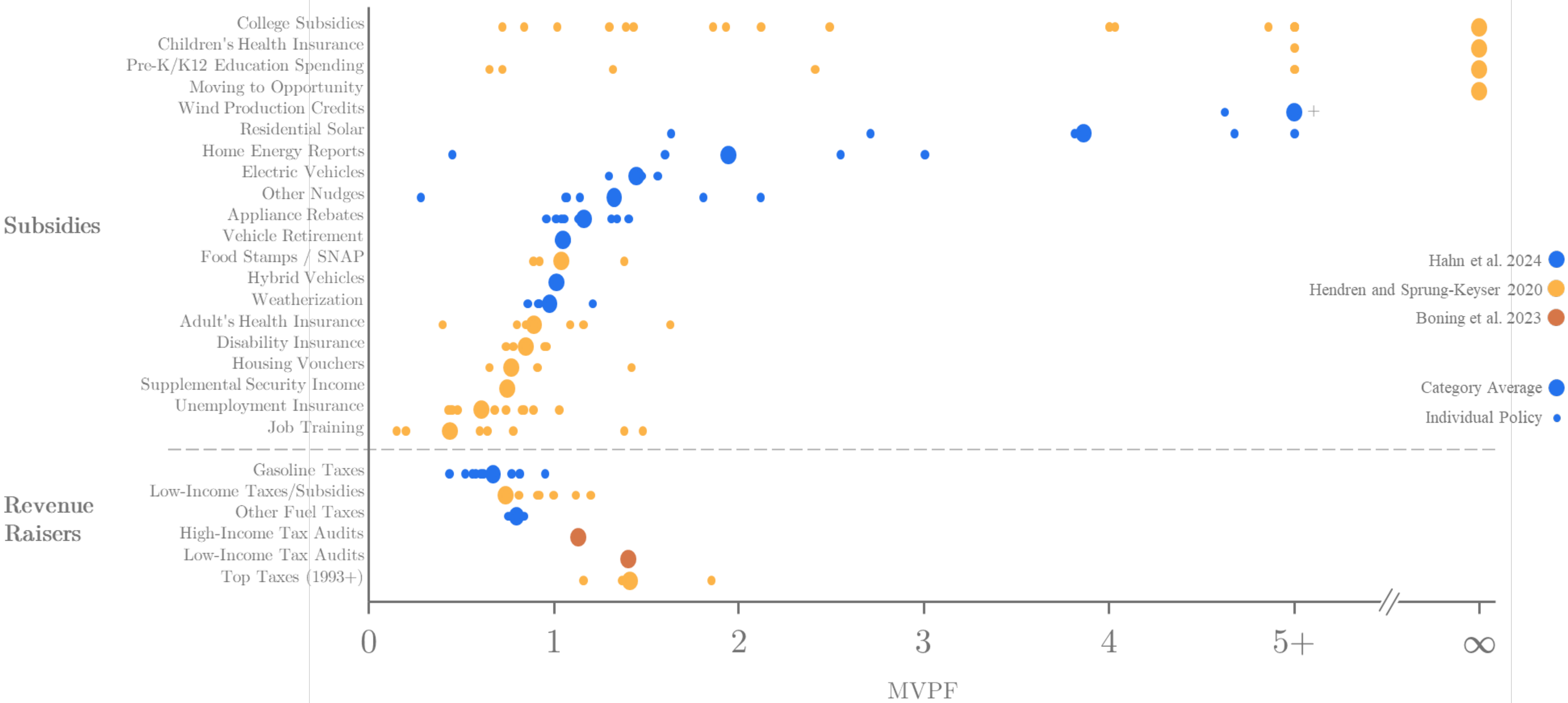

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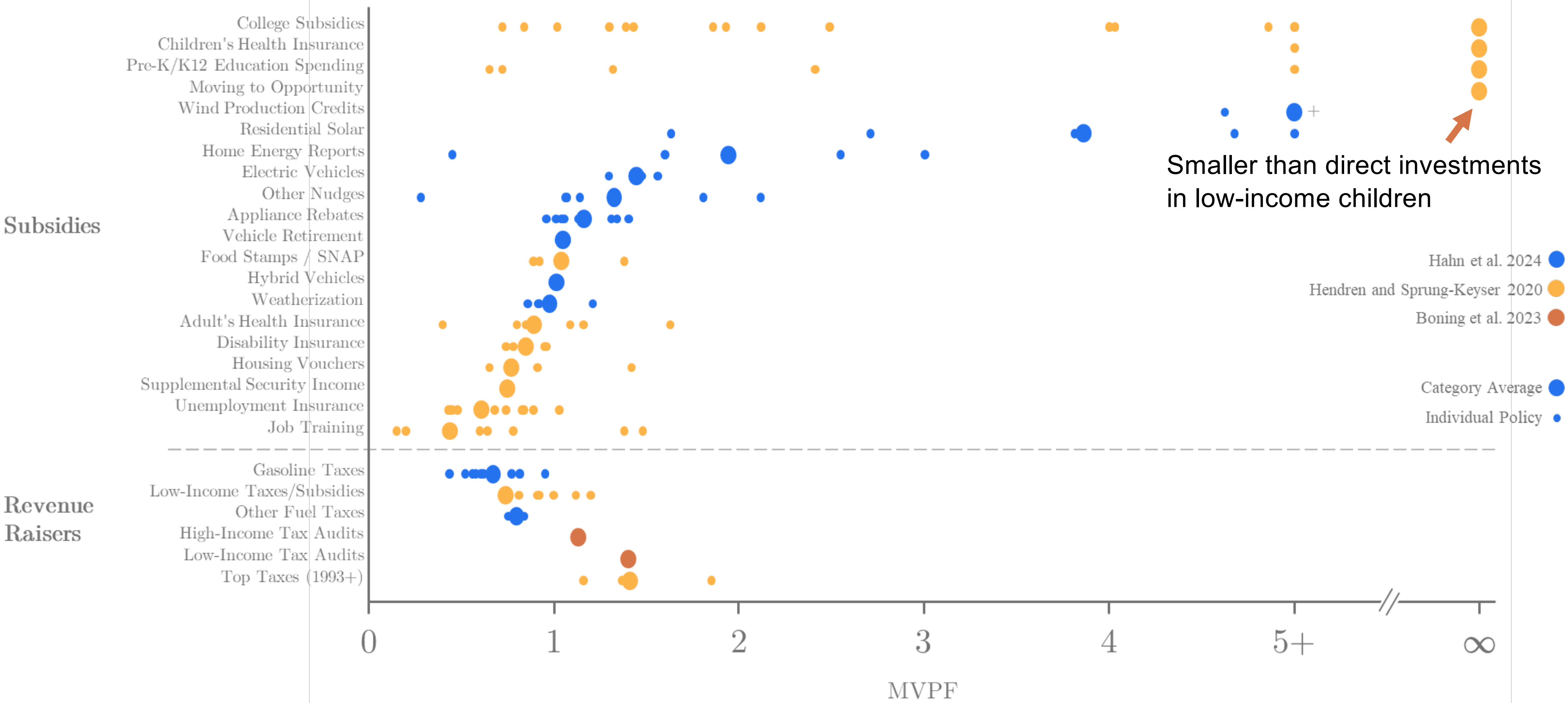
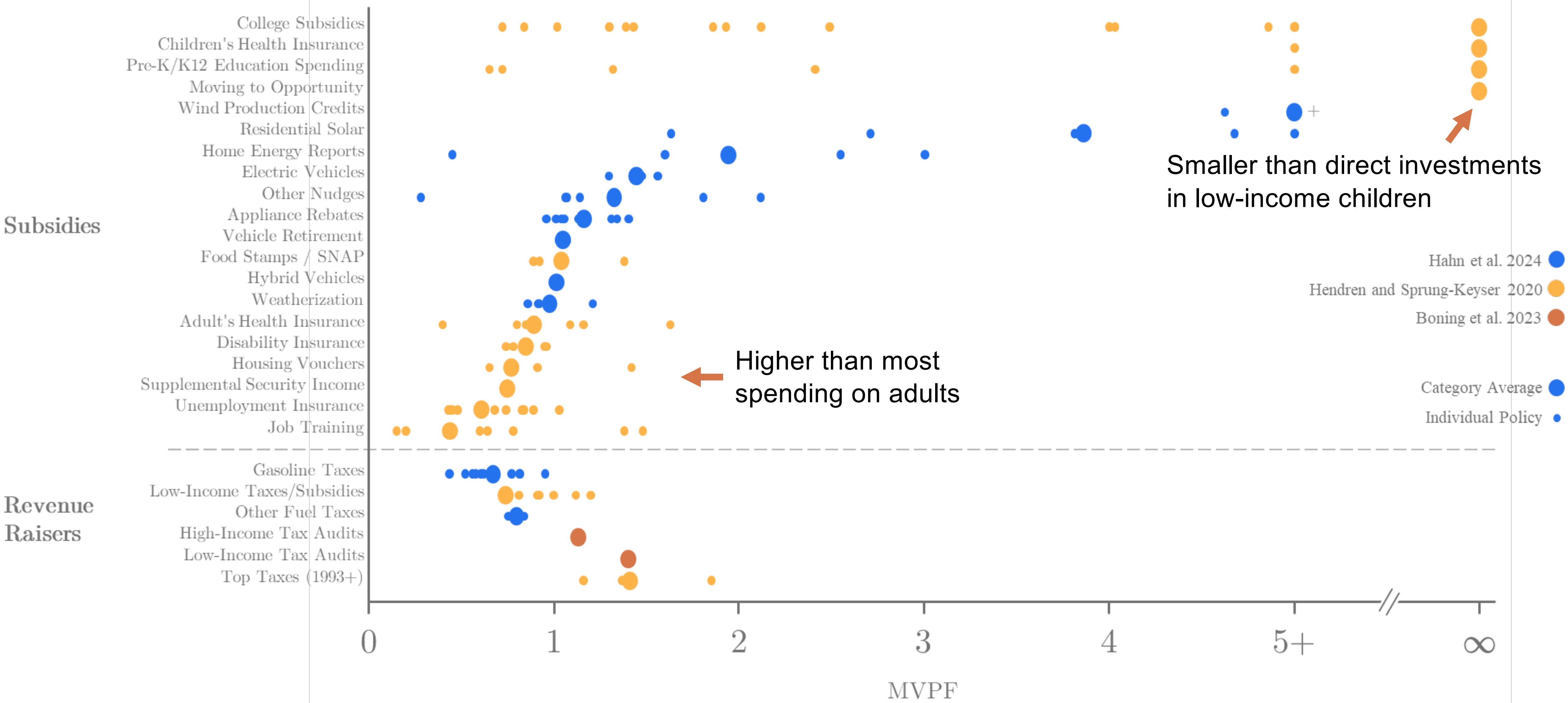
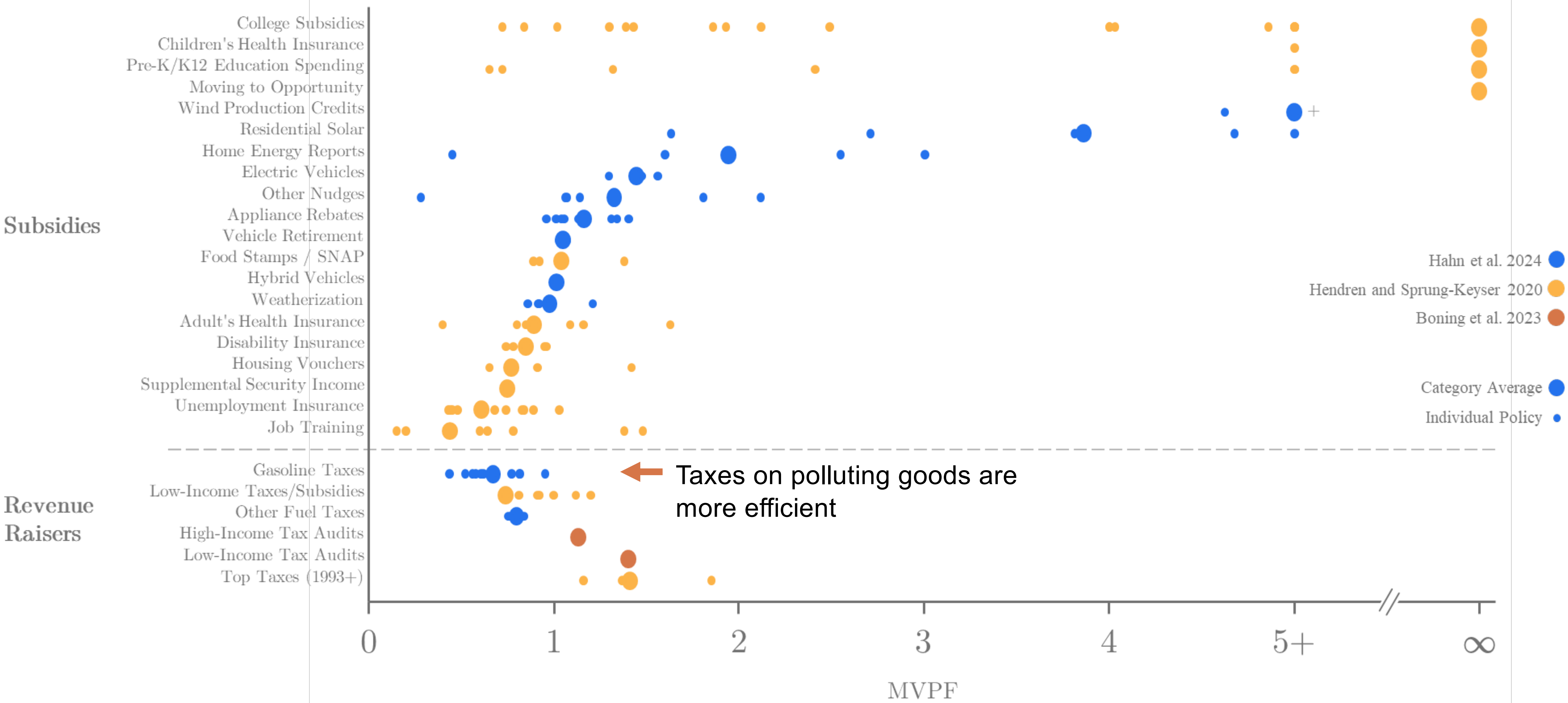


MVPFs of Environmental Policies Versus Other Policy Categories



MVPFs of Environmental Policies Versus Other Policy Categories



Contributions

1. Apples vs. apples comparison of all climate policies (taxes, permits, nudges, subsidies) using the new tools in public finance

2. Generate a way to incorporate learning-by-doing benefits into welfare appraisal and public finance more generally

3. Provide a new framework for how climate fiscal externalities might be important for welfare appraisal, especially for international policies

4. Demonstrate theoretically and empirically that cost per ton is not a good approach for measuring the change in welfare for tax and subsidy policies

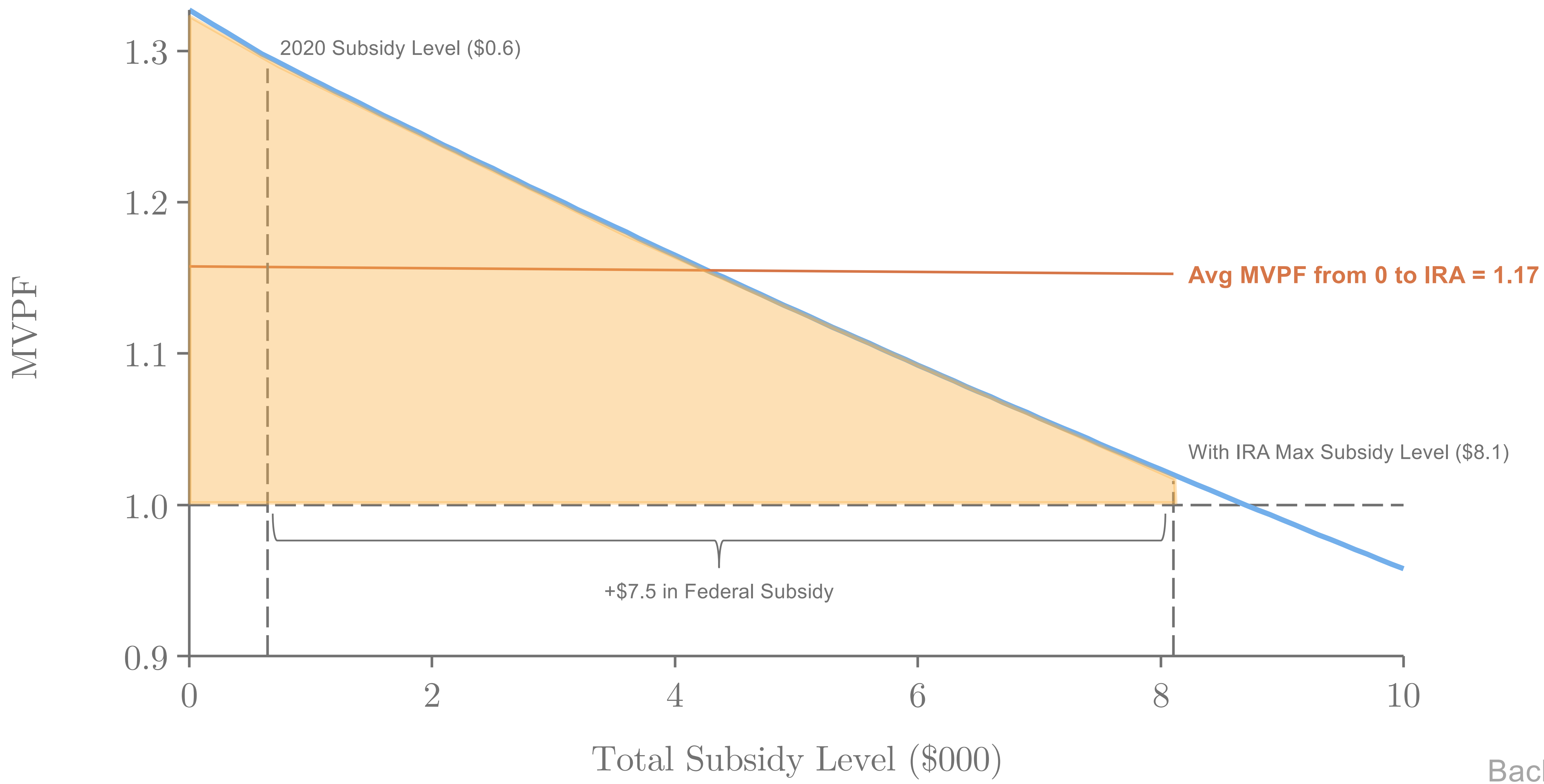
Thank you!

POLICY IMPACTS

Appendix Table 9: MVPF Versus Social Cost Per Ton with MCF Adjustment

		Net Social Cost Per Ton			
Panel A. With Learning by Doing	**MVPF**	**0% DWL**	**10% DWL**	**30% DWL**	**50% DWL**
Subsidies					
Wind Production Credits	5.870	-32	-24	-15	-6
Residential Solar	3.862	-67	-48	-31	-14
Electric Vehicles	1.445	-415	-259	1	260
Appliance Rebates	1.164	111	159	254	349
Vehicle Retirement	1.047	148	235	411	586
Hybrid Vehicles	1.012	-38	555	1,749	2,942
Weatherization	0.978	207	285	441	596
Nudges and Marketing					
Opower Elec. (166 RCTs)	2.548	70	78	93	109
Revenue Raisers					
Gasoline Taxes	0.671	-64	-140	-294	-448

Electric Vehicles: Non-Marginal (Average) MVPF



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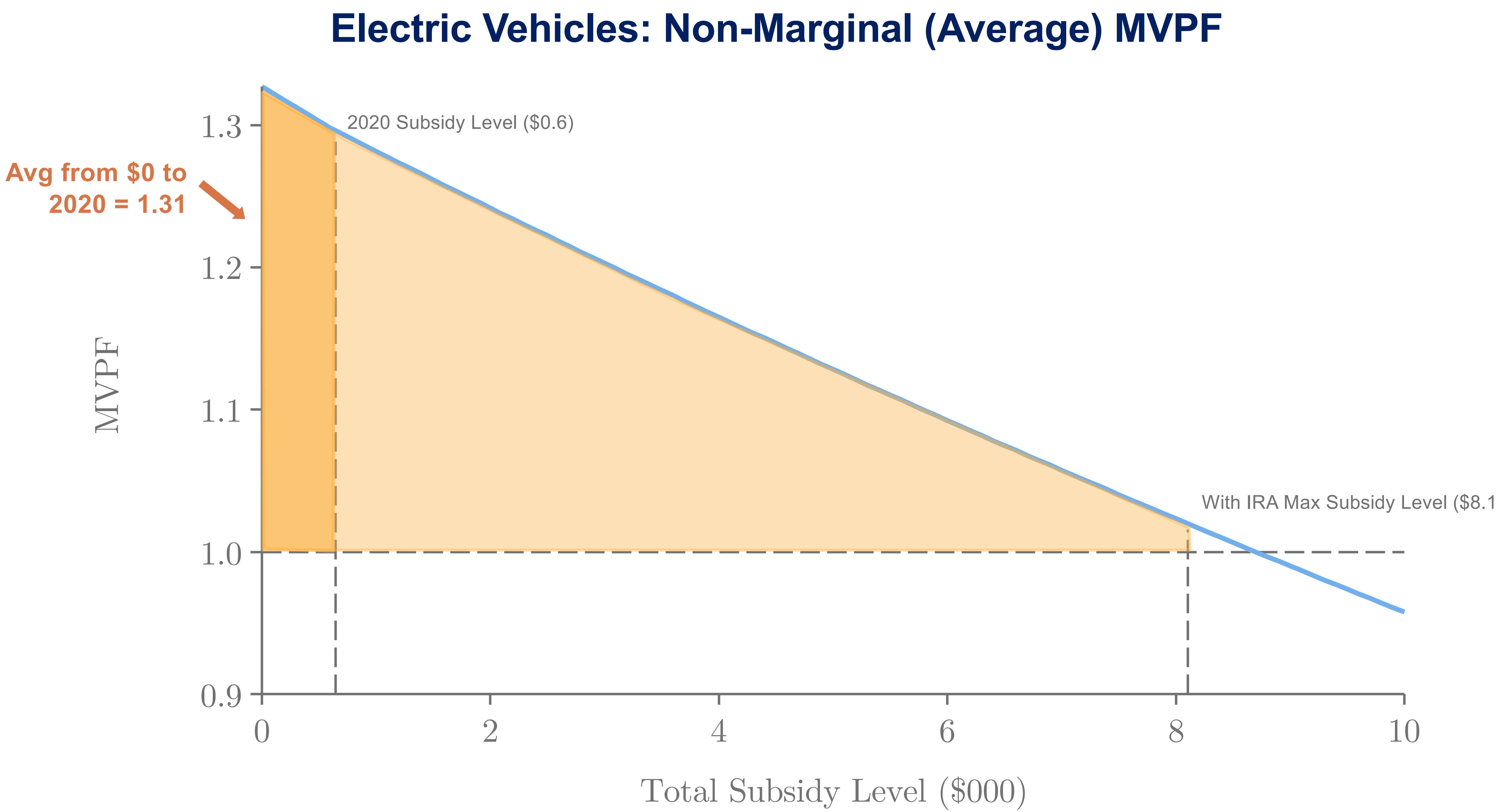
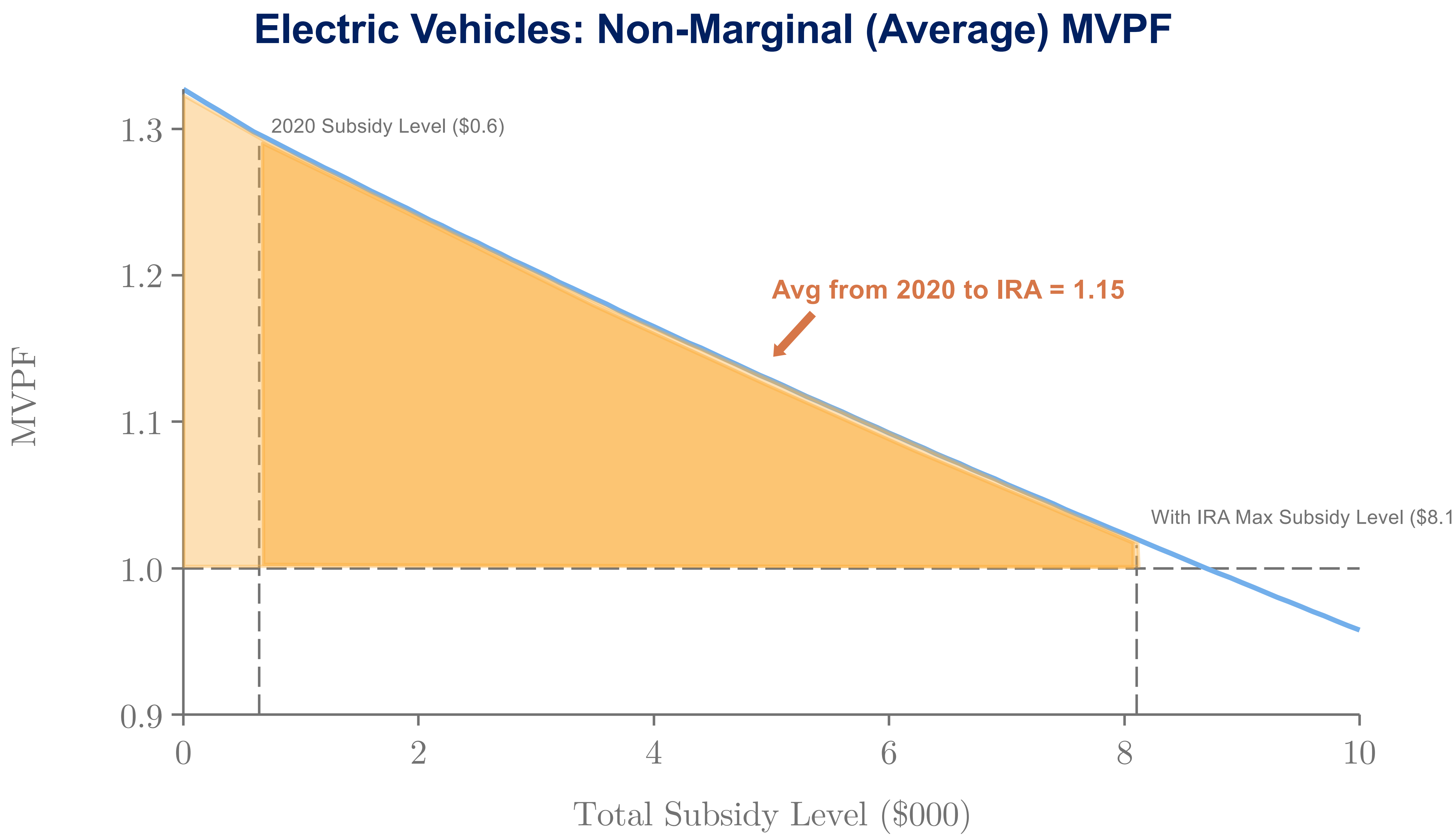

Electric Vehicles: Non-Marginal (Average) MVPF
2020 Subsidy Level ($0.6)
Avg from $0 to 2020 = 1.31
With IRA Max Subsidy Level ($8.1)
MVPF
1.3
1.2
1.1
1.0
0.9
0
2
4
6
8
10
Total Subsidy Level ($000)



Electric Vehicles: Non-Marginal (Average) MVPF
2020 Subsidy Level ($0.6)
Avg from 2020 to IRA = 1.15
With IRA Max Subsidy Level ($8.1)
MVPF
1.3
1.2
1.1
1.0
0.9
0
2
4
6
8
10
Total Subsidy Level ($000)

Aside: Determinants of the Social Cost of Carbon

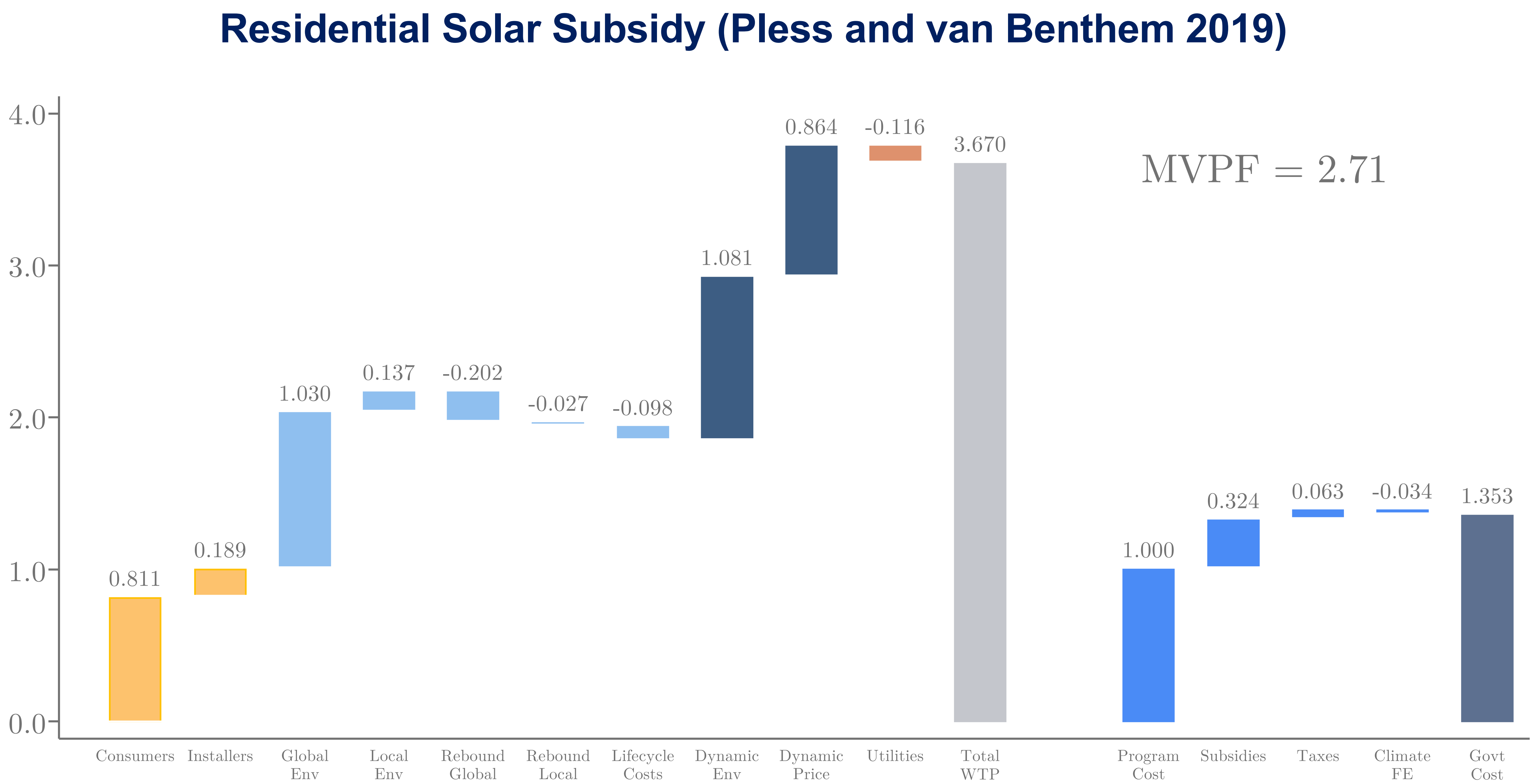
- Damages in IAMs are generally driven by a mix of health and productivity effects, broadly defined
  - Ex: GIVE (Rennert et al. 2022), DICE (Barrage and Nordhaus, 2023)
  - Other models focus exclusively on impacts on GDP (Nath et al. 2024; Bilal and Kanzig, 2024);

- This distinction might not matter for the concept of the SCC, but it matters for the government costs of climate policy
  - The US government has an equity stake in US productivity

- Our approach:
  - Use 50/50 productivity-mortality split (Rennert et al. 2022)
  - Allocate productivity in proportion to US share of GDP (Nordhaus, 2017)
  - Apply a 25.5% tax rate

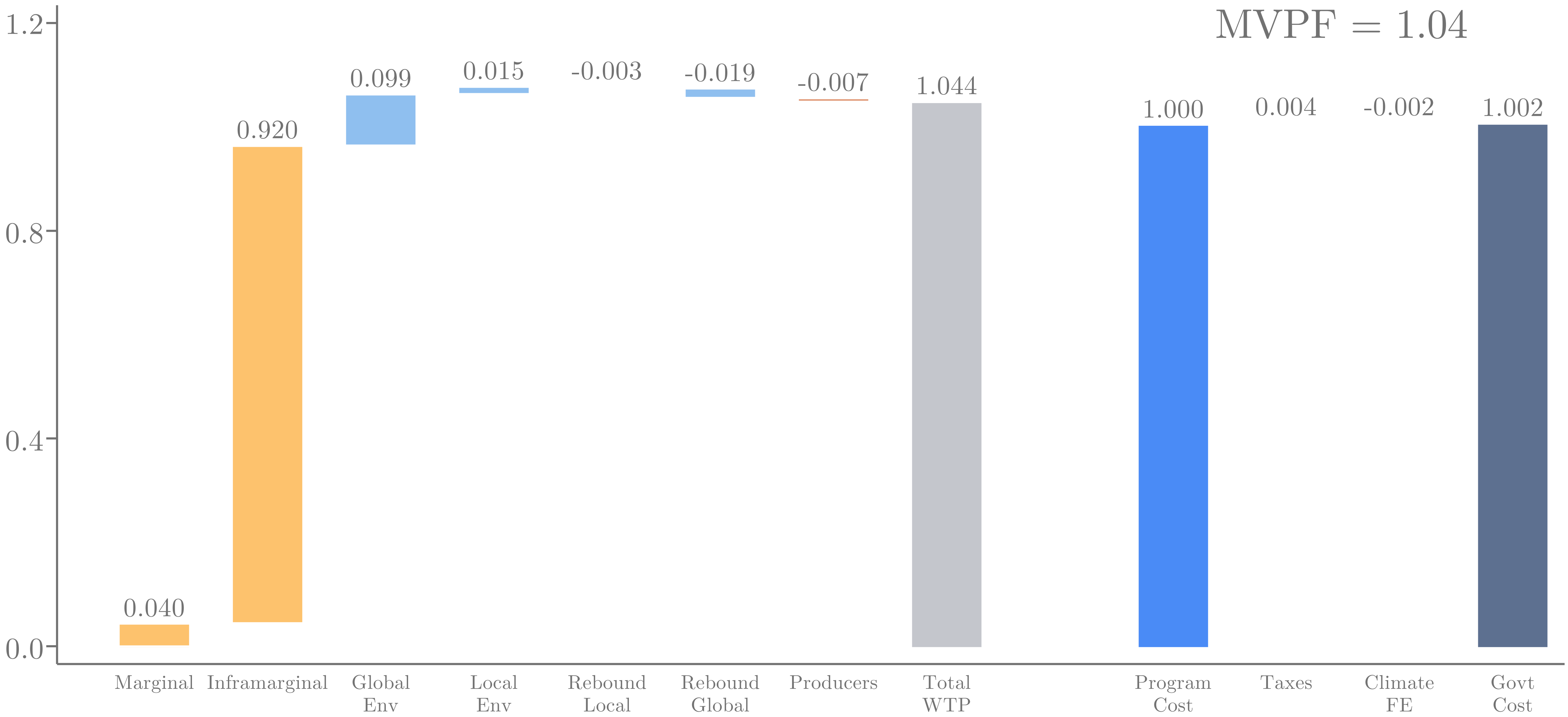
- Result: $3.70 of the $193 of the SCC falls on US government

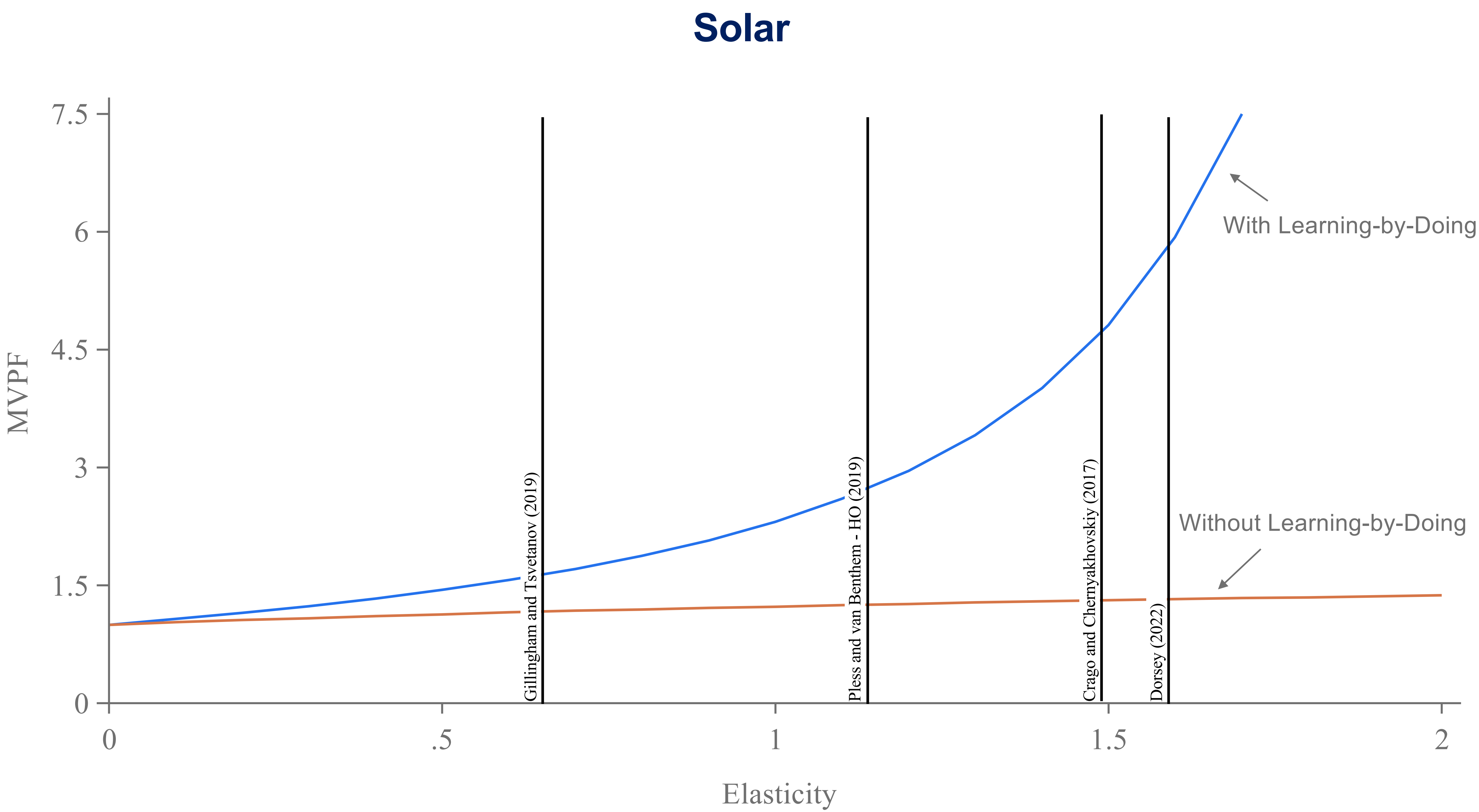
International MVPFs International MVPFs – US Only



Residential Solar Subsidy (Pless and van Benthem 2019)
MVPF = 2.71
4.0
3.0
2.0
1.0
0.0
0.811
0.189
1.030
0.137
-0.202
-0.027
-0.098
1.081
0.864
-0.116
3.670
1.000
0.324
0.063
-0.034
1.353
Consumers
Installers
Global Env
Local Env
Rebound Global
Rebound Local
Lifecycle Costs
Dynamic Env
Dynamic Price
Utilities
Total WTP
Program Cost
Subsidies
Taxes
Climate FE
Govt Cost

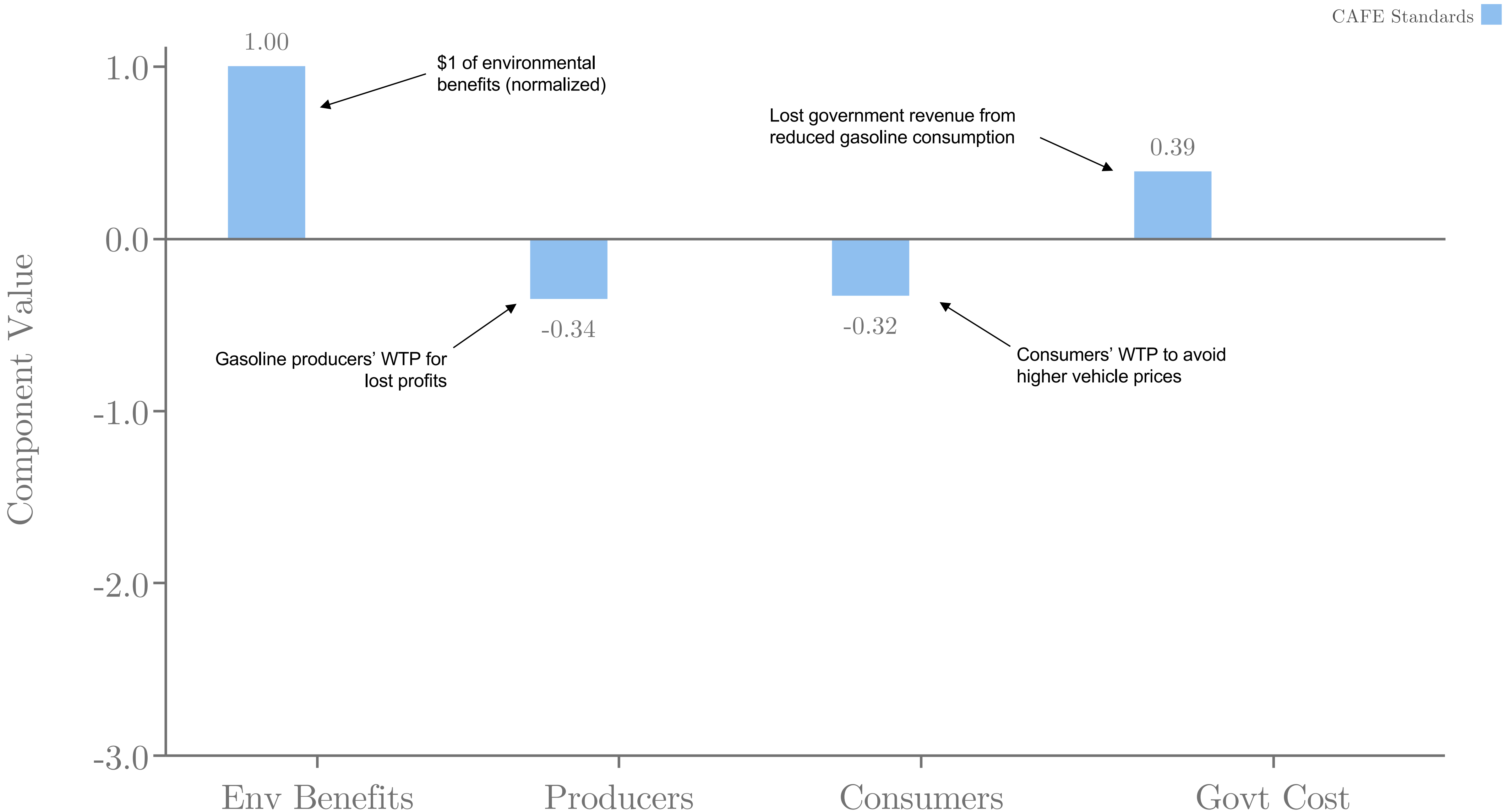
Energy-Efficient Refrigerator Rebate (Houde and Aldy 2017)



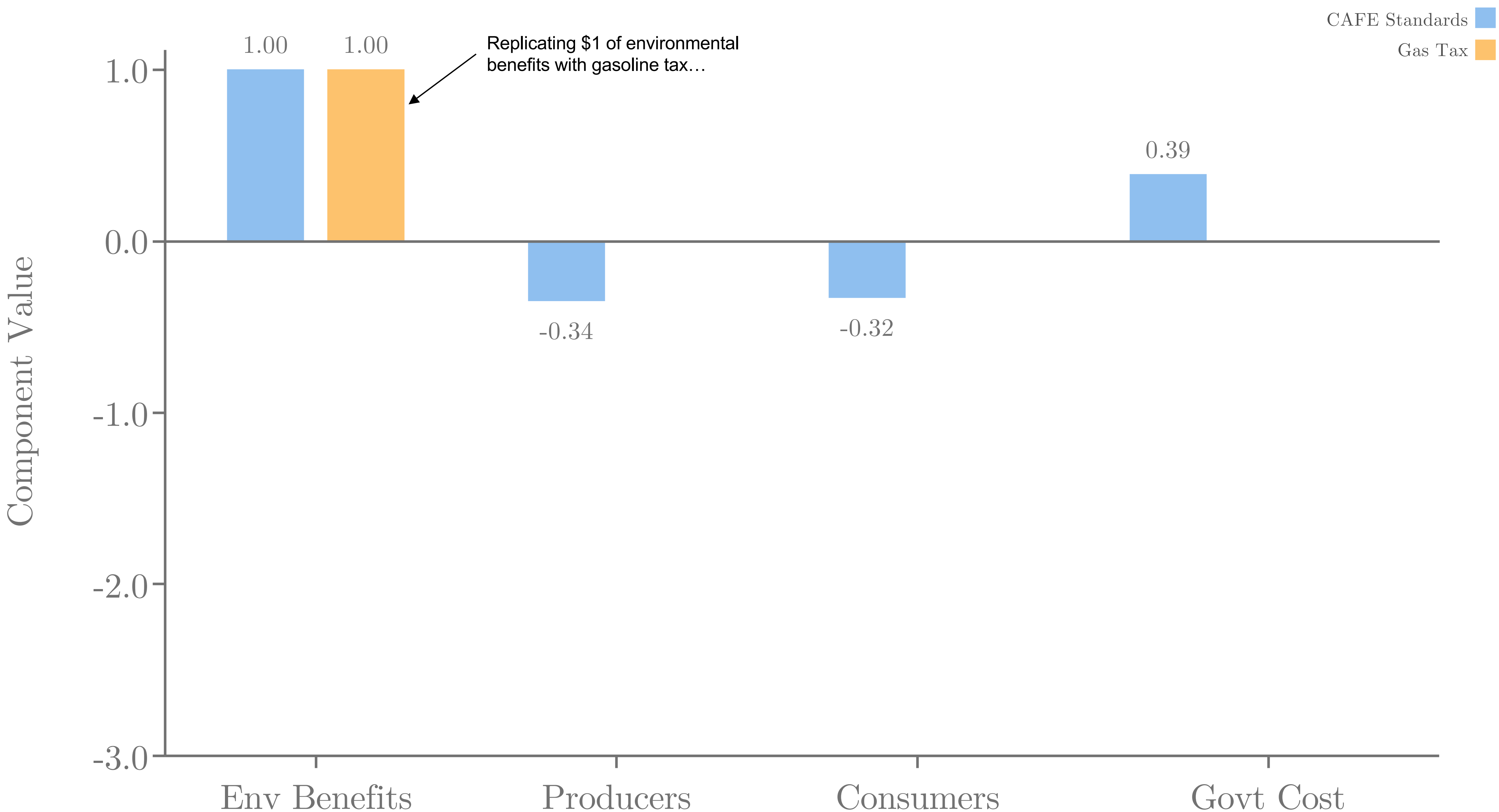


Solar
MVPF
7.5
6
4.5
3
1.5
0
0
.5
1
1.5
2
Elasticity
Gillingham and Tsvetanov (2019)
Pless and van Benthem - HO (2019)
Crago and Chernyakhovskiy (2017)
Dorsey (2022)
With Learning-by-Doing
Without Learning-by-Doing

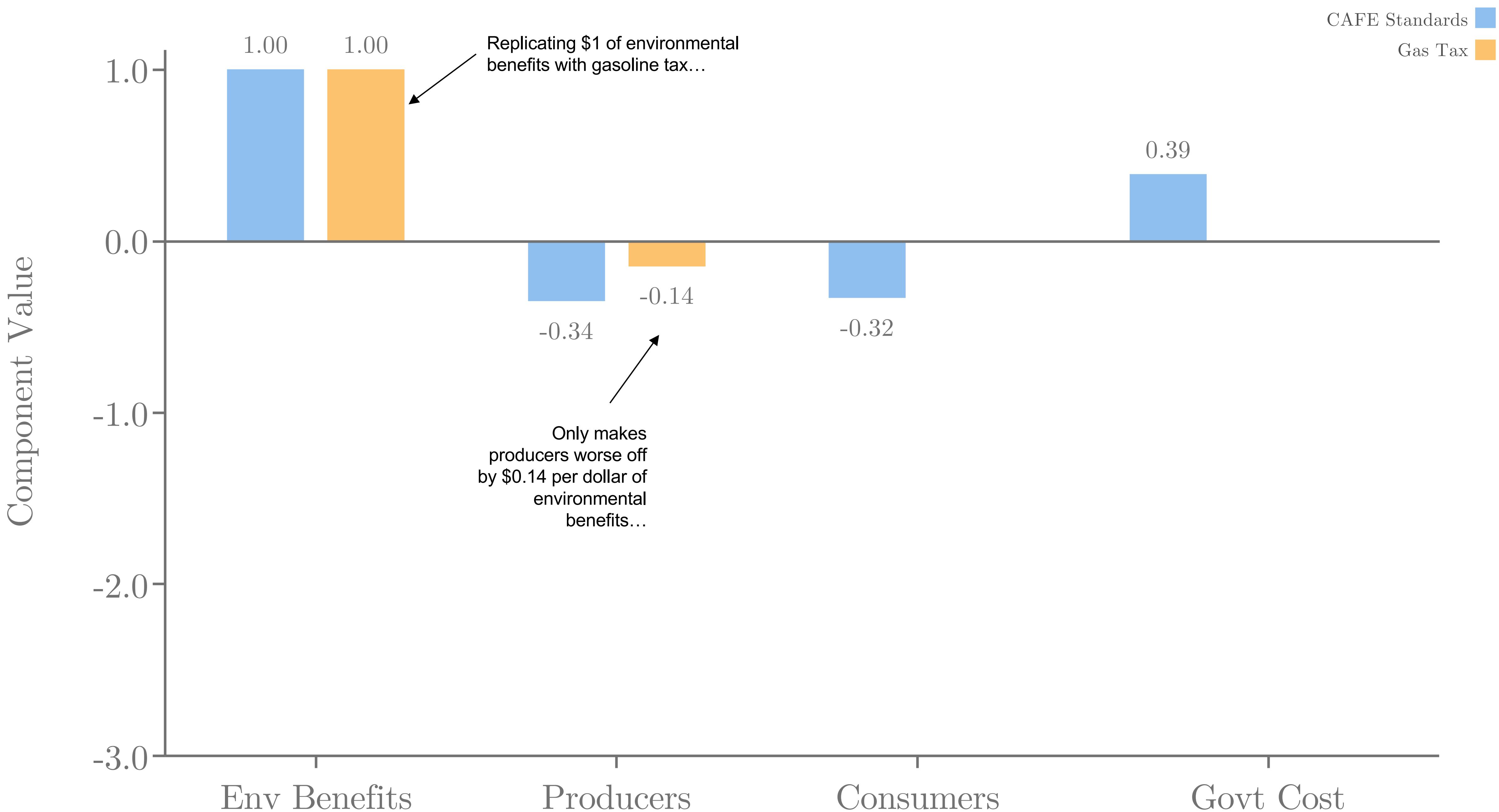
CAFE Comparison to Gas + Income Tax



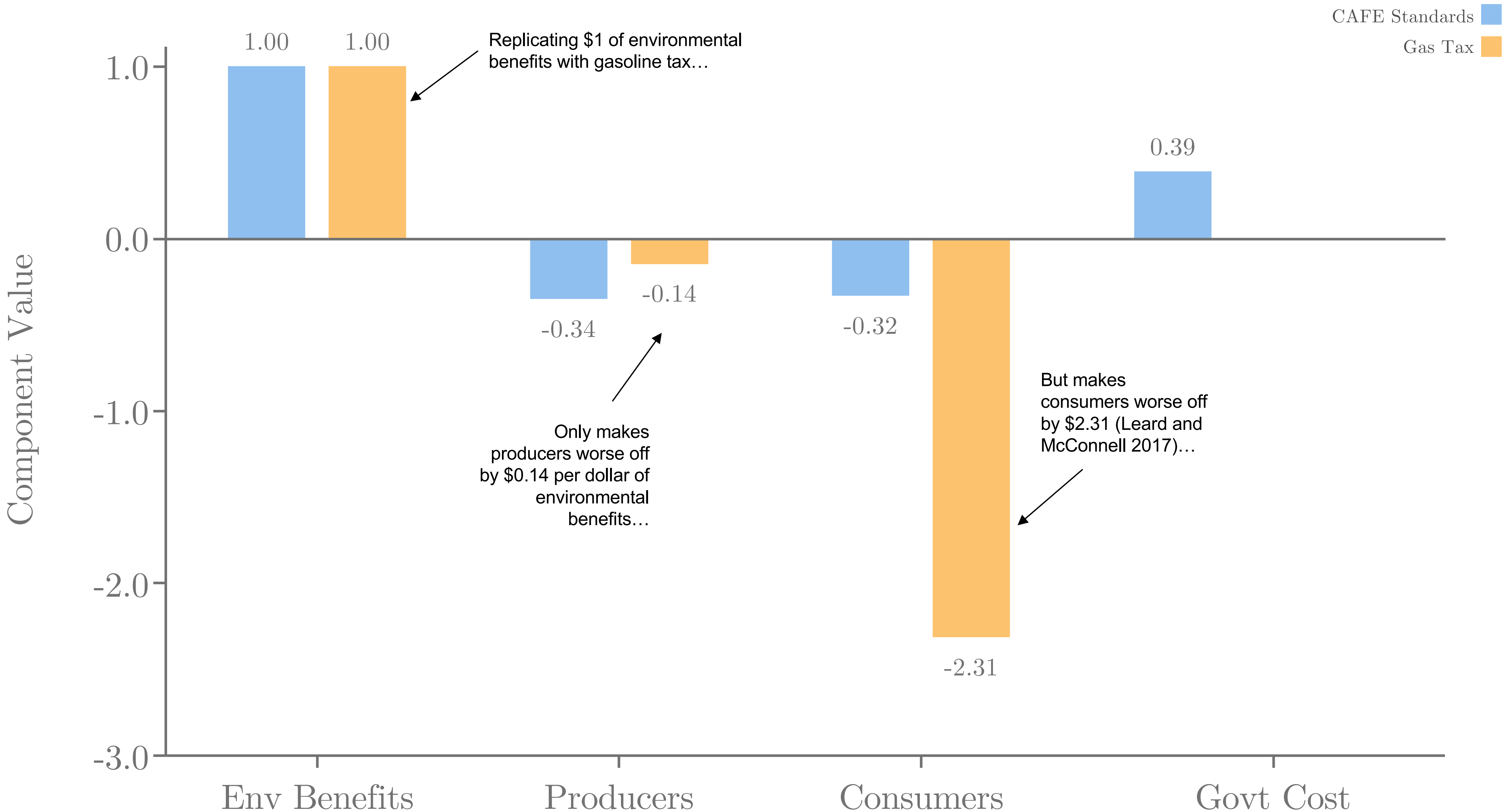
CAFE Comparison to Gas + Income Tax

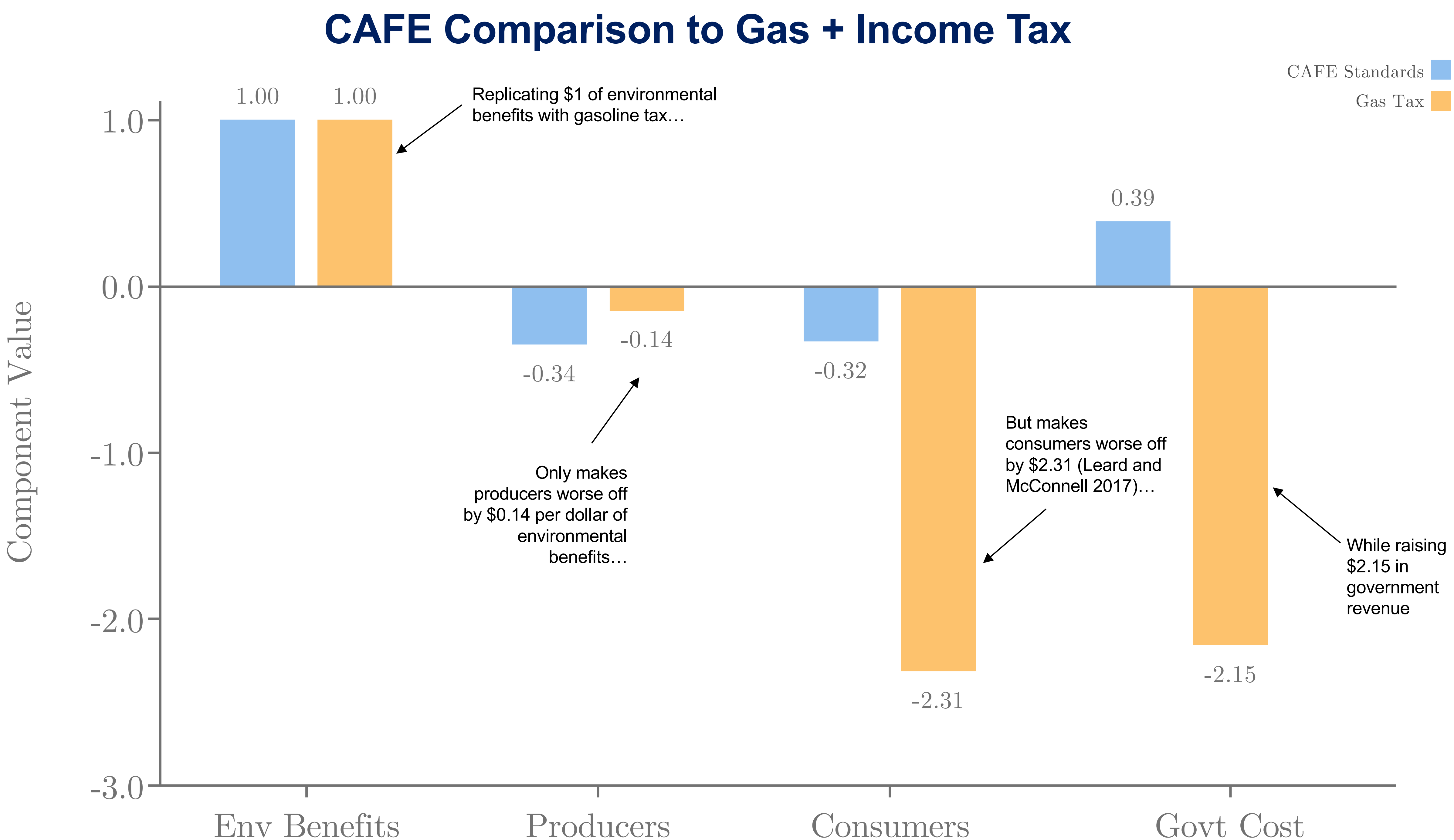


CAFE Comparison to Gas + Income Tax

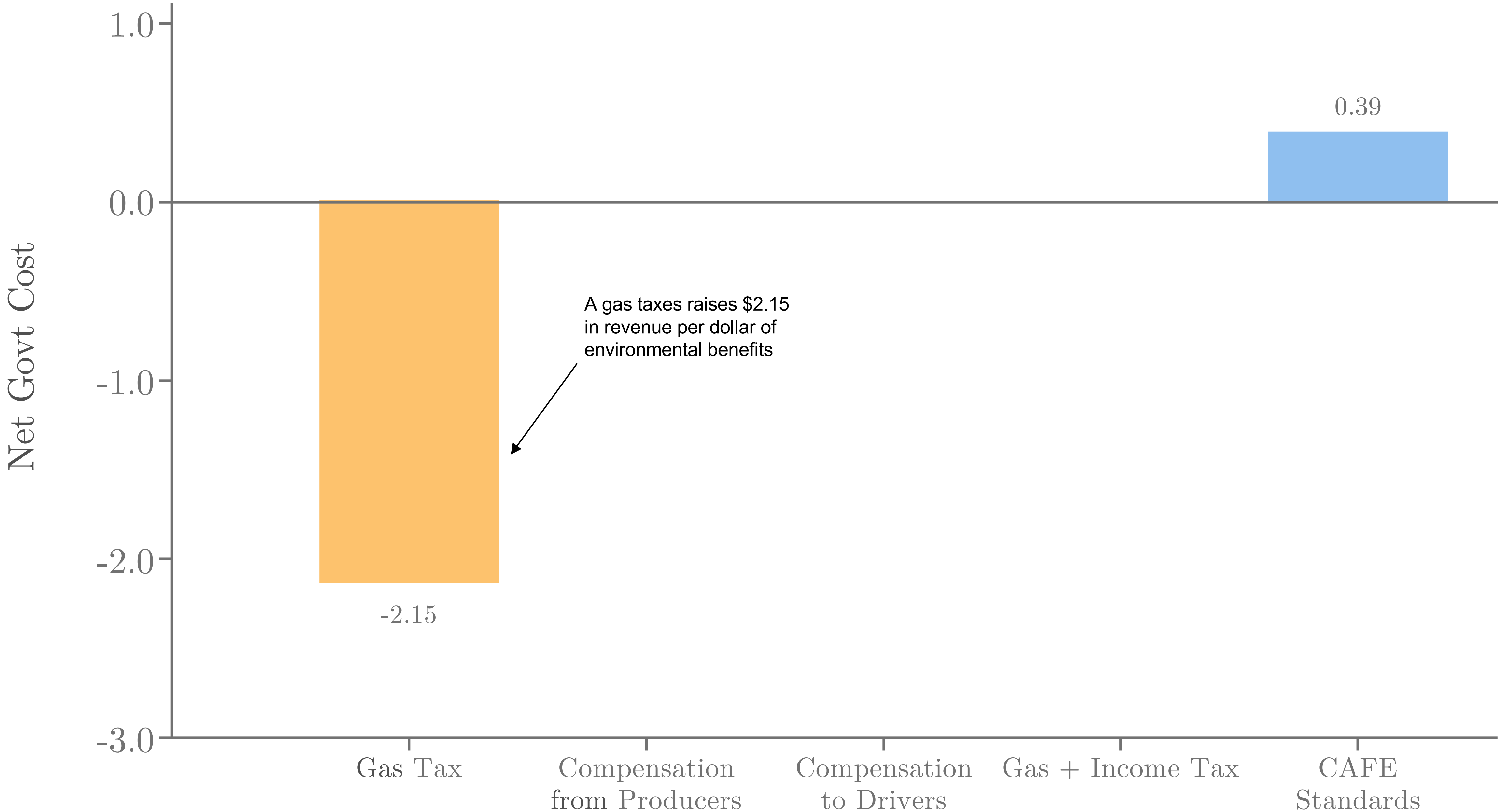


CAFE Comparison to Gas + Income Tax

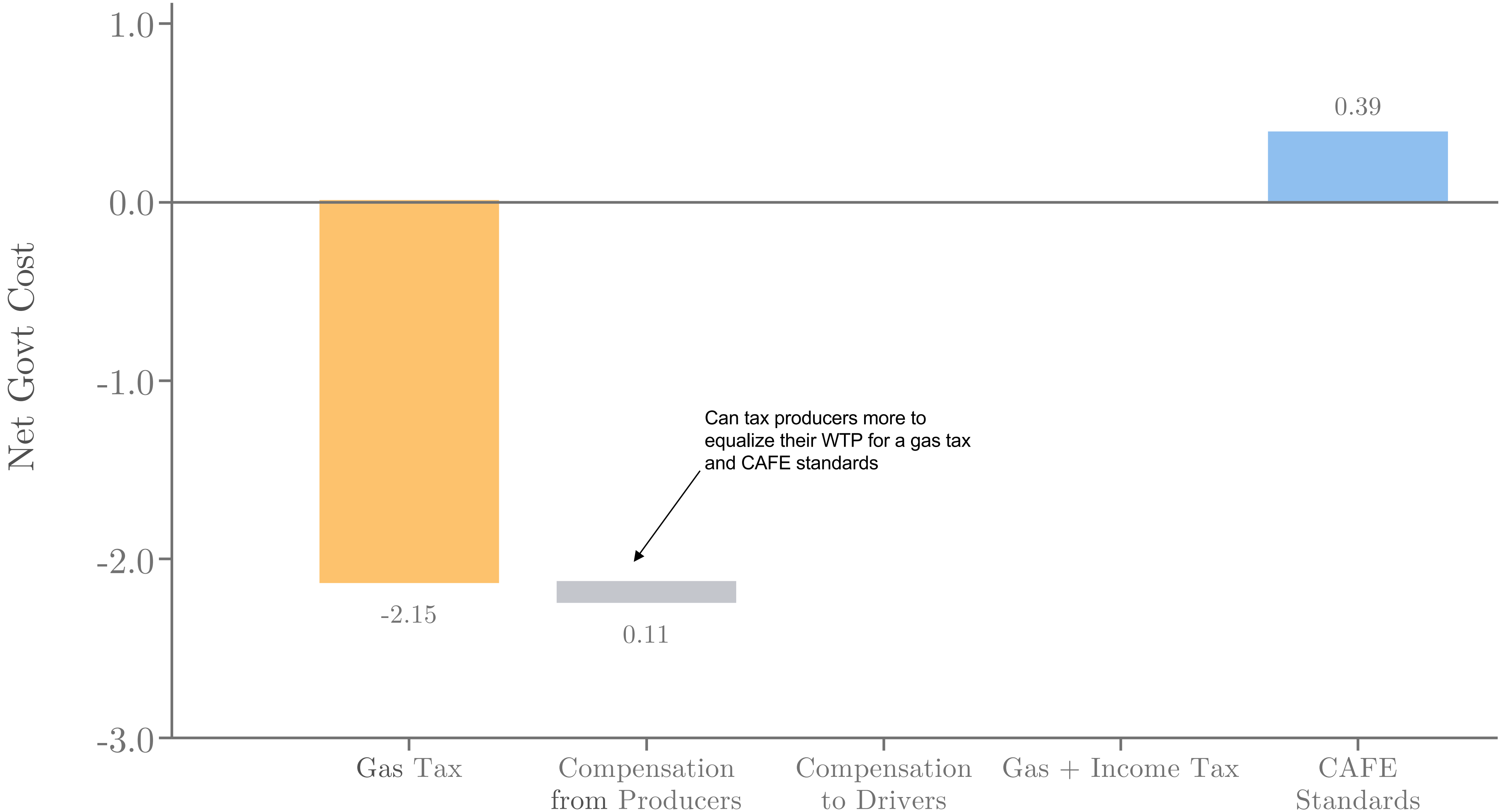



CAFE Comparison to Gas + Income Tax
CAFE Standards
Gas Tax
Component Value
1.0
0.0
-1.0
-2.0
-3.0
1.00
1.00
Replicating $1 of environmental benefits with gasoline tax…
-0.34
-0.14
Only makes producers worse off by $0.14 per dollar of environmental benefits…
-0.32
-2.31
But makes consumers worse off by $2.31 (Leard and McConnell 2017)…
0.39
-2.15
While raising $2.15 in government revenue
Env Benefits
Producers
Consumers
Govt Cost

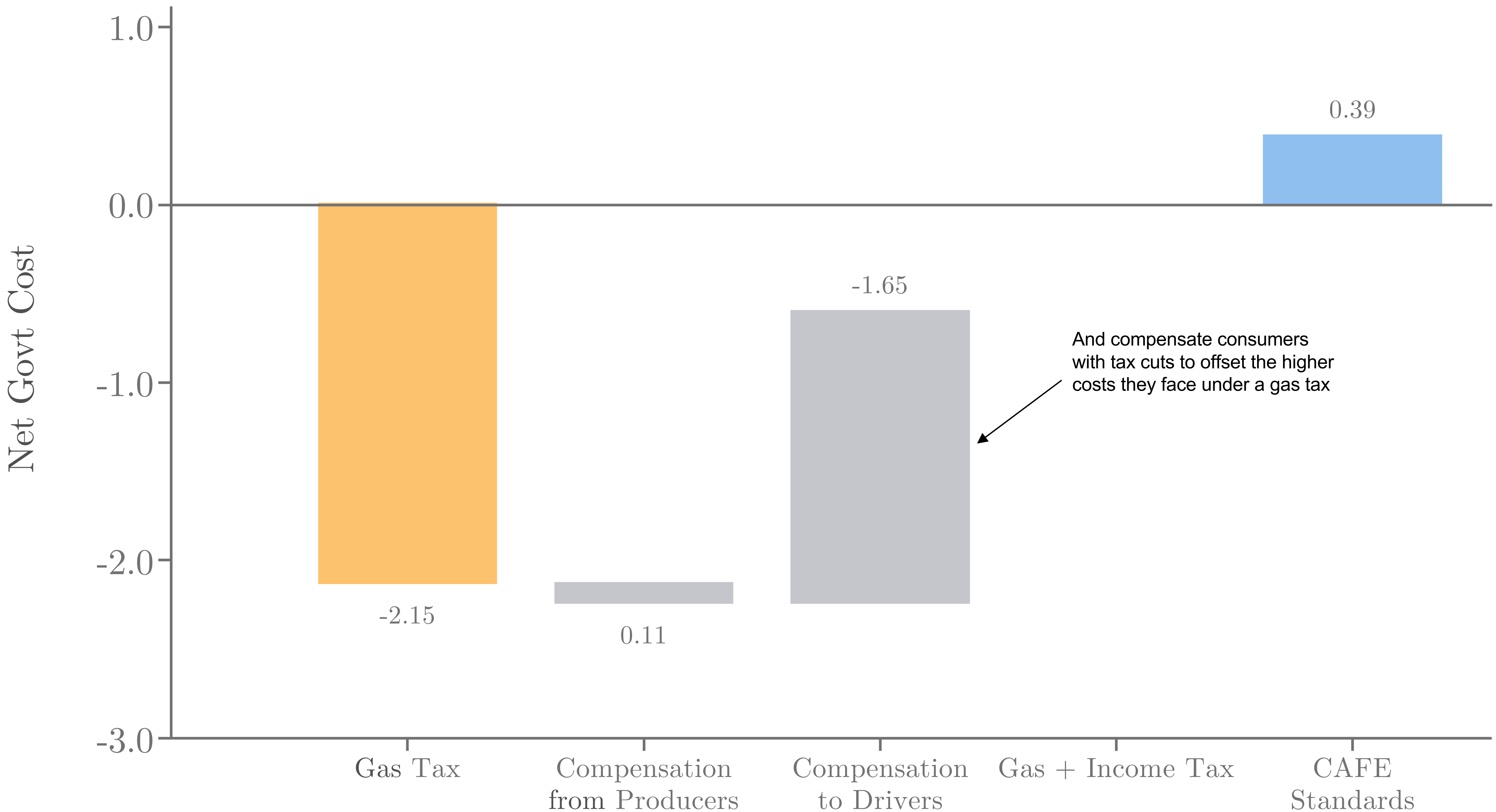
CAFE Comparison to Gas + Income Tax

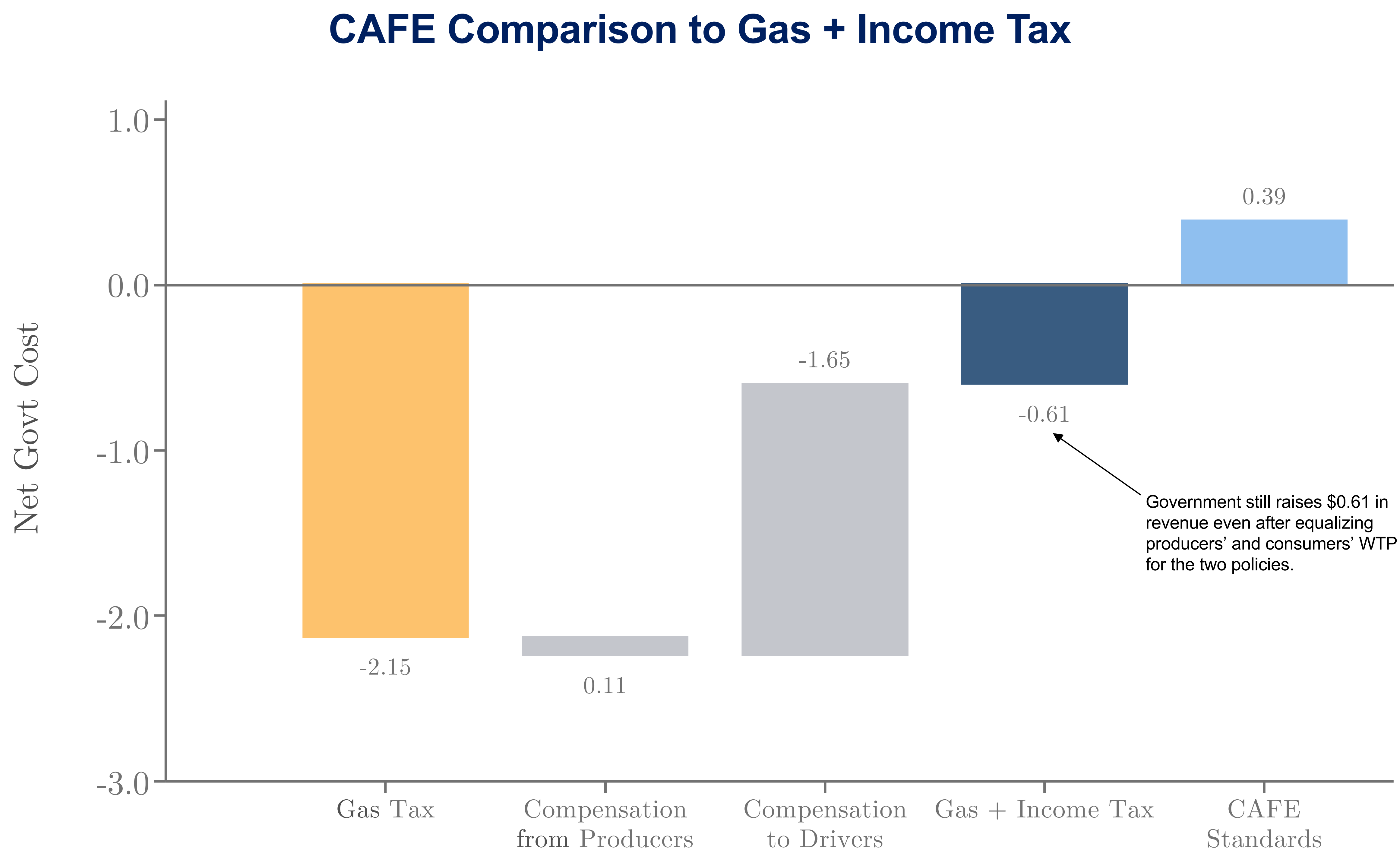


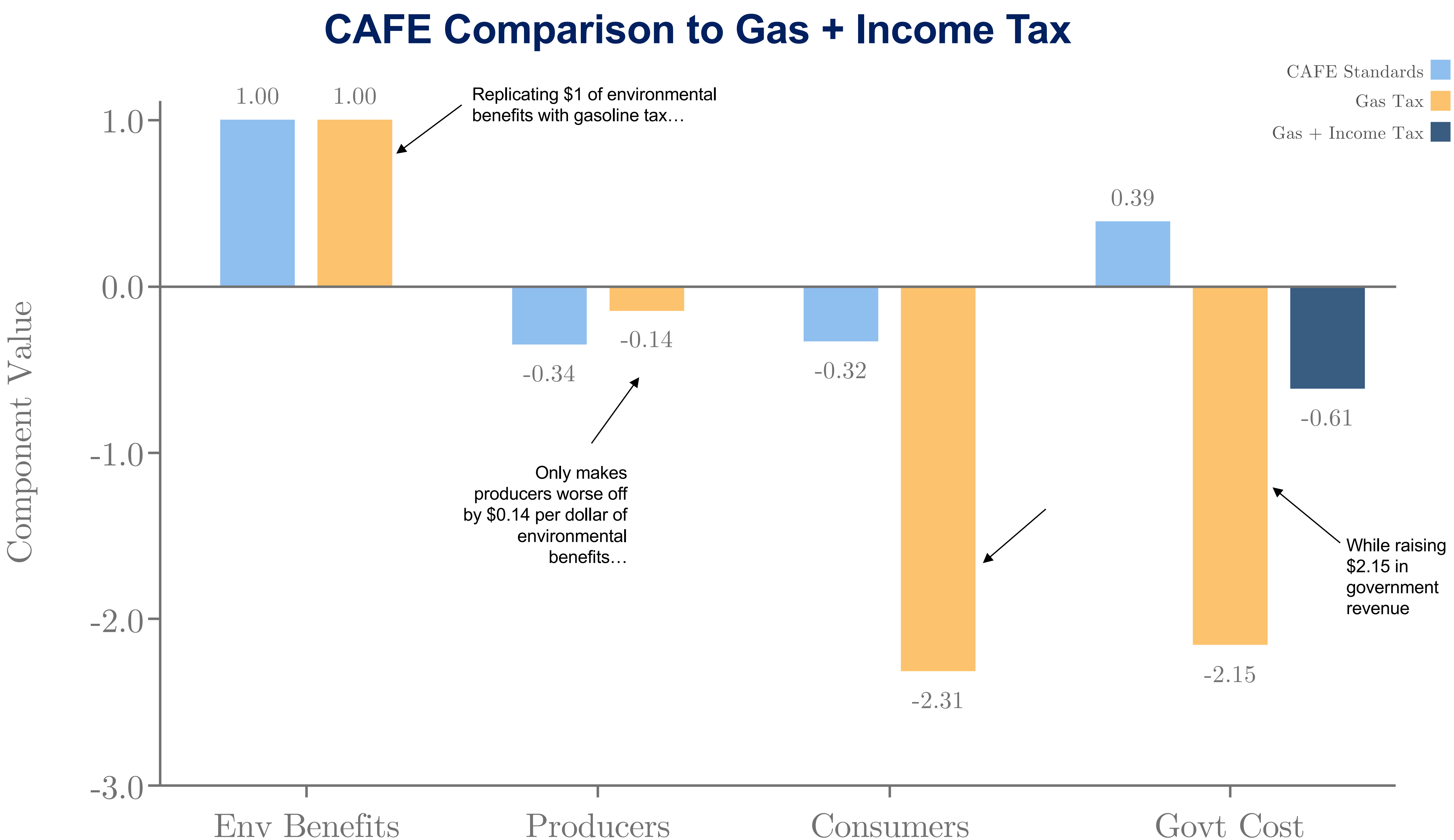
CAFE Comparison to Gas + Income Tax



CAFE Comparison to Gas + Income Tax




CAFE Comparison to Gas + Income Tax
Net Govt Cost
1.0
0.0
-1.0
-2.0
-3.0
-2.15
0.11
-1.65
-0.61
0.39
Government still raises $0.61 in revenue even after equalizing producers' and consumers' WTP for the two policies.
Gas Tax
Compensation from Producers
Compensation to Drivers
Gas + Income Tax
CAFE Standards


CAFE Comparison to Gas + Income Tax
CAFE Standards
Gas Tax
Gas + Income Tax
Component Value
1.0
0.0
-1.0
-2.0
-3.0
1.00
1.00
Replicating $1 of environmental benefits with gasoline tax…
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Only makes producers worse off by $0.14 per dollar of environmental benefits…
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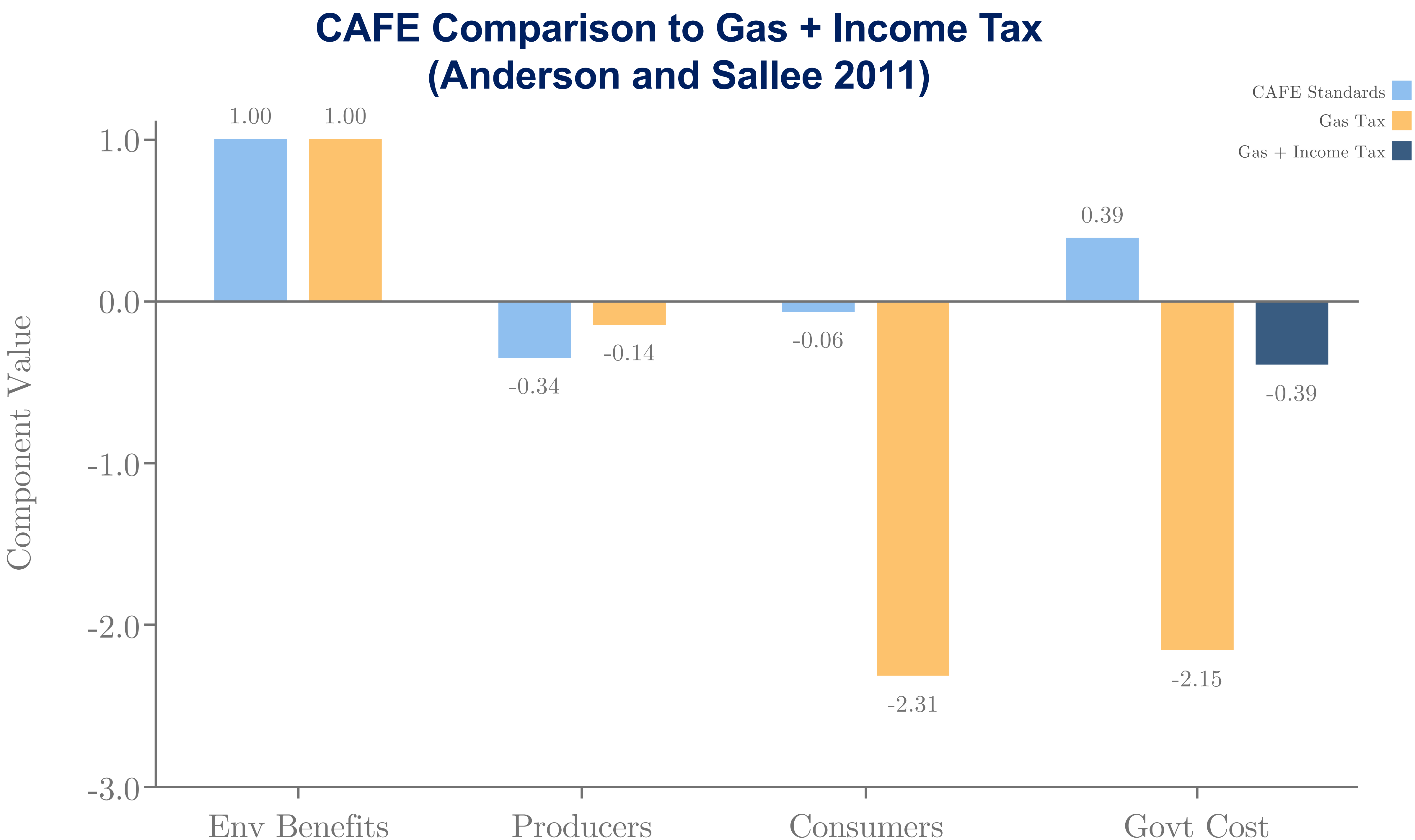
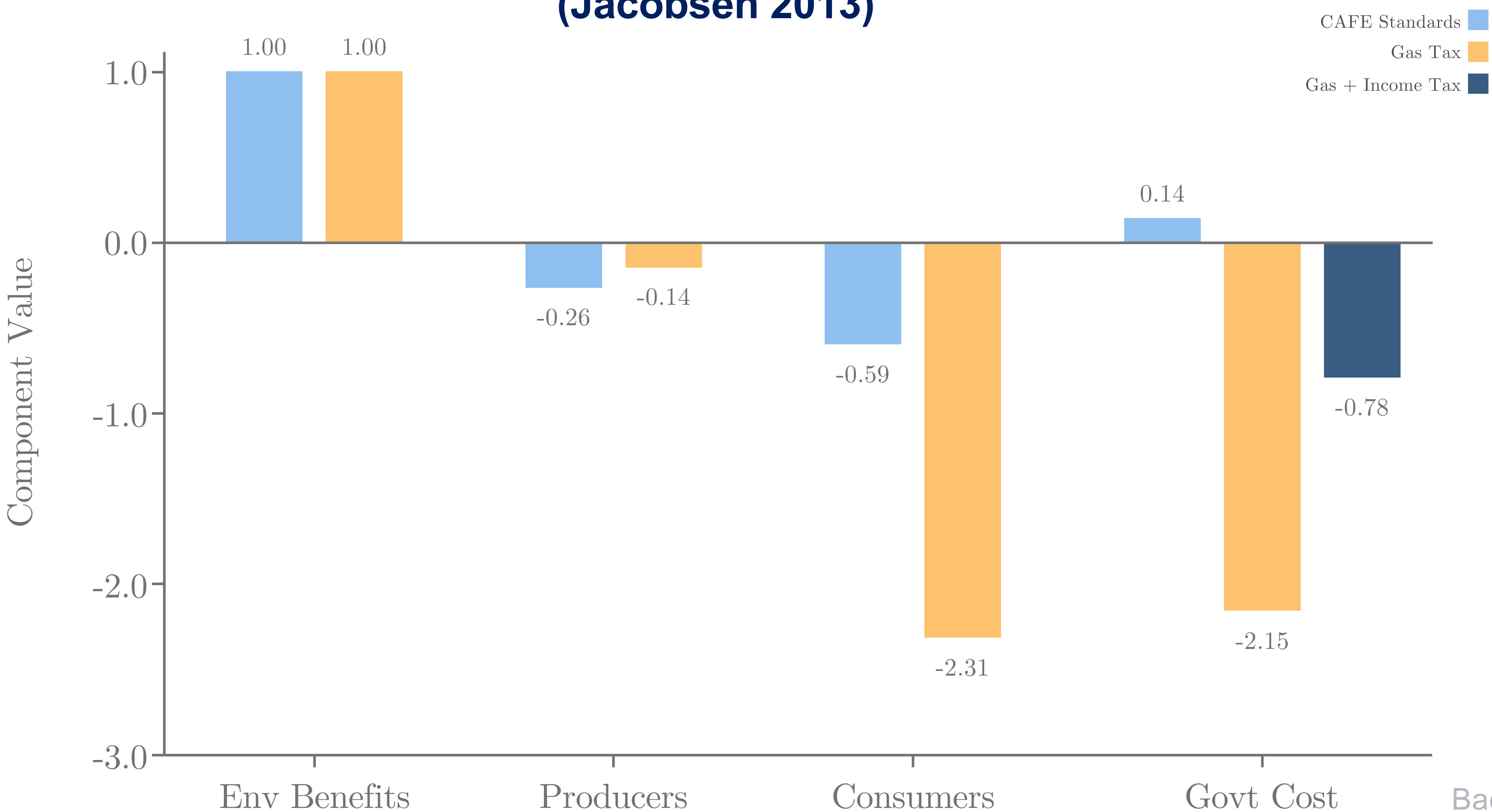
-0.61
While raising $2.15 in government revenue
Env Benefits
Producers
Consumers
Govt Cost


CAFE Comparison to Gas + Income Tax
(Anderson and Sallee 2011)
CAFE Standards
Gas Tax
Gas + Income Tax
Component Value
1.0
0.0
-1.0
-2.0
-3.0
1.00
1.00
-0.34
-0.14
-0.06
-2.31
0.39
-2.15
-0.39
Env Benefits
Producers
Consumers
Govt Cost

CAFE Comparison to Gas + Income Tax (Jacobsen 2013)



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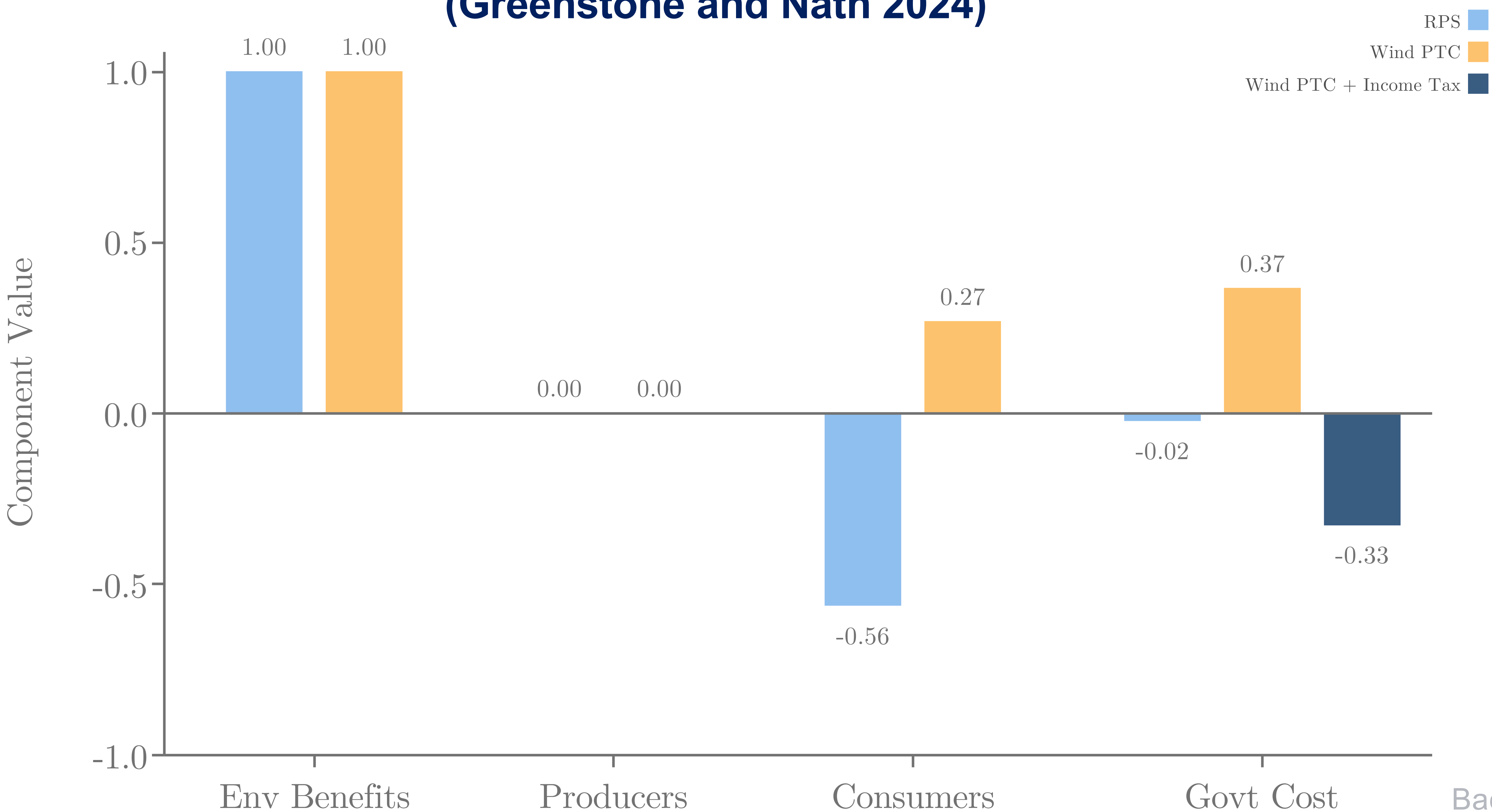
RPS Comparison to Wind PTC + Income Tax (Greenstone and Nath 2024)



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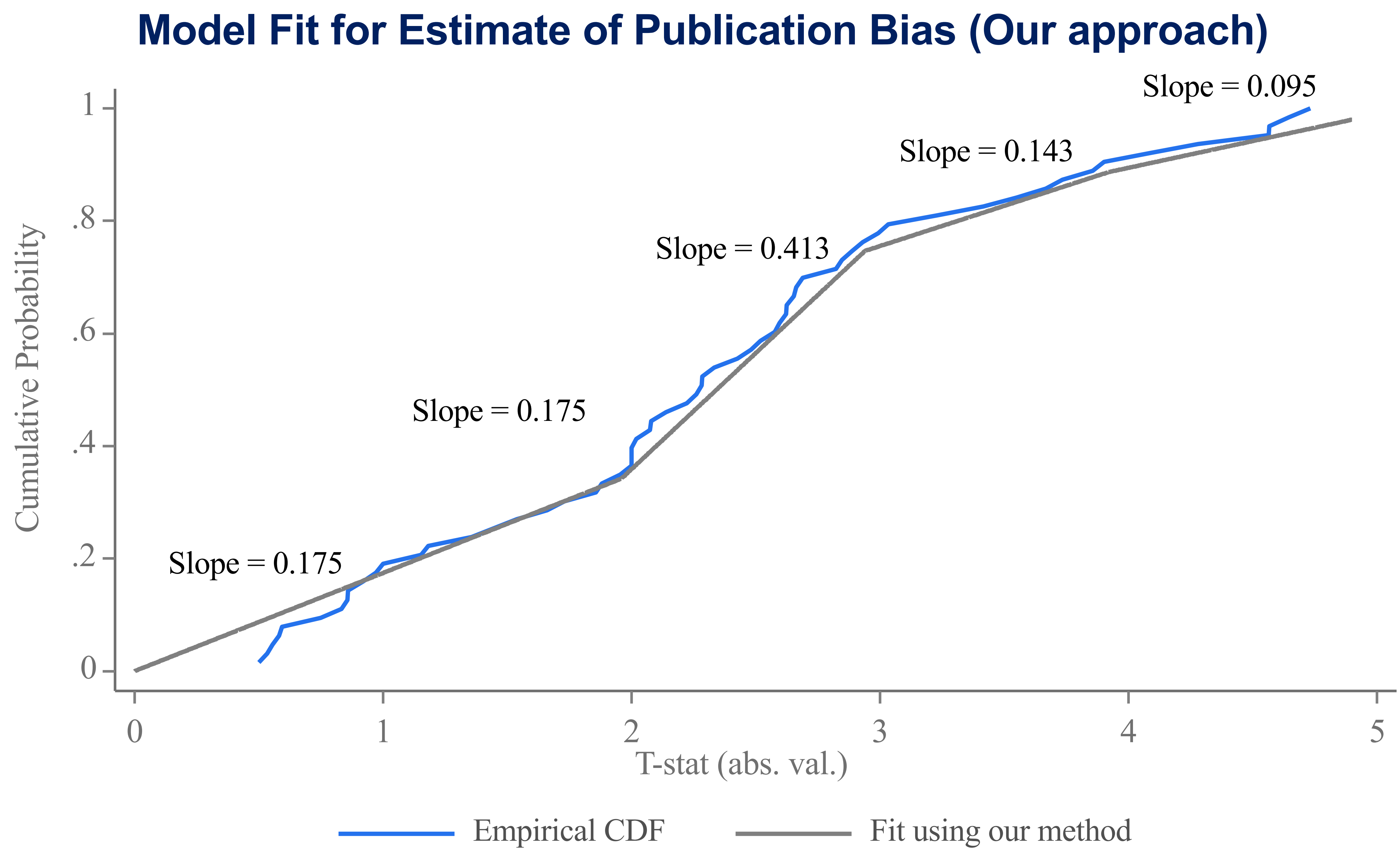
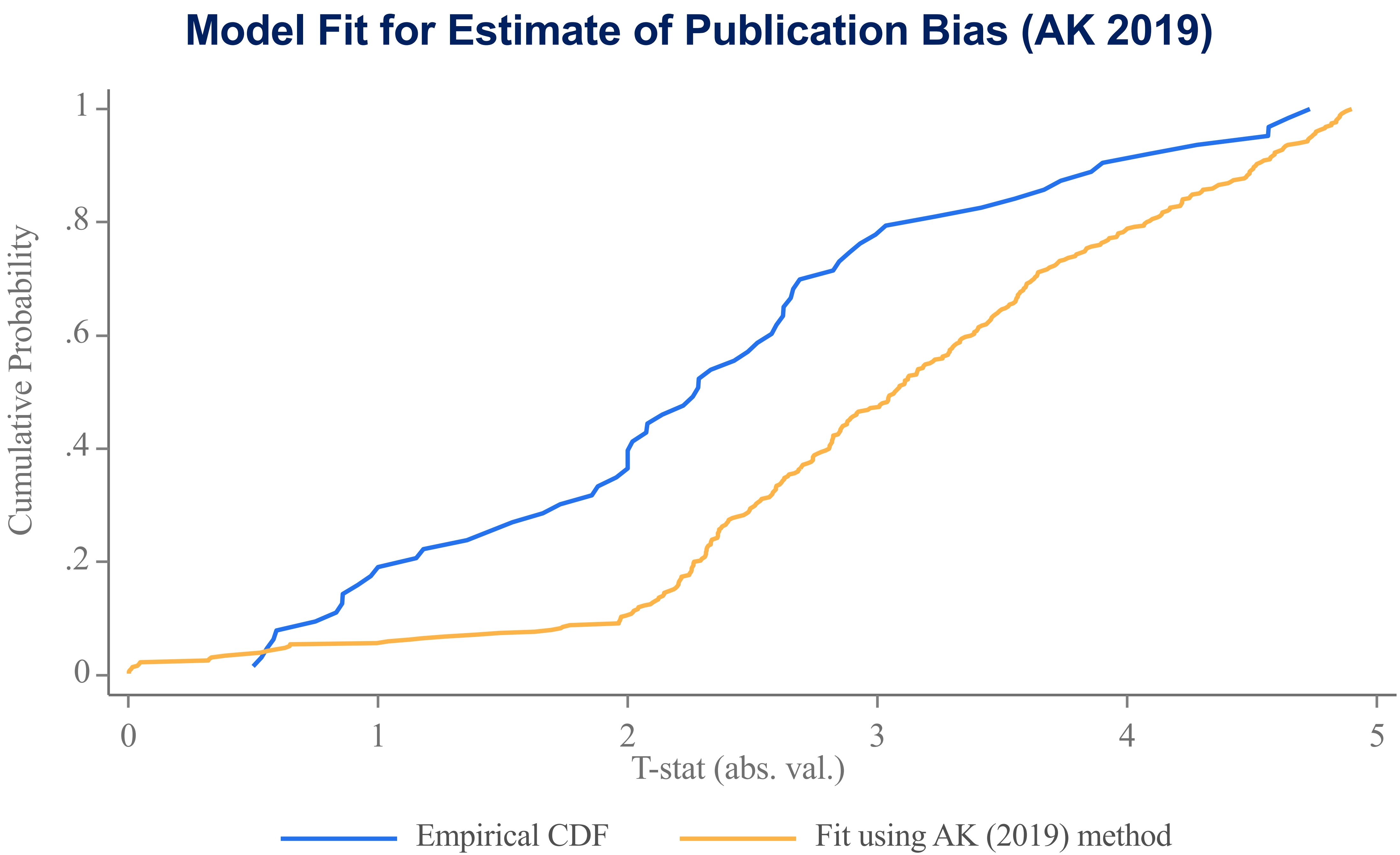
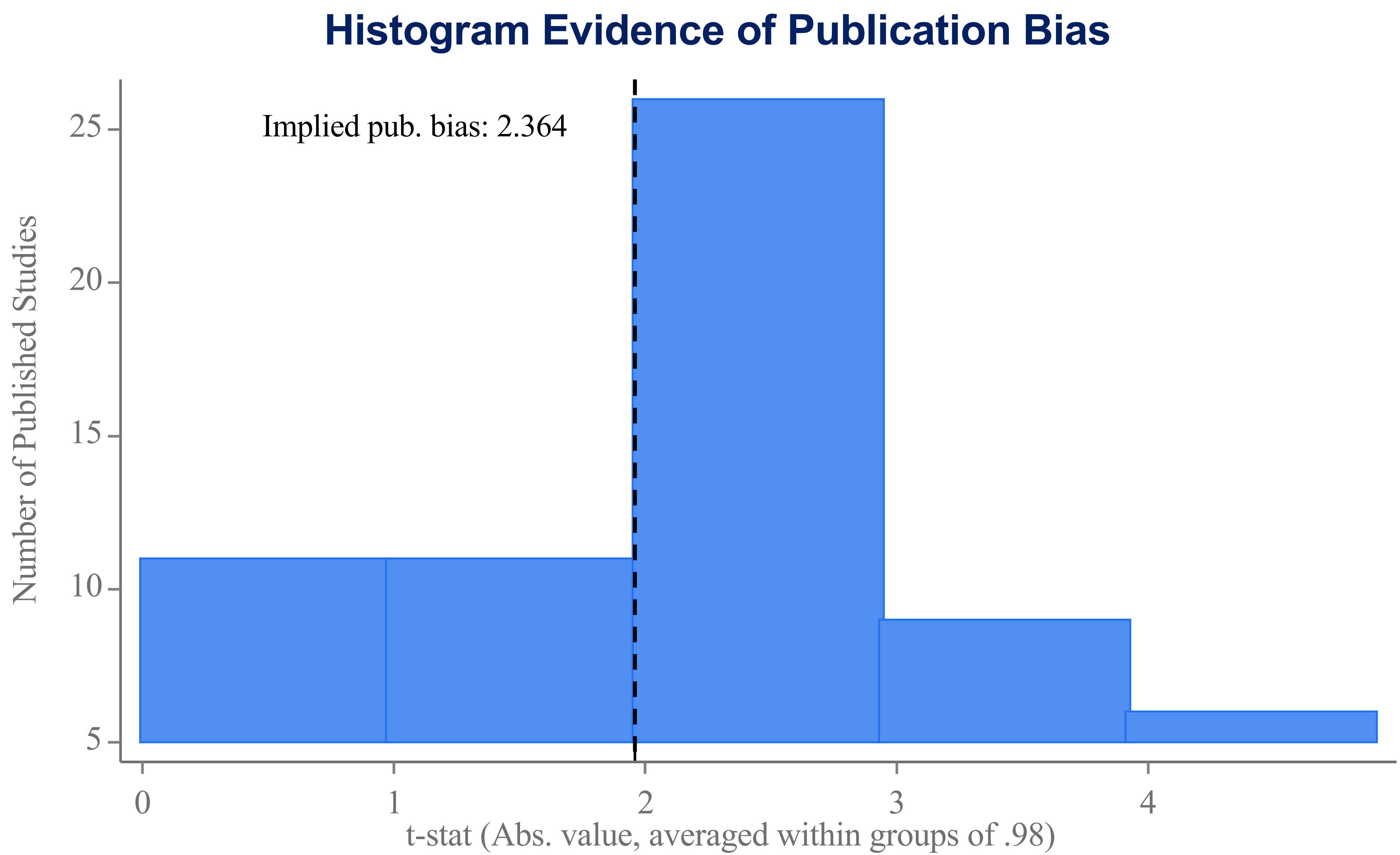
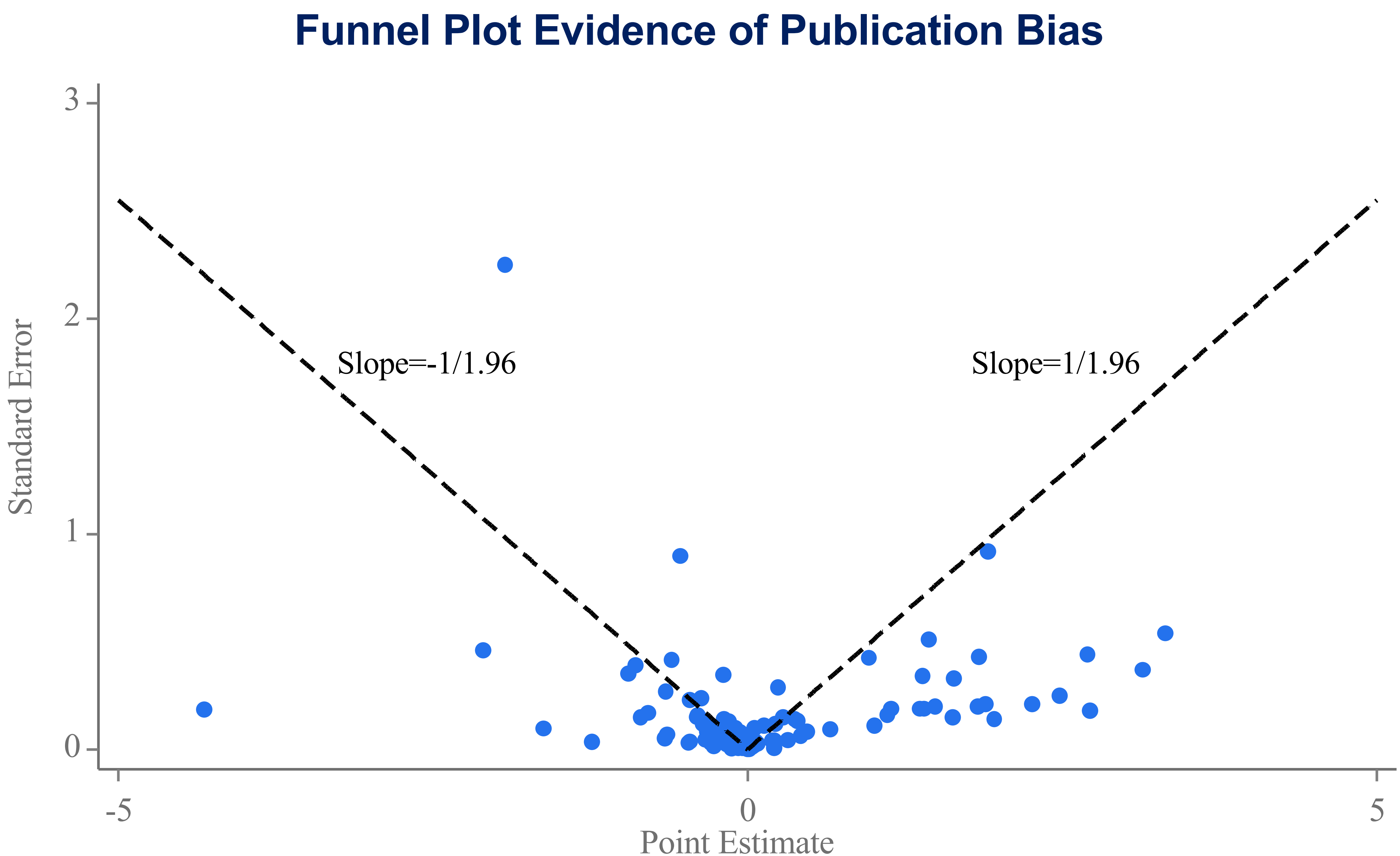


Model Fit for Estimate of Publication Bias (Our approach)
Slope = 0.095
Slope = 0.143
Slope = 0.413
Slope = 0.175
Slope = 0.175
Cumulative Probability
1
.8
.6
.4
.2
0
0
1
2
3
4
5
T-stat (abs. val.)
Empirical CDF
Fit using our method

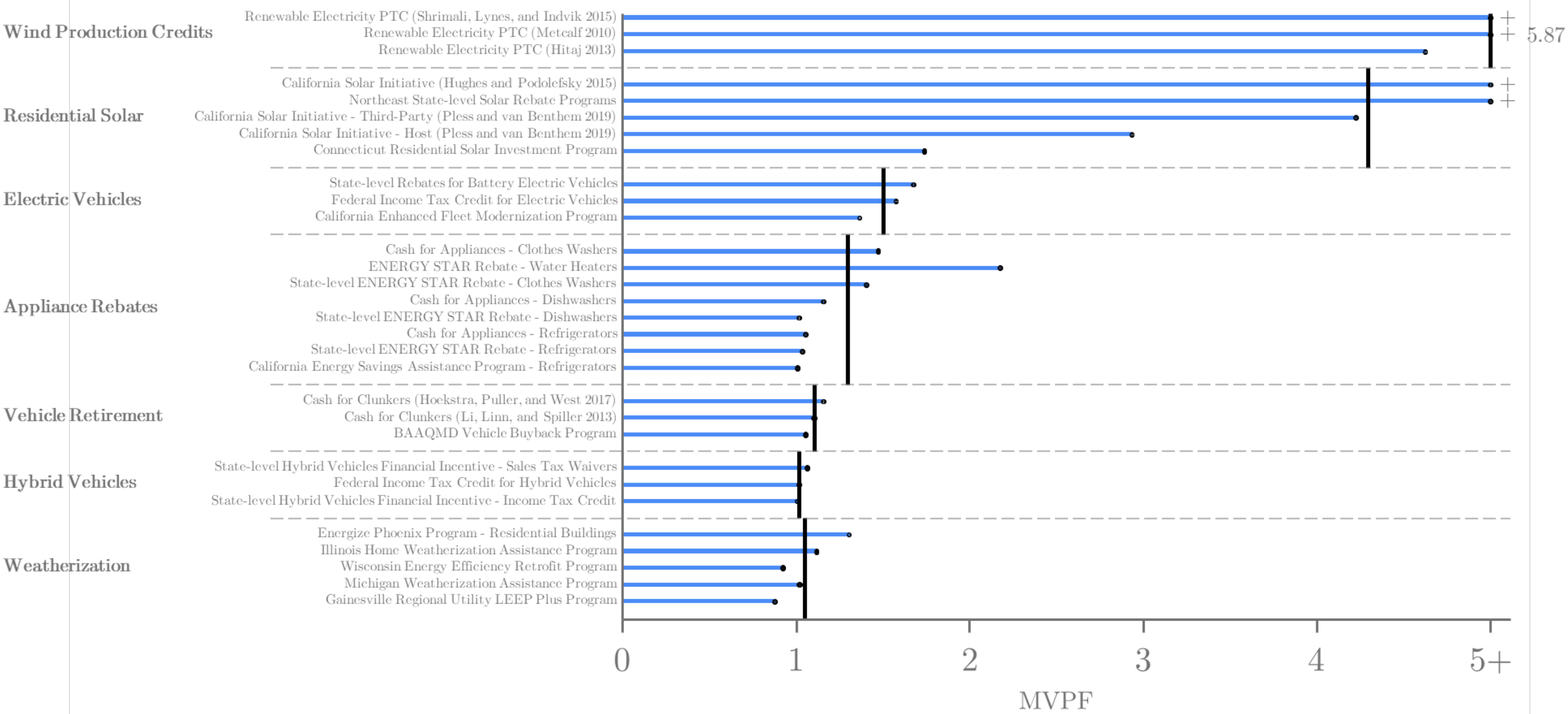

Model Fit for Estimate of Publication Bias (AK 2019)
Cumulative Probability
1
.8
.6
.4
.2
0
0
1
2
3
4
5
T-stat (abs. val.)
Empirical CDF
Fit using AK (2019) method


Histogram Evidence of Publication Bias
Implied pub. bias: 2.364
Number of Published Studies
25
20
15
10
5
0
1
2
3
4
t-stat (Abs. value, averaged within groups of .98)



Funnel Plot Evidence of Publication Bias
Slope=-1/1.96
Slope=1/1.96
Standard Error
Point Estimate
3
2
1
0
-5
0
5

MVPFs of Climate Subsidies (Excluding Profits)



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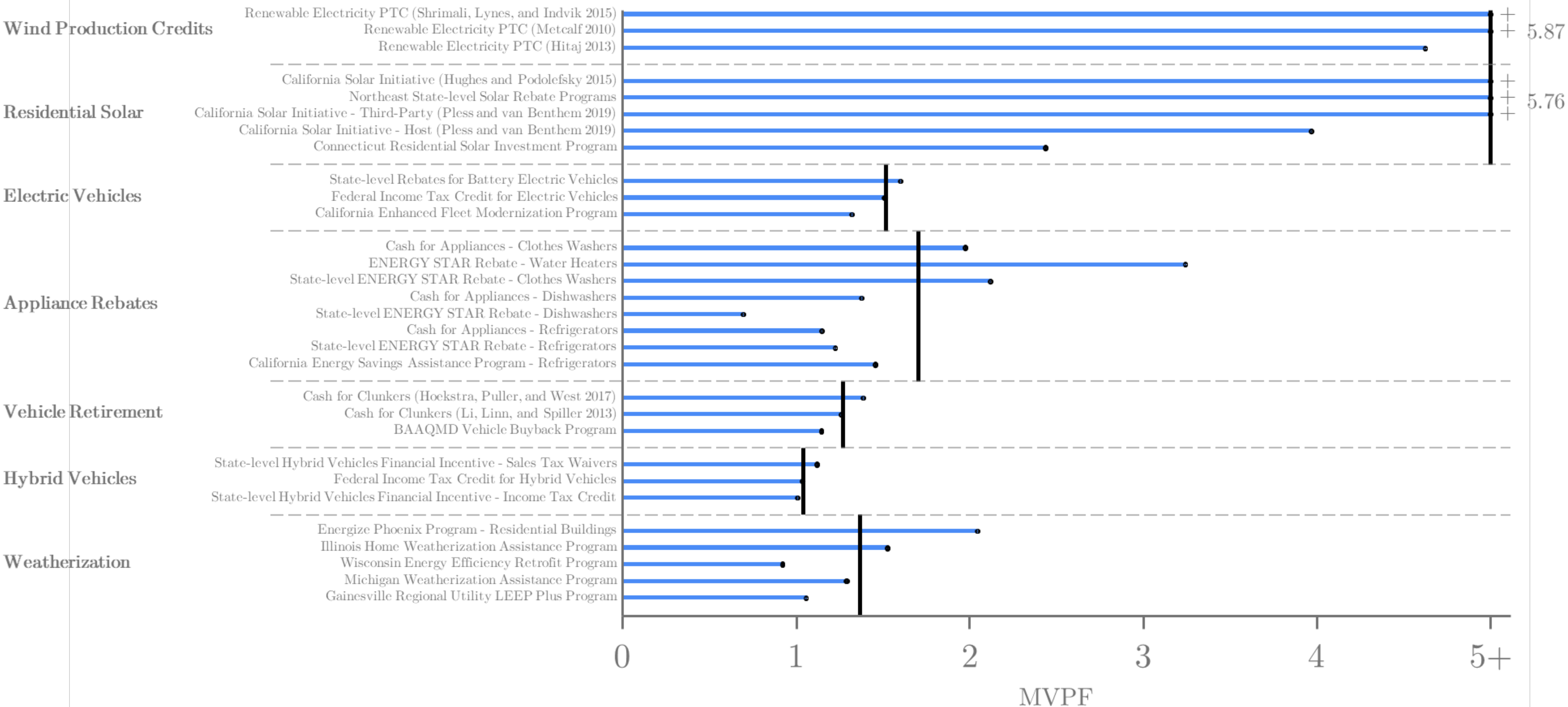
MVPFs of Climate Subsidies (Including Energy Savings)



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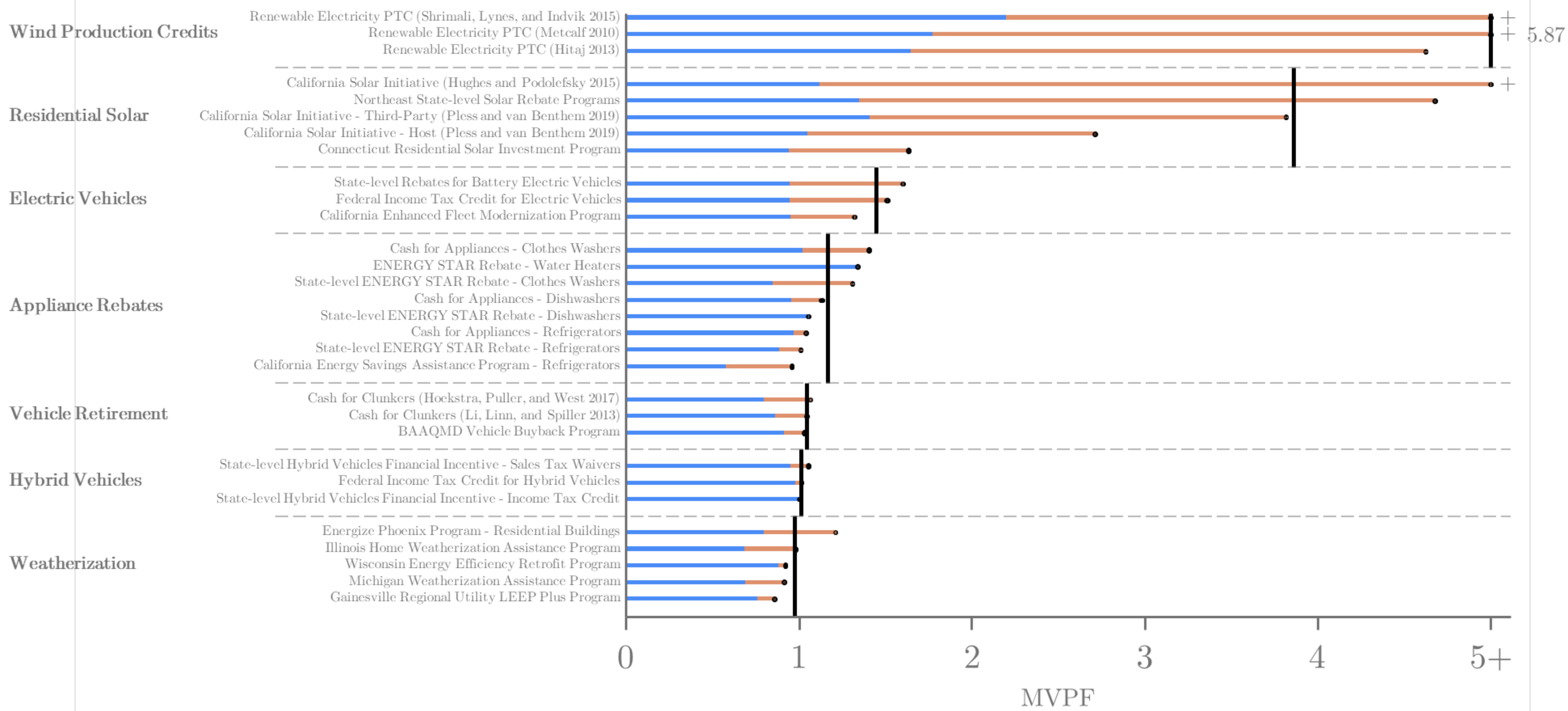
MVPFs of Climate Subsidies (US vs Rest of World)



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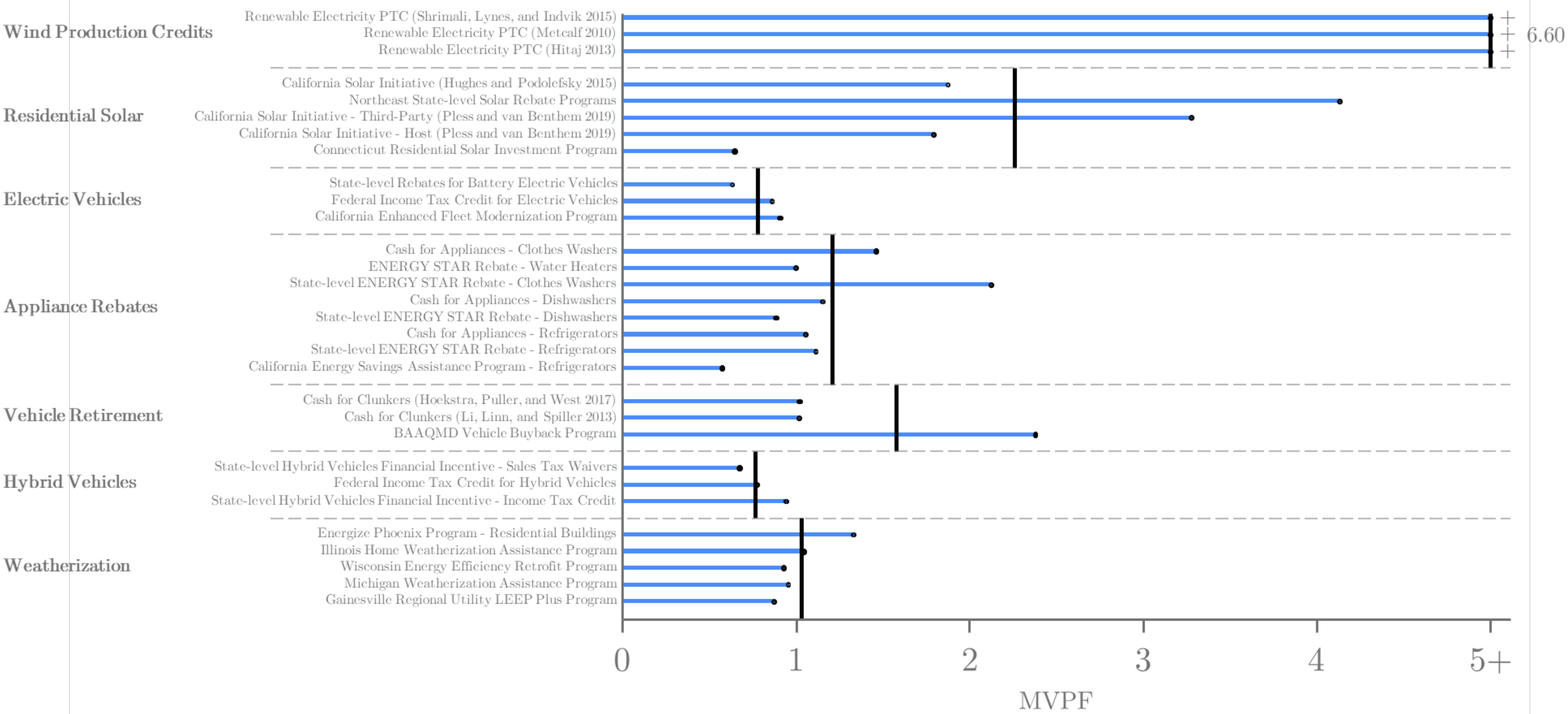
MVPFs of Climate Subsidies (In Context)



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MVPF Versus Cost Per Ton Excluding Learning by Doing

	MVPF	Cost Per Ton		
		Resource	Government	Social
Subsidies				
Wind Production Credits	3.851	-42	69	-8
Residential Solar	1.446	4	237	83
Electric Vehicles	0.961	963	2,422	283
Appliance Rebates	1.164	-2	474	111
Vehicle Retirement	1.047	987	876	148
Hybrid Vehicles	0.998	659	6,041	43
Weatherization	0.978	194	779	207
Nudges and Marketing				
Opower Elec. (166 RCTs)	2.548	-41	77	70
Revenue Raisers				
Gasoline Taxes	0.673	-104	-768	-62

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MVPF Versus Cost Per Ton Excluding Learning by Doing

	MVPF	Net Social Cost Per Ton			
		0% DWL	10% DWL	30% DWL	50% DWL
Subsidies					
Wind Production Credits	5.870	-32	-24	-15	-6
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Nudges and Marketing					
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Revenue Raisers					
Gasoline Taxes	0.671	-64	-140	-294	-448

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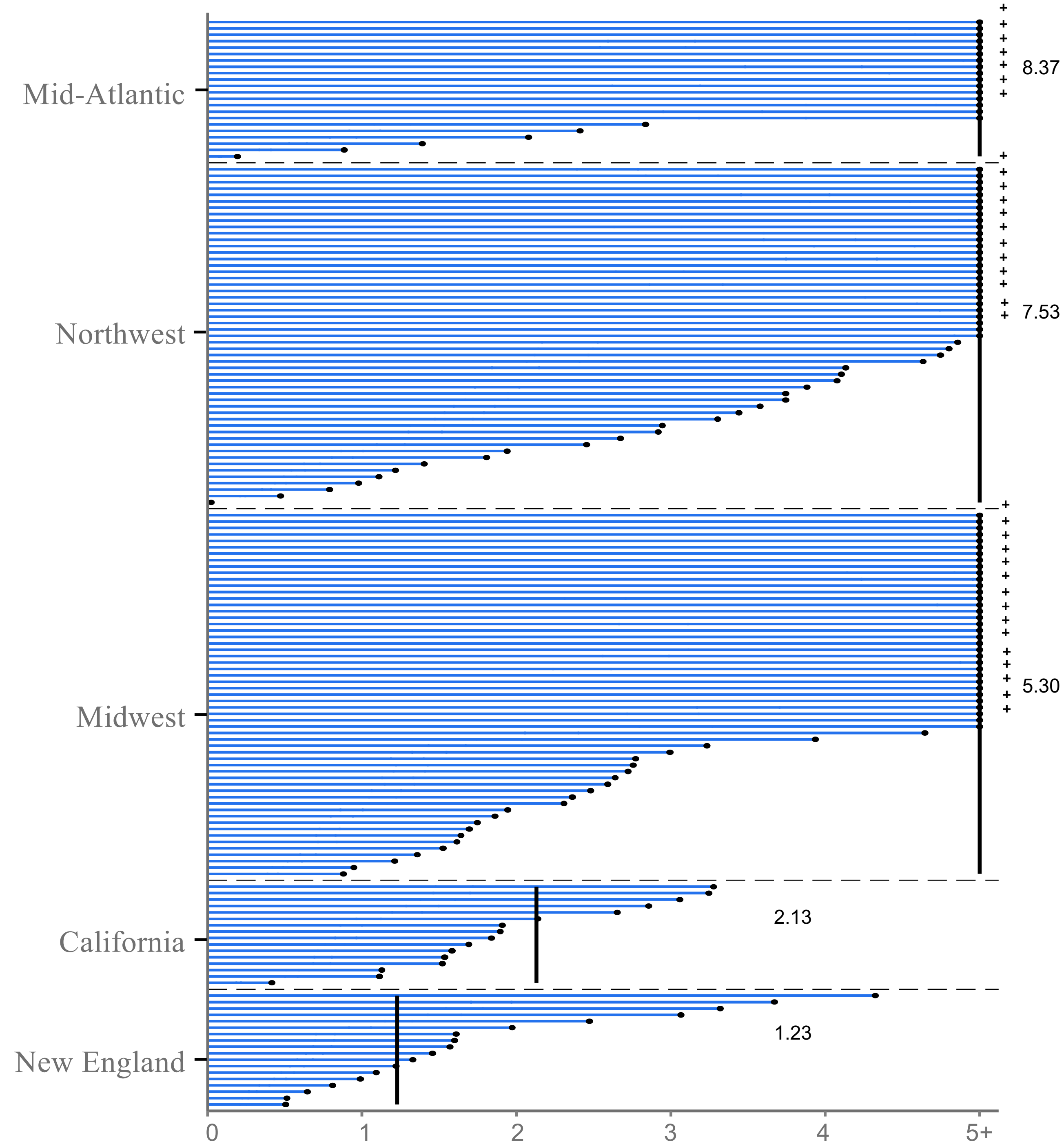
MVPFs of HERs With 49% Energy Savings



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Stock and Gillingham (2018)

Table 2

Static Costs of Policies based on a Compilation of Economic Studies
(ordered from lowest to highest cost)

	Policy	*Estimate ($2017/ton CO_{2e})*
Resource cost per ton	Behavioral energy efficiency	−190
	Corn starch ethanol (US)	−18 to +310
	Renewable Portfolio Standards	0–190
	Reforestation	1–10
Government cost per ton	Wind energy subsidies	2–260
	Clean Power Plan	11
social cost per ton	Gasoline tax	18–47
	Methane flaring regulation	20
	Reducing federal coal leasing	33–68
	CAFE Standards	48–310
	Agricultural emissions policies	50–65
	National Clean Energy Standard	51–110
	Soil management	57
	Livestock management policies	71
	Concentrating solar power expansion (China & India)	100
	Renewable fuel subsidies	100
	Low carbon fuel standard	100–2,900
Government cost per ton	Solar photovoltaics subsidies	140–2,100
	Biodiesel	150–250
	Energy efficiency programs (China)	250–300
Government cost per ton	Cash for Clunkers	270–420
	Weatherization assistance program	350
	Dedicated battery electric vehicle subsidy	350–640

Note: Figures are rounded to two significant digits. We have converted all estimates to 2017 dollars for comparability. See Appendix Table A-1 for sources and methods. CO_{2e} denotes conversion of tons of non-CO_2 greenhouse gases to their CO_2 equivalent based on their global warming potential.

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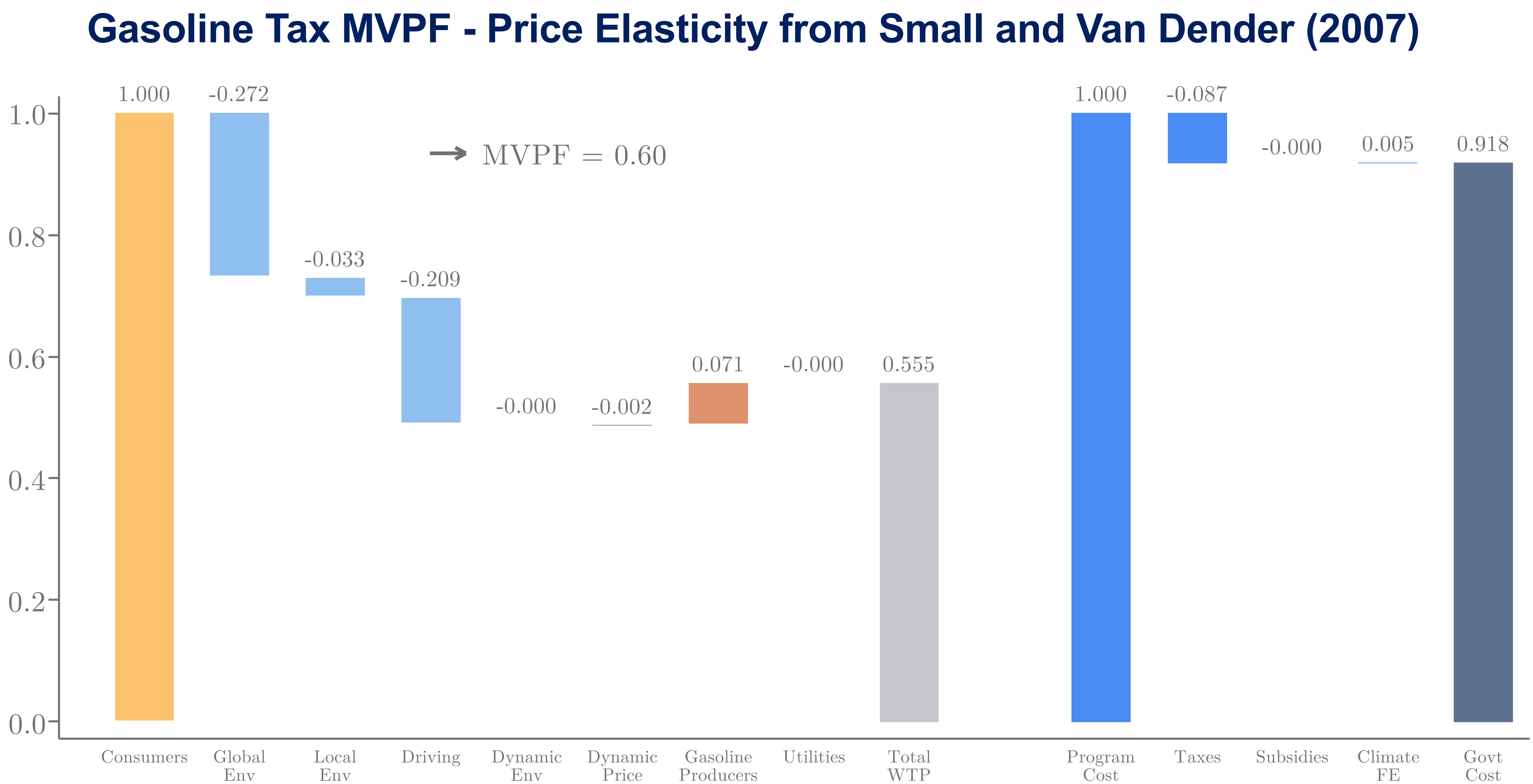
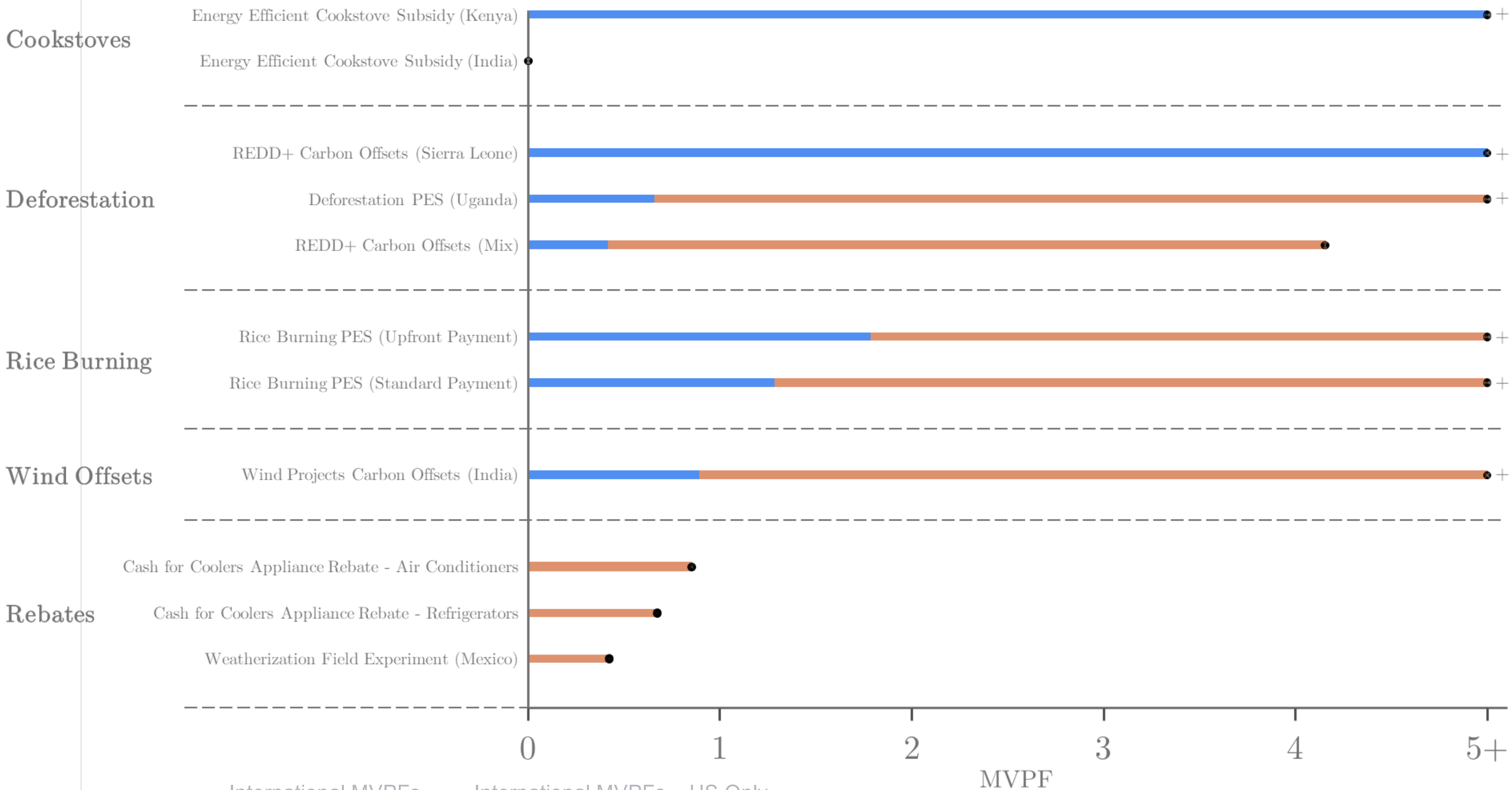
Additional Analyses in the Paper

- Regulation and Cap-and-Trade [Link]
  - Can use MVPF framework to compare regulation to tax/subsidy
  - Can construct MVPF of auctioned permits in Cap and Trade systems
- Distributional Incidence [Link]
  - Excluding non-US benefits → MVPFs near 1 for most US-based subsidies
  - Subsidies and taxes disproportionately affect the rich
- Publication Bias [Link]
  - Papers with t-stats > 1.96 are 2X more likely to be published
  - Adjusting for this using Andrews and Kasy (2019) does not meaningfully affect conclusions
- Non-Marginal analysis [Link]
  - Evaluate how MVPF varies for 1st vs. last dollar of subsidy/tax and consider non-marginal policy changes corresponding to EV, Residential Solar and Wind policies under the IRA
  - Relative orderings and broad magnitudes remain unchanged



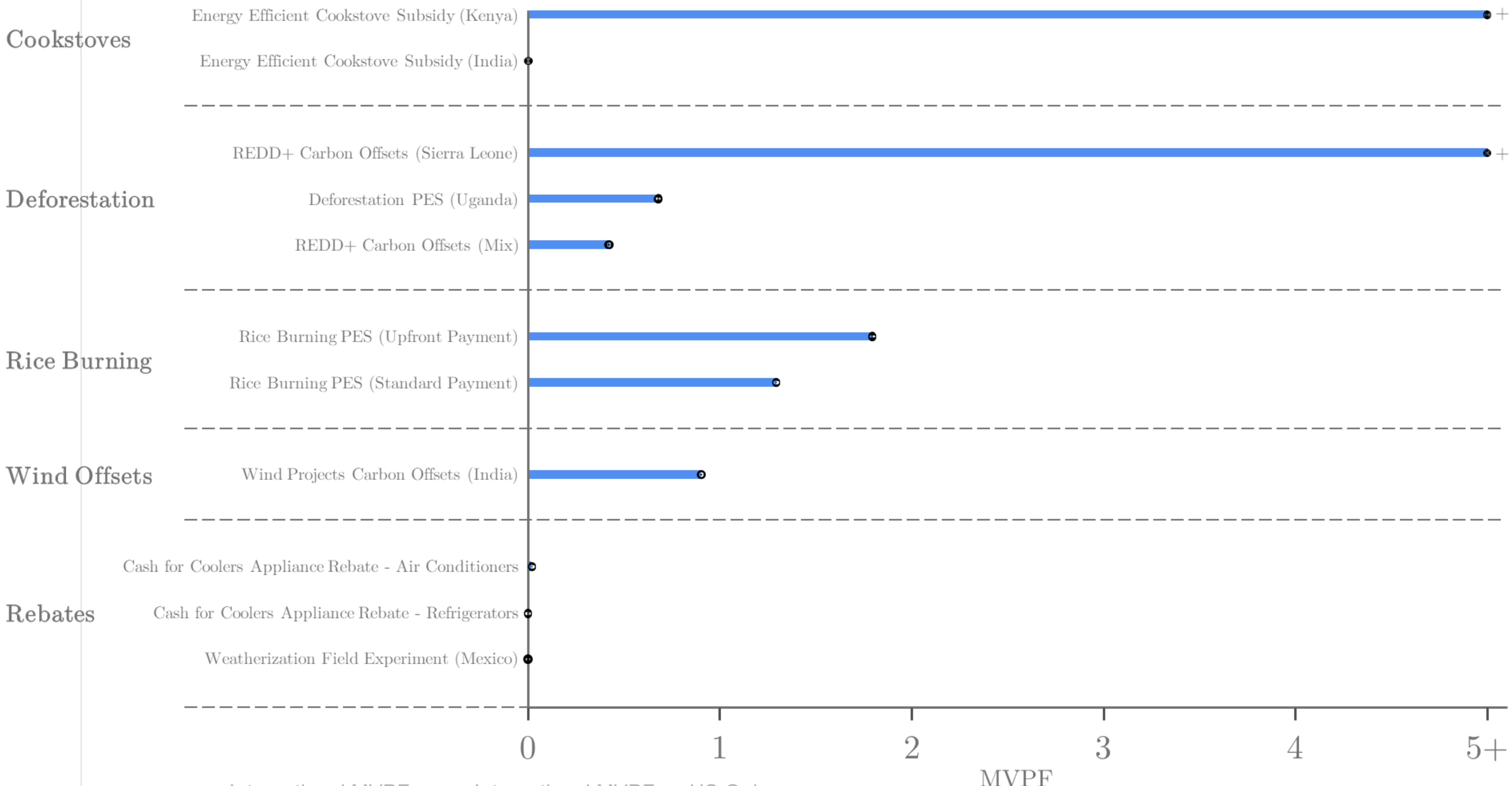
Gasoline Tax MVPF - Price Elasticity from Small and Van Dender (2007)
1.000
-0.272
-0.033
-0.209
-0.000
-0.002
0.071
-0.000
0.555
1.000
-0.087
-0.000
0.005
0.918
→ MVPF = 0.60
1.0
0.8
0.6
0.4
0.2
0.0
Consumers
Global Env
Local Env
Driving
Dynamic Env
Dynamic Price
Gasoline Producers
Utilities
Total WTP
Program Cost
Taxes
Subsidies
Climate FE
Govt Cost

US-Only MVPFs of International Policies



International MVPFs International MVPFs – US Only Back

US-Only MVPFs of International Policies



International MVPFs International MVPFs – US Only Back