THE DISTRIBUTIONAL EFFECTS OF US TAX CREDITS FOR HEAT PUMPS, SOLAR PANELS, AND ELECTRIC VEHICLES

Severin Borenstein and Lucas W. Davis

US households have received more than $47 billion in tax credits since 2006 for heat pumps, solar panels, electric vehicles, and other "clean energy" technologies. Using information from tax returns, we show that these tax credits have gone predominantly to higher-income filers. The bottom three income quintiles have received about 10 percent of all credits, while the top quintile has received about 60 percent. The most extreme is the tax credit for electric vehicles, for which the top quintile has received more than 80 percent. These patterns have changed little over time. We then present evidence on cost-effectiveness and discuss broader economic considerations.

Keywords: tax expenditures, distribution of income, concentration index, climate change

JEL Codes: D30, H23, H24, H50, Q41, Q48

I. INTRODUCTION

The year 2023 was by far the warmest year on record, with average temperatures 1.35°C above the preindustrial average (NOAA, 2024). Increased temperatures, drought, wildfires, and other climate impacts are intensifying the efforts of policy makers to transition markets away from fossil fuels. The Intergovernmental Panel on Climate Change concludes that greenhouse gas emissions must be reduced dramatically this decade if warming is to be limited to 2°C (IPCC, 2023).

Severin Borenstein: Haas School of Business at University of California, Berkeley and Energy Institute at Haas, Berkeley, CA, USA (severinborenstein@berkeley.edu); Lucas W. Davis: Haas School of Business at University of California, Berkeley and Energy Institute at Haas, Berkeley, CA, USA (lwdavis@berkeley.edu)

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Economists nearly universally agree that pricing greenhouse gases directly would be the most efficient approach to reduce emissions. Instead, the dominant approach, particularly in the United States, has been to subsidize clean energy technologies. Compared with first-best policies, relatively less is known about the economic efficiency and distributional effects of this type of policy.

This paper uses data from US federal income tax returns from 2006 to 2021 to examine the distributional effects of clean energy tax credits. During this period, US households received more than $47 billion in tax credits for buying heat pumps, solar panels, electric vehicles, and related technologies. The biggest single category is solar panels, with more than $4 billion in tax credits annually by the end of our sample period.

We find that clean energy tax credits have gone predominantly to higher-income filers. The bottom three income quintiles have received about 10 percent of all credits, while the top quintile has received about 60 percent. The most extreme is the tax credit for electric vehicles, for which the top quintile has received more than 80 percent of all credits, and the top 5 percent has received about 50 percent.

The concentration of tax credits among high-income filers has changed little over time. We find a slight broadening for the electric vehicle credit since 2018, but even by the end of the time period the top quintile is still receiving about 80 percent of all credits. To put these numbers in the context of income shares, the US Census reports that during 2018–2022, the top quintile of households received about 52 percent of household income, while the bottom quintile received about 3 percent of household income.

We then present evidence on cost-effectiveness and discuss broader economic considerations. Examining aggregate national data on heat pumps, solar panels, and electric vehicles, we look for changes in adoption in years when tax credits were phased in, phased out, or otherwise changed significantly. Overall, we find little correlation between tax credits and technology adoption. For heat pumps, in particular, it is hard to see any discernible impact from significant past changes in the availability of the tax credit, though it is difficult to draw strong causal conclusions from year-to-year comparisons.

Our paper updates and extends previous studies of clean energy tax credits (Crandall-Hollick and Sherlock, 2014; Borenstein and Davis, 2016; Neveu and Sherlock, 2016; Coyne and Globus-Harris, forthcoming). Our paper uses publicly available data, not administrative data, so we cannot examine outcomes by state like Coyne and Globus-Harris (forthcoming), but the publicly available data have the advantage of being available for the entire time period 2006–2021. We follow closely Borenstein and Davis (2016), incorporating almost a decade of additional data along with comparisons over time and additional analyses. We think now is a particularly opportune time for such an update given increased attention and funding for clean energy tax credits under the Inflation Reduction Act of 2022 (IRA).

Examining distributional effects using data from household income tax returns has a number of limitations: (1) These data do not reflect tax credits received for clean energy technologies that are leased. (2) These data miss households that do not file a tax return, which is estimated to be approximately 18 percent of all US households.[1] (3) Studying which households claim a tax credit does not address how much the benefits are absorbed by sellers of the good through price increases. (4) Any analysis based on a single year of household income captures imperfectly the notions of equity that would concern most policy analysts.

The study is related to a broader literature on the distributional effects of environmental policy. Previous papers have examined, for example, gasoline taxes (Poterba, 1991; Bento et al., 2009; Glaeser, Gorback, and Poterba, 2023), carbon taxes (Metcalf, 1999; Williams et al., 2015; Goulder et al., 2019), cap-and-trade for carbon emissions (Dinan and Rogers, 2002; Burtraw, Sweeney, and Walls, 2009), fuel economy standards (Davis and Knittel, 2019), building codes (Bruegge, Deryugina, and Myers, 2019), and solar panel subsidies (Borenstein, 2017; Feger, Pavanini, and Radulescu, 2022).

The study is also related to a well-known literature in economics considering the role of direct and indirect taxes for redistribution. Atkinson and Stiglitz (1976) derive conditions under which all redistribution should be done through direct taxes. Saez (2002) shows small indirect taxes can be desirable when tastes are heterogeneous, and Allcott, Lockwood, and Taubinsky (2019) provide formulas for optimal indirect taxes with heterogeneous tastes, externalities, and behavioral biases.

II. BACKGROUND

In this section, we review the major categories of income tax credits available to US households since 2006 for clean energy investments.

A. Energy Efficiency

Tax credits for windows and other residential investments in energy efficiency are known as “Section 25C” credits. Expenditures that are eligible for this tax credit include ceiling and wall insulation, energy-efficient windows, doors, and certain roofs, as well as certain energy-efficient heating and cooling equipment such as heat pumps. Homeowners can receive a tax credit equal to a fixed percentage (usually 10 percent) of the installed price of the equipment up to some maximum value. Neither renters nor landlords are eligible, and these tax credits are for improvements to existing homes, not for new homes.

In the distributional analyses that follow, we are unable to distinguish between different categories of expenditures. Internal Revenue Service (IRS) publications do make it possible, however, to see in aggregate how much is claimed by category. In 2020, major categories included qualified roofs (23 percent), ceiling and wall

[1] See https://taxfoundation.org/blog/us-households-paying-no-income-tax/.

insulation (21 percent), energy-efficient doors (14 percent), and energy-efficient windows and skylights (13 percent).[2]

This category of tax credits has a long history, going back to the Federal Energy Tax Act of 1978. The original rationale for the credits was a response to the energy crises of the 1970s and an effort to increase "energy security." Research on these early credits found that they were claimed more often in places with cold winters, high energy prices, and high incomes (Dubin and Henson, 1988). These credits expired in 1985 and lay dormant for two decades until they were restarted under the Energy Policy Act of 2005 and made available in 2006.

Between 2006 and 2021, these credits were known as the Nonbusiness Energy Property Credit or NEPC. During most years the NEPC provided a 10 percent tax credit for eligible investments up to a maximum of $500. However, across years there have been several interruptions and other changes. The credits expired at the end of 2007 and were not available during 2008. Then as part of the American Recovery and Reinvestment Act (ARRA), the credit was reinstated for two years at a higher level. Thus, during 2009 and 2010, the credit was increased from 10 to 30 percent, and the cap was increased from $500 to $1,500.

The credit then continued at the standard 10 percent rate with a $500 maximum from 2011 to 2017. The NEPC expired at the end of 2017 and was not available during 2018 before being reinstated in 2019.[3] See Neveu and Sherlock (2016) and Crandall-Hollick and Sherlock (2018) for a complete legislative history.

With the IRA, these credits became much more generous.[4] Starting in 2023, the standard credit rate increased from 10 to 30 percent, and limits increased for most categories from $500 to $1,200. For heat pumps, the maximum credit amount increased from $300 to $2,000. Our analysis uses data from 2006 to 2021 and thus represents the period before the IRA, but it will be interesting in future work to assess this later period.

B. Residential Solar

Tax credits for residential solar and other types of residential renewables are known as "Section 25D" credits as well as by the somewhat confusing name

[2] Authors' calculations based on IRS, "Individual Income Tax Returns: Line Item Estimates (Publication 4801)."

[3] The temporary suspensions of the NEPC in 2008 and 2018 explain why in the data described later in the paper there are no expenditures for these years. Taxpayers in 2019 were allowed to file amended returns for 2018 claiming the NEPC, but our data do not include information from amended returns.

[4] The IRA was signed into law by President Biden on August 16, 2022. See Inflation Reduction Act of 2022, H.R. 5376, 117th Congress. Public Law 117–169. Under the IRA these credits were expanded, extended, and renamed the *Energy Efficiency Home Improvement Credit*. See Congressional Research Service, "Residential Energy Tax Credits: Changes in 2023," November 21, 2022, and IRS, "Frequently Asked Questions about Energy Efficient Home Improvements and Residential Clean Energy Property Credits," December 2022.

Residential Energy Efficiency Property Credit (REEPC). In practice, the REEPC goes overwhelmingly to residential solar. During 2020, for example, 89 percent of the expenditures under this credit went to residential solar ("solar electric property" in IRS parlance), compared with 4 percent for solar water heating systems, 4 percent for geothermal heat pumps, 1 percent for small wind projects, and 1 percent for fuel cell property costs.[5]

The generosity of these credits has varied considerably over time. First established by the Energy Policy Act of 2005, the REEPC provided between 2006 and 2008 a 30 percent credit for qualified expenditures, up to a maximum of $2,000 for most categories. Notably, this $2,000 maximum did not apply to commercially owned systems, which gave leasing preferential treatment in the residential solar market (Borenstein, 2017). A company like Sunrun could own the solar panels, collect a 30 percent tax credit for the entire cost of the system, and then lease the system to the homeowner using a monthly fee or other arrangement.

The $2,000 maximum was removed starting in 2009 under ARRA. Residential solar systems typically cost tens of thousands of dollars, so removing the cap was a significant increase in the generosity of the program. A homeowner installing a $20,000 system, for example, could collect a $6,000 tax credit. The change in 2009 also leveled the playing field between customer-owned systems and third-party-owned systems, both leased and power purchase agreements.[6]

Starting in 2020, the credit was decreased from 30 to 26 percent, before being increased back to 30 percent under the IRA in 2022. A household installing solar panels in early 2022 would likely have expected to receive a 26 percent credit, but the IRA passed in August 2022 and restored the 30 percent credit for any installations made during 2022.[7] Under the IRA, the REEPC is scheduled to remain at 30 percent through 2031, then decrease to 26 percent in 2032, and to 22 percent in 2034.

C. Electric Vehicles

The income tax credits for electric vehicles are known as "Section 30D" credits, and for much of this period by the name Qualified Plug-In Electric Drive Motor Vehicle Credit, or PEDVC.

First available in 2010, the PEDVC is available to households who purchase new electric and plug-in hybrid vehicles. Tax credits range from $2,500 to $7,500, depending on the battery capacity of the vehicle. In practice, most vehicles qualified for the full $7,500 credit, including all Tesla vehicles, Nissan Leaf, and Chevrolet

[5] Authors' calculations based on IRS, "Individual Income Tax Returns: Line Item Estimates (Publication 4801)."

[6] Under a power purchase agreement, a third party installs panels on the home and bills the homeowner for the electricity generated by those panels. The third party retains ownership of the system.

[7] For details see, e.g., Congressional Research Service, "Residential Energy Tax Credits: Changes in 2023," November 21, 2022, https://crsreports.congress.gov/product/pdf/IN/IN12051.

Volt and Bolt, though the Toyota Prius Plug-in Hybrid, with its smaller battery, qualified for a $2,500 credit.

An unusual feature of the PEDVC is that the tax credit was phased out when a manufacturer sold 200,0000 qualifying vehicles. The first manufacturer to reach this threshold was Tesla, so the tax credit for Tesla was reduced from $7,500 to $3,750 on January 1, 2019, then to $1,875 on July 1, 2019, and to $0 on January 1, 2020. GM was the second manufacturer to reach the threshold, so the tax credit for GM was similarly phased out, with a four-month delay compared with Tesla.

The PEDVC was changed considerably under the IRA. Vehicles purchased between August 16, 2022, and December 31, 2022, were required to have undergone final assembly in North America. Then, starting in 2023, several additional changes took effect: (1) the manufacturer phaseout was discontinued, (2) a maximum income requirement for eligibility was implemented, for example, married couples filing jointly must have annual income below $300,000, (3) the vehicle's manufacturer's suggested retail price cannot exceed $80,000 for SUVs and other large vehicles or $55,000 for smaller vehicles, and (4) vehicles must meet a series of increasingly stringent critical mineral and battery component requirements. Our analysis uses data from 2006 to 2021 so does not reflect these changes under the IRA.

D. Other Related Credits

During this time period, there were also a couple of smaller related tax credits that we did not examine. Probably best known is the Alternative Motor Vehicle Credit (AMVC). Between 2006 and 2010, the AMVC provided a tax credit of up to $4,000 for qualified conventional hybrid vehicles like the original Toyota Prius. Since 2011 there has been no tax credit available for conventional hybrid vehicles, but the AMVC continues to exist and is available for buyers of hydrogen and fuel cell vehicles. A total of $861 million went to the AMVC between 2006 and 2021, with a maximum annual expenditure of $185 million in 2007.[8] See Gallagher and Muehlegger (2011), Sallee (2011), and Borenstein and Davis (2016) for more on the AMVC.

Another related credit is the Alternative Fuel Vehicle Refueling Property Credit (AFVRPC). This tax credit is small compared with the others, with only $96 million in total tax expenditure between 2005 and 2021.[9] The AFVRPC is for eligible investments in residential electric vehicle chargers and other alternative fuel vehicle refueling equipment. During 2021, for example, a household could receive a 30 percent credit (up to a maximum of $1,000) for electric vehicle charging

[8] Authors' calculations based on IRS, "Individual Income Tax Returns Complete Report (Publication 1304)," 2006–2021, https://www.chicagofed.org/publications/blogs/chicago-fed-insights/2023/charging-ahead-trends-in-leasing-bevs.

[9] Authors' calculations based on IRS, "Individual Income Tax Returns Complete Report (Publication 1304)," 2006–2021.

equipment. The AFVRPC was expanded and extended with the IRA, so it will be worth examining closely in future research.

III. DISTRIBUTIONAL ANALYSIS

In this section, we use income tax return data to examine the distributional consequences of clean energy tax credits from 2006 to 2021. We describe the IRS data, summarize total tax expenditures, calculate average credit amounts by income category, construct concentration curves, calculate concentration indexes, and then discuss additional results and limitations.

A. Data Description

The information for the distributional analysis was compiled using data from the US Department of Treasury, IRS. We compiled information from two different sources from the IRS Statistics of Income program.

The first data source is the IRS "Individual Income Tax Returns Complete Report (Publication 1304)," which describes the number of returns filed, sources of income, exemptions, itemized deductions, and other features of the income tax system, as well as information about how these features vary by adjusted gross income (AGI), marital status, age of taxpayer, and other characteristics. For the distributional analyses that follow, we focus in particular on "Table 3.3 All Returns: Tax Liability, Tax Credits, and Tax Payments."

This report is published annually with a delay of about two years. The most recent available data (for the tax year 2021) were released in November 2023. For each tax credit, these data report the total number of returns that claimed that credit and the total dollar value of claims. Statistics are reported for 19 or 20 different categories of AGI (depending on the year). In some of our analyses, we collapse these categories into approximate quintiles to make the evidence easier to interpret.

This information from the IRS is based on large representative samples drawn from the 160+ million individual income tax returns filed each year. The IRS reports standard errors for all summary statistics, expressed as a percentage of the statistic being estimated.[10] The IRS does not provide the entire variance-covariance matrix, so we are unable to formally test for differences between statistics.

In some cases, it is possible for households to carry credits across tax years. In general, it has been possible to carry forward the REEPC (solar panels) but not the NEPC (energy efficiency) or PEDVC (electric vehicles). The IRS data describe

[10] See IRS, "Individual Income Tax Returns Complete Report (Publication 1304)," "Table 3.3CV: Coefficients of Variation for All Returns: Tax Liability, Tax Credits, and Tax Payments," https://www.chicagofed.org/publications/blogs/chicago-fed-insights/2023/charging-ahead-trends-in-leasing-bevs. The underlying samples included, e.g., 370,000+ returns in 2019 and 385,000+ returns in 2020.

tax credits in the year that they are used, regardless of when the original credit was generated.

The second data source is the IRS "Individual Income Tax Returns: Line Item Estimates (Publication 4801)." These annual reports go line-by-line through the 1040 and accompanying schedules and forms, providing an estimate of the number of filers that included a nonzero number and the sum recorded by all filers. This line-item information is estimated using the same large representative samples used for the summary statistics.

The advantage of the line-item estimates is that they provide more details in some cases. For example, the line-item estimates are available separately for the NEPC (energy-efficiency credits) and the REEPC (residential solar credits), whereas the summary statistics combine these two categories. The line-item estimates from Form 5695, "Residential Energy Credits," are also interesting because they show, in the aggregate, how much of the credit is going to, for example, energy-efficient doors versus energy-efficient windows versus other types of investments as we reported earlier. These line-item estimates do not allow us to examine the correlation between tax credits and income, which is why we rely instead on the other data set for our main results.

B. Summary of Total Tax Expenditures

Table 1 reports annual expenditures for the three major categories of clean energy tax credits. Between 2006 and 2021, total expenditures were $47.7 billion. The tax credit for residential solar is the largest of the three categories, with total expenditures of $24.9 billion. Tax credits for energy efficiency are the second largest category, with a total expenditure of $17.3 billion, though more than 60 percent comes from two years, 2009 and 2010, when this tax credit was temporarily increased from 10 to 30 percent. Tax credits for electric vehicles are smaller: total expenditures of $5.5 billion, with a peak of $1.5 billion in 2018 before the tax credit was phased out for Tesla and GM.

Tax expenditures vary considerably across years. Some of this variation reflects changes in take-up. The year-to-year increases in tax expenditures for residential solar, for example, reflect the steady growth of this sector throughout the time period. But much of the variation in Table 1 also reflects changes over time in the tax code. In the case of energy efficiency, for example, not only were there two unusually generous years 2009 and 2010, but there were also two years (2008 and 2018) during which the tax credit was not available.

Although substantial, it is worth pointing out that these tax credits are not among the top 10 largest tax expenditures in the United States. Total annual tax expenditures in the United States in 2019 were $1.2 trillion (Congressional Budget Office, 2021). The exclusion for employment-based health insurance, for example, was $280 billion. The childcare tax credit and earned income tax credit were $118 billion and $70 billion, respectively. About half of all US income tax expenditures go

Table 1
Annual Expenditures on US Clean Energy Tax Credits, in Millions

Year	Windows and Other Energy-Efficiency Investments (NEPC)	Residential Solar and Other Residential Renewables (REEPC)	Qualified Plug-In Electric Vehicle Credit (PEDVC)
2005	0	0	0
2006	957	43	0
2007	938	69	0
2008	0	217	0
2009	5,177	645	129
2010	5,420	754	1
2011	755	921	76
2012	449	818	139
2013	622	992	231
2014	518	1,120	263
2015	517	1,570	252
2016	513	1,823	375
2017	248	1,877	537
2018	0	2,512	1,541
2019	331	3,176	643
2020	406	3,469	313
2021	446	4,886	1,037
Total	17,297	24,892	5,537

Note: This table was constructed by the authors using the IRS "Individual Income Tax Returns Complete Report (Publication 1304)," 2006–2021 and the IRS "Individual Tax Returns: Line Item Estimates (Publication 4801)," 2006–2021.

to households in the top income quintile (Congressional Budget Office, 2021).[11] Part of the reason for the concentration among higher-income households is that many of the largest tax expenditures require a filer to itemize deductions.[12]

C. Average Credit per Return

Figure 1 plots the average credit per return by AGI. We focus on two categories of tax credits: residential energy credits and electric vehicle credits. The first category

[11] There are also studies that have examined in more detail the distributional effects of specific categories of tax expenditures, e.g., the mortgage interest deduction (Poterba and Sinai, 2011), tax credits for higher education (Bulman and Hoxby, 2015), and the earned income tax credit (Linos et al., 2022).

[12] According to the Congressional Budget Office (2021), only 11 percent of tax filers itemized deductions in 2019. In practice, it tends to be filers with relatively high incomes for whom the value of itemized deductions exceeds the standard deduction.

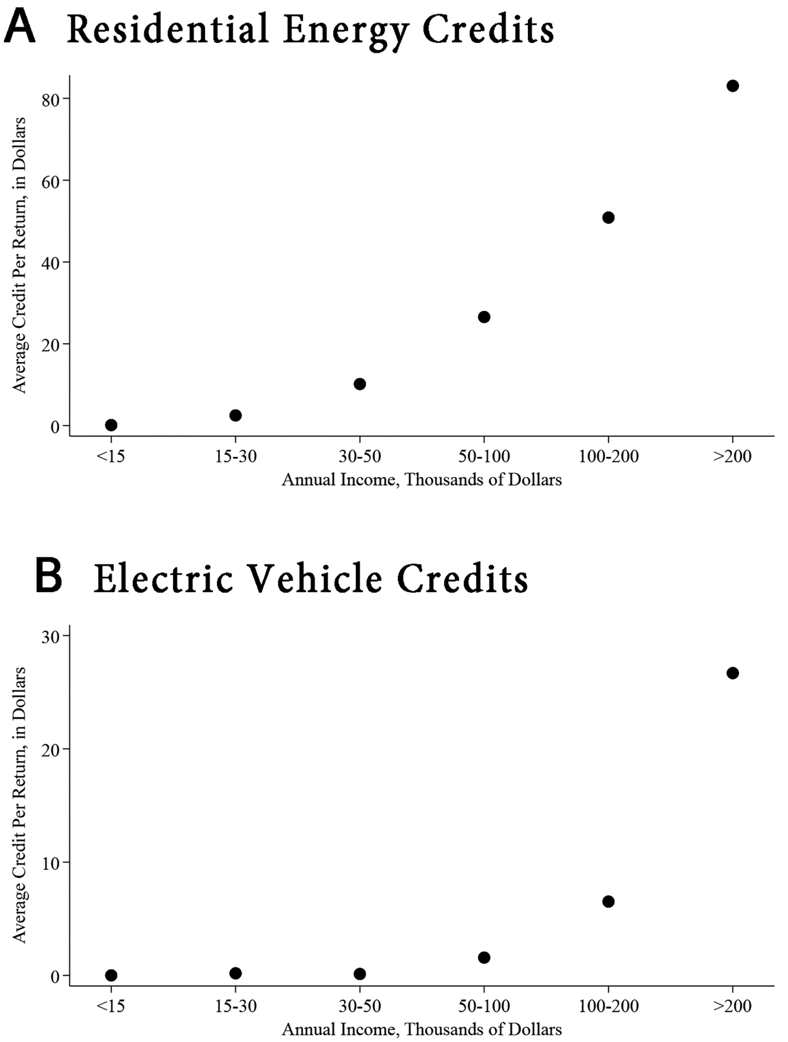


Figure 1. Average credit per return, by AGI. This figure was created by the authors using data from the IRS, "Individual Income Tax Returns Complete Report (Publication 1304)", "Table 3.3 All Returns: Tax Liability, Tax Credits, and Tax Payments", 2006–2021. For each year the table reports the total tax credits claimed for 20 AGI categories, which we pool across years and collapse into approximate quintiles (with the last two categories representing approximately the fifth quintile).

is the combination of the NEPC (energy-efficiency credits) and the REEPC (residential solar credits). Ideally, we would examine these credits separately, but the IRS annual reports combine these two categories.

For this figure we pooled data from across all years for which the credit was available; 2006–2021 for the left panel and 2009–2021 for the right panel. We divided AGI into six categories. The first four categories are approximately quintiles, and the last two categories together make up approximately the top quintile.[13]

The y-axis in these panels is the average credit per tax return. We calculate this average over all tax returns, including both filers who did and did not claim these credits. For example, the far-right observation in the first panel means that, among filers with more than $200,000 in AGI, the average amount claimed in residential energy credits was $83. The means in Table 1 are precisely estimated, so we do not plot 95 percent confidence intervals.

Both types of tax credits have gone predominantly to high-income filers. Tax filers with AGI below $50,000 receive little of either tax credit. With residential energy credits, the average credit per return is below $15 in the bottom three AGI categories, compared with $27, $51, and $83 in the three highest AGI categories.

The electric vehicle tax credit is even more concentrated. The average credit per return is less than $2 for filers with AGI below $100,000, compared with $7 for $100,000 to $200,000 and $27 for filers with AGI above $200,000. Compared with Borenstein and Davis (2016), these calculations incorporate nine additional years of data, yet the overall pattern is quite similar.

Part of the reason that the electrical vehicle credit tends to go to high-income households is that these households are more likely to buy new vehicles. US households in 2021 spent on new vehicles an average of $300, $1,000, $2,100, $2,600, and $5,100, respectively, across income quintiles.[14] The electric vehicle credit is even more concentrated in the highest income quintile than new vehicle spending overall.

D. Concentration Curves

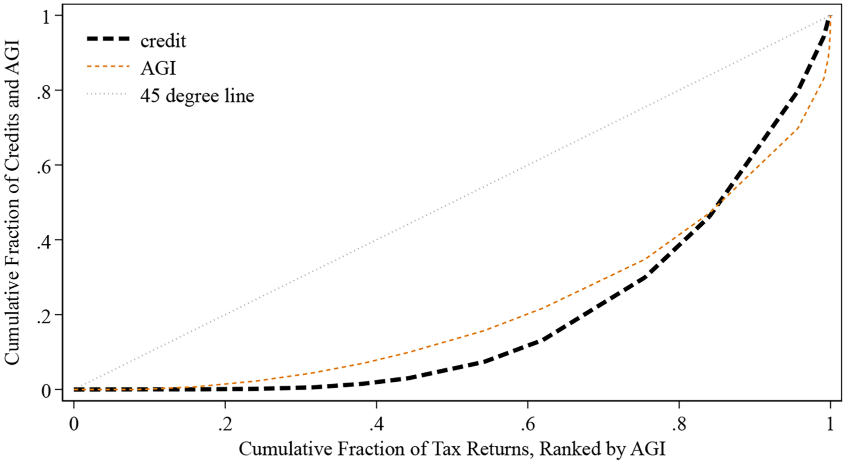
Figure 2 plots concentration curves for both credits to provide a visual representation of the degree to which they are concentrated among high-income filers. The figures also plot the concentration of income, making it possible to discern visually whether the distribution of tax credits is more or less concentrated than income. In constructing these figures, we use the same data as in the previous subsection, except that we now use all 19 or 20 income categories rather than just the six categories used previously.

It is first worth noting that income itself is highly concentrated. The AGI curve in each panel plots the cumulative fraction of AGI received by that percentile of filers. If income were equally distributed across filers, then the AGI curve would exactly follow the 45-degree line with, for example, the bottom three quintiles receiving 60 percent of all income. The farther below the 45-degree line, the more concentrated

[13] In 2021, e.g., the six categories included 20, 17, 18, 23, 15, and 7 percent of all tax returns, respectively.

[14] These statistics from the Federal Reserve Bank of St. Louis (FRED) were compiled using data from the US Bureau of Labor Statistics, Consumer Expenditure Survey.

A Residential Energy Credits



B Electric Vehicle Credits

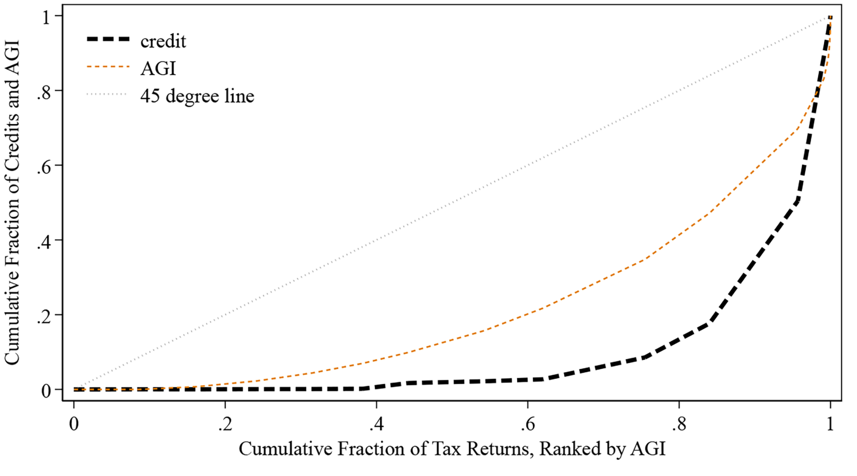


Figure 2. Concentration curves. This figure was created by the authors using data from the IRS, "Individual Income Tax Returns Complete Report (Publication 1304)", "Table 3.3 All Returns: Tax Liability, Tax Credits, and Tax Payments", 2006–2021. For each year the table reports the total tax credits claimed for 20 AGI categories, which we pool across years. From this same source, we also know the total number of returns by AGI category, which we use to construct the AGI curve.

income is among high-income filers. The figures show that the bottom three quintiles receive about 20 percent of all AGI and that the bottom four quintiles receive a bit more than 40 percent of all AGI.

The concentration curves for tax credits show the cumulative fraction received by each percentile of tax returns.[15] The curves are precisely estimated, so we do not plot 95 percent confidence intervals.

The residential energy credits are highly concentrated among high-income filers. The bottom three income quintiles have received about 10 percent of all residential energy credits, while the top quintile has received about 60 percent. The credits are more concentrated than income for low- and middle-income levels but are less concentrated than income for high-income levels.

The electric vehicle credits are even more highly concentrated. The bottom three quintiles have received less than 3 percent of electric vehicle credits, while the top quintile has received more than 80 percent. The concentration curve is nearly vertical at the top, with the top 5 percent of filers receiving about 50 percent of electric vehicle tax credits. The credits are much more concentrated than income at almost all income levels, and visually, the concentration curve for the electric vehicle credits is significantly lower than the concentration curve for residential energy credits.

These concentration curves are quite similar to Borenstein and Davis (2016), which performs this same exercise using tax credits for 2006–2012. The differences are subtle but suggest the residential energy credits may have become somewhat more concentrated and the electric vehicle credits may have become somewhat less concentrated.

E. Concentration Indexes

Figure 3 plots the concentration index by year. As usual, the concentration index is calculated as the ratio of the area between the concentration curve and the 45-degree line over the total area under the 45-degree line. A concentration index of zero indicates a credit that is equally distributed across all income levels, whereas a concentration index of one indicates maximum concentration, with a credit that is received entirely by the very top income category.

The concentration of these tax credits among high-income filers is relatively constant over time. The electric vehicle credit is more concentrated than the residential

[15] Concentration curves are similar to Lorenz curves but with the horizontal axis always ordering observations by income regardless of what is being measured on the vertical axis. The AGI curve in Figure 2 is a Lorenz curve, as the ordering on the horizontal axis (income) is the same attribute as is being measured on the vertical axis (income). Similarly, the concentration index, which we calculate in the following subsection, is similar to a Gini coefficient, though, again, with the horizontal axis ordering observations by income. Finally, the concentration index is similar to the Suits index, which is calculated relative to income and is generally used to measure the concentration of tax burden rather than receipt of tax credits. A progressive tax is one that is concentrated among high-income individuals; the curve is below the 45-degree line, and the Suits index is positive. A regressive tax has a curve above the 45-degree line, and the Suits index is negative.

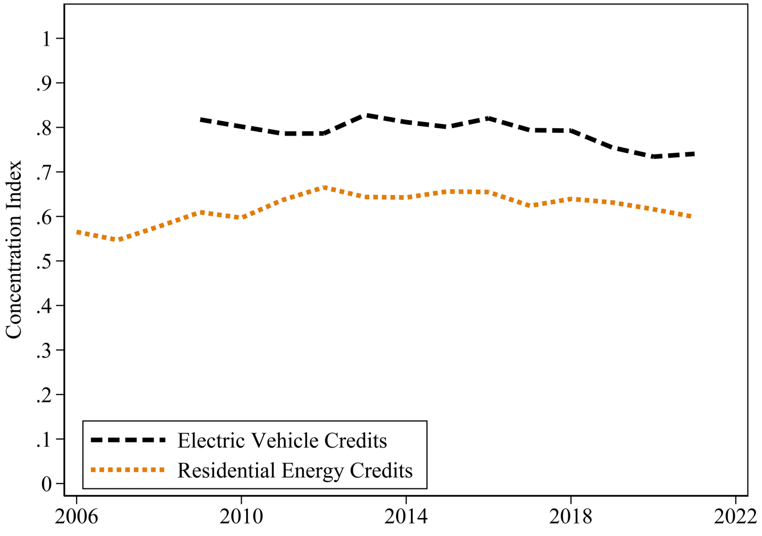


Figure 3. Concentration index by year. This figure was created by the authors using data from the IRS, "Individual Income Tax Returns Complete Report (Publication 1304)," "Table 3.3 All Returns: Tax Liability, Tax Credits, and Tax Payments," 2006–2021. For each year, the table reports the total tax credits claimed for 20 AGI categories. The concentration index is then calculated as the area between the concentration curve and the 45-degree line as a fraction of the total area under the 45-degree line.

energy credits, consistent with the results in the previous subsection. As a point of comparison, the Gini coefficient (i.e., the concentration index for AGI) using these same data pooled across all years is 0.57, so the residential energy credits are approximately equally concentrated as income, whereas the electric vehicle credits are considerably more concentrated than income.

There is relatively little year-to-year variation and only a slight downward trend for the electric vehicle credit and a slight upward trend for the residential energy credits. There are potential explanations for both trends. The increasing concentration of residential energy credits is consistent with a compositional shift of these credits away from energy efficiency and toward rooftop solar.[16] Related research has shown that rooftop solar tends to be highly concentrated among high-income households (Borenstein, 2017), and from the annual aggregate expenditures reported in Table 1, we know that REEPC has grown steadily and is now much larger than the NEPC.

[16] One of the authors of Coyne and Globus-Harris (forthcoming) was an employee at the US Treasury, so they were able to use administrative data from the Form 5695 "Residential Energy Credits" to examine the distributional effects of the REEPC and NEPC separately. Their evidence tends to find that the tax credit for solar panels (REEPC) is more concentrated among high-income filers than the tax credit for energy efficiency (NEPC).

The decreasing concentration of electric vehicle credits is consistent with a subtle broadening of the electric vehicle market over this period. At the beginning of this period there were only a couple of electric vehicle models for sale in the United States, but there are now more than a hundred. In addition, battery costs have continued to fall throughout this period, making electric vehicles accessible to a wider range of households. At the same time, we do not want to overstate this trend. Even by the end of our sample period, the concentration index for the electric vehicle credit is near .80, which is higher than the concentration index for the residential energy credits in all years.

F. Additional Results and Limitations

Additional results in the Appendix (available online) show the extensive and intensive margins separately, as a function of AGI. Both margins tend to increase steadily with income. For the residential energy credits, for example, less than 1 percent of filers with AGI below $30,000 claim the credit, compared with more than 4 percent of filers with AGI above $100,000. Similarly, the average credit per claimant is less than $500 for filers with an AGI below $30,000, compared with almost $2,000 for filers with an AGI above $200,000. Thus, higher-income filers are both more likely to claim these credits and tend to claim larger credit amounts.

One limitation of an analysis based on household income tax returns is that they do not reflect leases. This is generally not an issue with heat pumps, energy-efficient windows, or most types of energy-efficiency investments, which are rarely leased. But solar panels and electric vehicles are frequently leased. When a household leases solar panels or an electric vehicle, the lessor is able to claim the tax credit but the household is not.

This purchase versus lease distinction could affect distributional analysis, because previous research has shown that low-income households tend to be more likely than high-income households to use leases. Forrester et al. (2023) show that the percentage of residential solar systems that are adopted using third-party ownership (i.e., leases or power purchase agreements) decreases steadily across income groups: 34 percent below $50,000; 29 percent for $50,000–$100,000; 25 percent for $100,000–$150,000; 22 percent for $150,000–$200,000; and 17 percent above $200,000.

Figure 4 plots lease shares for electric vehicles and residential solar. We compiled this information to assess how leasing could be potentially influencing our results. Interestingly, the lease shares have fluctuated significantly over time. But while the lease share has been going up and down, the concentration of these tax credits among high-income filers has remained nearly constant (Figure 3). This suggests that leasing is unlikely to be substantially biasing our distributional analysis. Related analyses based on alternative data sources also suggest that leasing is unlikely to explain much of the patterns we observe (Borenstein, 2017; Muehlegger and Rapson, 2022; Forrester et al., 2023; Davis, 2024).

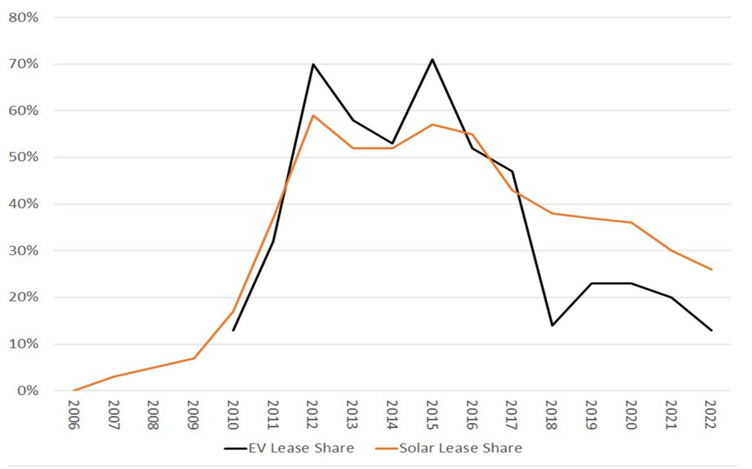


Figure 4. Lease share of electric vehicles (EVs) and residential solar by year. This figure was created by the authors using solar installation data from the Tracking the Sun database at Lawrence Berkeley National Laboratory (https://emp.lbl.gov/tracking-the-sun) and approximating the lease share of battery electric vehicles from Figure 1 of Bognar and Klier (2023).

The tax data also do not include nonfilers, and the IRS statistics are weighted to reflect all filed income tax returns.[17] And, of course, nonfilers cannot claim tax credits. Many analyses have suggested that low-income households are overrepresented among nonfilers, so our analysis will understate the true concentration indexes for beneficiaries of these tax credits.

Another limitation of the analysis is that income may be a poor proxy for overall household well-being. This is an issue with AGI, which, by definition, reflects deductions that households adopt at different rates. There is also the broader challenge that annual income is a poor proxy for lifetime income, which most would argue is a better measure of a household's overall need.[18]

IV. ADOPTION BEHAVIOR

The cost-effectiveness of tax credits hinges on their ability to change household behavior. Do tax credits cause households to make clean energy investments? Or are most tax credit recipients non-additional, receiving a subsidy for clean energy investments they would have made otherwise?

[17] For a detailed discussion of the weighting of observations in the IRS statistics, see Appendix A of https://www.cbo.gov/publication/58781.

[18] Previous research has shown, e.g., that distributional consequences of gasoline and carbon taxes tend to be more evenly distributed when viewed in a lifetime income framework (Poterba, 1989; Hassett, Mathur, and Metcalf, 2009).

Concerns about non-additionality have been around for a long time. During a congressional hearing in 1979 about an energy-efficiency tax credit, for example, Representative Bill Frenzel argued that "the tax credit does not motivate, but rather simply occurs at the end of the year when the fellow finds out there was a tax credit available."[19]

For their part, economists have been concerned about non-additionality in related contexts at least since the early 1990s (Joskow and Marron, 1992). Empirical studies have looked at this question, for example, with subsidies for hybrid and electric vehicles (Chandra, Gulati, and Kandlikar, 2010; Xing, Leard, and Li, 2021), energy efficiency (Boomhower and Davis, 2014; Houde and Aldy, 2017), solar panels (Hughes and Podolefsky, 2015), and the "cash for clunkers" program (Mian and Sufi, 2012).

Determining additionality with tax credits is challenging. The federal tax credits are available to all US households, making it hard to build a credible counterfactual for what would have occurred in the absence of the tax credit. Instead, one approach used in previous studies has been to examine state-level tax credits (Dubin and Henson, 1988; Hassett and Metcalf, 1995).[20] This approach has clear advantages from an identification perspective but is also hard to generalize given that state-level credits tend to be less salient for households.

Another potential research design is to use variation in federal tax credits over time. The following subsections present data on the US annual adoption of heat pumps, solar panels, and electric vehicles. These patterns are juxtaposed against changes in the availability and generosity of the tax credits. If tax credits are causing households to make clean energy investments, then we would expect to see increases in technology adoption when tax credits are available or relatively generous. This approach is not a panacea, but it provides a first step for assessing the relationship between tax credits and technology adoption.

A. Heat Pump Shipments

Figure 5 plots US heat pump shipments by year. These data come from the Air Conditioning, Heating, and Refrigeration Institute (AHRI). The figure also highlights some of the major changes for the tax credit.

There seems to be no evidence that heat pump shipments responded to any of the five policy changes. The credit was introduced in 2006, yet adoption decreased in that year. The credit was not available in 2008 and 2018, but there was no discernible decline in heat pump shipments during those years. Moreover, during 2009

[19] US Congress, House Committee on Ways and Means, as quoted by Crandall-Hollick and Sherlock (2018).

[20] Using tax audit data from 1978, Dubin and Henson (1988) find that claimed federal energy tax credits are no higher in states with state-level energy tax credits. Using panel data on individual tax returns and state-level variation, Hassett and Metcalf (1995), in contrast, find that energy tax credits increase conservation investments.

Figure 5. Do tax credits matter for heat pump adoption? This figure was created by the authors using annual data on US shipments of air-source heat pumps from AHRI.

and 2010 the credit increased from 10 to 30 percent, yet there was no pronounced increase in heat pump shipments in those years. Finally, the tax credit increased from 10 to 30 percent in 2023, but shipments decreased by 16 percent.

In each case, there are other possible explanations for these patterns. For example, in 2009 and 2010 the United States was in the middle of a profound economic downturn, which could provide an alternative explanation for the lack of an increase in heat pump shipments in those years. Moreover, experts have suggested that supply constraints, high interest rates, and low natural gas prices may have hurt heat pump sales in 2023.[21] More generally, it could also be that the amount of the tax credit (equal to $300 in most years) was just too small to matter.

It is also worth emphasizing that our study does not take on the question of the incidence of these credits. In particular, the lack of responsiveness to tax credits could reflect firm behavior rather than household behavior. When a tax credit for heat pumps is made more generous, for example, one might expect heat pump prices to increase, thereby benefiting the firms that manufacture, sell, and install heat pumps. The economic incidence of a subsidy can vary across sectors and change over time, making this important to consider for distributional consequences. Previous papers tend to find that buyers bear most of the economic incidence of these types of subsidies (Sallee, 2011; Gulati, McAusland, and Sallee, 2017; Pless and Van Benthem, 2019; Barwick et al., 2023), though some news reports suggest sellers were able to absorb significant shares of at least some of the subsidies.[22] It would be interesting to test this explicitly in future research. For example, if supply constraints have slowed heat pump sales since 2023, then we would also expect a high degree of pass-through

[21] See, e.g., Nerkar, Santul, and Madeleine Ngo, "Heat Pump Installations Slow, Impeding Biden's Climate Goals," *New York Times*, November 9, 2023.

[22] See, e.g., https://electrek.co/2019/01/02/tesla-reduces-price-us-tax-credit-model-3/.

to heat pump sellers. An empirical analysis could correlate transaction prices with year-to-year variation in credit generosity to measure economic incidence.

B. Residential Solar Installations

Figure 6 plots annual capacity additions for US residential solar. These data come from the Solar Energy Industries Association (SEIA). During the period 2000–2023 there has been dramatic growth for residential solar, with annual capacity additions increasing from near zero in 2000 to 7 gigawatts of new capacity added in 2023. Borenstein (2017) attributes the growth in residential solar to sharp decreases in solar panel prices, retail electricity rates that benefit residential solar (through "net metering" policies that compensate solar output at the retail rate), and state and federal subsidies. See also Borenstein and Bushnell (2022a) and Borenstein and Bushnell (2022b) on the central role that retail electricity pricing plays in driving residential solar adoption, as well as the adoption of heat pumps and electric vehicles.

Tax credits have likely played a significant role in driving residential solar adoption, but quantifying this impact is difficult. Compared with heat pumps, there are relatively few changes in credit generosity and no years in which the credit was idiosyncratically unavailable. Probably the two most consequential changes were in 2006 and 2009 when the credit was first introduced (up to $2,000 for purchases) and then made much more generous (up to $6,000). Notably, there were only modest increases in installations in 2006 and 2009, perhaps suggesting relatively low responsiveness of solar panel adoption to the generosity of the tax credit. Still, it

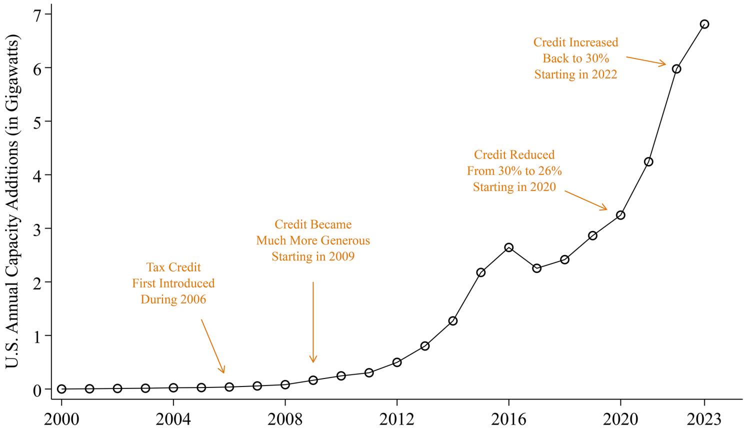


Figure 6. Do tax credits matter for residential solar installations? This figure was created by the authors using US residential solar annual capacity from the SEIA "Solar Market Insight Report." We calculate annual capacity additions as the year-to-year difference in annual residential solar capacity.

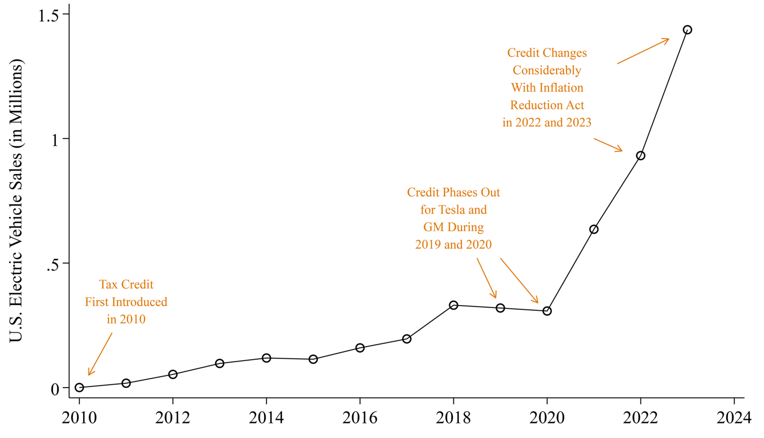


Figure 7. Do tax credits matter for electric vehicle sales? This figure was created by the authors using data on US electric vehicle sales from Argonne National Laboratory, "Light Duty Electric Drive Vehicles Monthly Sales Updates." These data describe sales separately for plug-in electric vehicles and battery electric vehicles, and this figure plots the sum.

is hard to draw strong conclusions from these year-to-year comparisons and, overall, hard to know how much of the dramatic growth in residential solar would have occurred without the tax credit.[23]

C. Electric Vehicle Sales

Figure 7 plots US electric vehicle sales since 2010. Electric vehicle sales have grown dramatically. Much like with the pattern for residential solar, the tax credits have been in place for essentially the entire period, so it is again difficult to make strong causal statements about the effect of the tax credit on electric vehicle adoption. That said, the slowdown in sales in 2019 and 2020 is notable because it happened at the same time the tax credit was phased out for Tesla and GM, which was widely publicized and likely well understood by potential electric vehicle buyers.[24] Relative to the heat pump credit, the electric vehicle credit is for a much larger dollar amount ($7,500) and in a sector with more media coverage, which could help explain what appears to be stronger evidence of a behavioral response.

Still, it is unclear how large of a role the electric vehicle tax credit has played relative to other factors. The market for electric vehicles is evolving rapidly, and

[23] In related research, Hughes and Podolefsky (2015) estimated the effect of rebates on residential solar adoption in California between 2007 and 2012. Exploiting variation in rebates across California's electric utilities, the authors estimate that about half of all rebate recipients were non-additional.

[24] See, e.g., Higgins, Tim, "Tesla Turns to China with U.S. Tax Credit Ending," *Wall Street Journal*, December 31, 2019.

there have been technological advancements and other changes over this time period that have benefited electric vehicles significantly. This period coincides with steep cost declines for batteries (Forsythe et al., 2023), rapid growth in the number of charging stations (Li, 2023), enhanced state-level subsidies (Muehlegger and Rapson, 2022), and the introduction of zero-emissions vehicle mandate in California and nine other states (Armitage and Pinter, 2022).

Thus, across all three technologies (heat pumps, solar panels, and electric vehicles), the evidence is mixed. Probably the strongest evidence that tax credits matter for technology adoption comes from electric vehicles in 2019 and 2020. Otherwise, there is little evidence based on these annual data of a relationship between tax credit generosity and adoption. The evidence for heat pumps, in particular, is disappointing from the perspective of cost-effectiveness, as there seems to be no discernible impact from year-to-year changes in tax credit availability. It is always difficult to draw strong causal conclusions based on year-to-year comparisons, but in our view this evidence raises at least some concern about the effectiveness of tax credits for motivating technology adoption.

V. CONCLUSION

Economists have long argued that the most efficient approach to reducing externalities is to price them directly, using, for example, a tax or cap-and-trade program. Pricing externalities from fossil fuels would increase the adoption of electric vehicles and other clean energy technologies, but it would also motivate a much broader range of responses, for example, encouraging walking, bicycling, and public transportation. Pricing externalities would also lead people to use less energy overall, strengthen the incentives for innovators to come up with alternative technologies, and generate revenue that can be used to reduce distortionary taxes in other sectors.

Instead, there is growing enthusiasm for policies that subsidize clean energy technologies. In addition to the income tax credits that we study, current US policies provide subsidies for zero-carbon electricity generation, clean hydrogen, sustainable aviation fuel, and carbon capture and storage (Bistline, Mehrotra, and Wolfram, 2023). While the two approaches may seem similar, a growing literature in economics shows that subsidies are considerably less efficient than first-best policies, in large part, because they encourage a narrower set of behaviors.[25] Still, pricing externalities directly seems unlikely, particularly in the United States over the next few years, so it makes sense to design subsidies to be as efficient as possible. In addition, if subsidies have favorable distributional effects, that might strengthen the economic argument for these approaches.

[25] One exception is Borenstein and Kellogg (2023), who argue that at low natural gas prices, the benefits from pricing GHG externalities of electricity generators may have little or no welfare advantage over a minimum share of renewable generation or subsidies for zero-carbon sources. They stress, however, that this finding is unlikely to extend to other sectors.

Our paper examines, in particular, the distributional effects of US clean energy tax credits. We find that during 2006–2021 these tax credits went predominantly to higher-income filers, with 60 percent of credits going to the top income quintile. We find a slight broadening for the electric vehicle credit since 2018, but overall there is little change in this pattern over time.

Part of the explanation for the regressivity is that all of these clean energy tax credits are nonrefundable. About 40 percent of US households pay no federal income tax, so millions of mostly low- and middle-income filers are simply ineligible for these credits.[26] From the perspective of reducing negative externalities, there is no difference between filers with positive and negative tax liability, so this asymmetric treatment is hard to rationalize. Indeed, some experts have questioned more generally the economic rationale for nonrefundable tax credits (Batchelder, Goldberg, and Orszag, 2006).

Another part of the explanation is that renters and landlords are ineligible for the tax credits aimed at heat pumps and other energy-efficient investments. In the United States, more than one-third of homes are rented, so this is a significant omission, particularly given that owner-occupied and rental homes in the United States are approximately equally likely to have heat pumps (Davis, 2024). Principal-agent problems make rental housing challenging (Myers, 2020), but at the same time it seems odd to completely exclude this large share of the housing stock, and the exclusion almost certainly increases overall regressivity.[27]

The cost-effectiveness of subsidies hinges on their ability to change household behavior, but, particularly for heat pumps, we find little correlation between tax credits and technology adoption. Tax credits for rooftop solar and electric vehicles have likely been more effective, though with limited variation in the generosity of federal tax credits over time, this is difficult to establish empirically. A key priority for future research is to better understand these adoption decisions.

In future work, it will also be interesting to evaluate several significant changes to these tax credits under the IRA. One of the biggest changes is a move toward point-of-sale subsidies. Starting in 2024, for example, the electric vehicle credit has been available at the point of sale. This is potentially quite a significant change compared with having to wait months to file taxes. Technology subsidies are likely to be most effective at encouraging technology adoption when they are salient to buyers, so it will be interesting to see how this change affects subsidy uptake and cost-effectiveness.

[26] Tax Policy Center, "Tax Units with Zero or Negative Federal Individual Income Tax under Current Law, 2011–2032," October 27, 2022. https://taxpolicycenter.org/tax-model-analysis/tax-units-zero-or-negative-federal-individual-income-tax-october-2022. Using administrative tax data, Splinter (2019) finds that the fraction of working-age adults paying no federal income tax increased between 1985 and 2015 from 20 to 36 percent.

[27] According to the Federal Reserve Bank of St. Louis, the percentage of homeowners in the United States across the income quintiles was 45, 57, 63, 74, and 87 percent, respectively, in 2022.

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DISCLOSURE

We have not received any financial compensation for this project, nor do we have any financial relationships that relate to this research. The analysis relies entirely on publicly available data, and all data and code will be posted on our websites upon completion of the project.

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