Energy Institute WP 348R

The Distributional Effects of U.S. Tax Credits for Heat Pumps, Solar Panels, and Electric Vehicles

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Revised July 2024

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Abstract

Over the last two decades, U.S. households have received $47 billion in tax credits for buying 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 households. The bottom three income quintiles have received about 10% of all credits, while the top quintile has received about 60%. The most extreme is the tax credit for electric vehicles, for which the top quintile has received more than 80% of all credits. The concentration of tax credits among high-income filers is relatively constant over time, though we do find a slight broadening for the electric vehicle credit since 2018. The paper then turns to the related question of cost effectiveness, examining how clean energy technology adoption has changed over time and discussing some of the broader economic considerations for this type of tax credit.

Key Words: Tax Expenditures; Distribution of Income; Concentration Index, Climate Change
JEL: D30, H23, H24, H50, Q41, Q48

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1 Introduction

The year 2023 was by far the warmest year on record with average temperatures 1.35°C above the pre-industrial average (NOAA, 2024). Increased temperatures, drought, wildfires, and other climate impacts are intensifying the efforts of policymakers 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).

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. Relatively less is known about the economic efficiency and, in particular, about the distributional effects of this type of policy.

This paper uses data from U.S. federal income tax returns 2006-2021 to examine the distributional effects of clean energy tax credits. During this period, U.S. households received $47 billion in tax credits for buying heat pumps, solar panels, electric vehicles and related technologies. As we show in the paper, 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% of all credits, while the top quintile has received about 60%. The most extreme is the tax credit for electric vehicles, for which the top quintile has received more than 80% of all credits, and the top 5% has received about 50%.

As we document in the paper, the concentration of tax credits among high-income filers is relatively constant 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% of all credits. To put these numbers in the context of income shares, the U.S. Census reports that during 2018-2022, the top quintile of households received about 52% of household income, while the bottom quintile received about 3% of household income.

We then switch gears to examine a separate but related question. The cost effectiveness of tax credits hinges on their ability to increase adoption of clean energy technologies. We examine aggregate national data on heat pumps, solar panels, and electric vehicles, looking 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; Neveu and Sherlock, 2016; Borenstein and Davis, 2016; Coyne and Globus-Harris, forthcoming). We follow closely Borenstein and Davis (2016), incorporating almost a decade of additional data along with comparisons over time and additional analyses. 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 has the advantage of being available for the entire time period 2006-2021 and for all tax credits including the electric vehicle credit.

Examining distributional effects using data from household income tax returns has a number of limitations, which we discuss in greater detail later, but we will note here: (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% of all U.S. 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 also 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 et al., 2023), carbon taxes (Metcalf, 1999; Williams et al., 2015; Goulder et al., 2019), cap-and-trade for carbon emissions (Dinan and Rogers, 2002; Burtraw et al., 2009), fuel economy standards (Davis and Knittel, 2019), building codes (Bruegge et al., 2019), and solar panel subsidies (Borenstein, 2017; Feger et al., 2022). One of the main takeaways from this literature is that distributional effects depend critically on what is done with any revenues that are generated.

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

More generally 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) derives 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 et al. (2019) provides formulas for optimal indirect taxes with heterogeneous tastes, externalities, and behavioral biases. These more recent papers imply that optimal subsidies should be lower for goods preferred by high-income households.

The paper proceeds as follows. Section 2 presents background information about the major categories of clean energy tax credits. Section 3 provides our main results, presenting evidence on distributional effects, concentration curves, and concentration indexes. Section 4 then turns to the related question of cost effectiveness, incorporating information from various sources on how clean energy adoption has changed over time. Section 5 concludes.

2 Background

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

2.1 Energy Efficiency

We first discuss the tax credits for windows and other residential investments in energy efficiency. These are known as "Section 25C" credits because they are described in section 25C of the internal revenue code. 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%) of the installed price of the equipment up to some maximum value. Neither renters not 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 not able to distinguish between different categories of expenditures. 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%), ceiling and wall insulation (21%), energy-efficient doors (14%) and energy-efficient windows and skylights (13%).[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 there 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 Prop-*

[2] These calculations were performed by the authors using information from Internal Revenue Service, Statistics of Income, "Individual Income Tax Returns: Line Item Estimates (Publication 4801)".

erty Credit, or NEPC. During most years the NEPC provided a 10% tax credit for eligible investments up to a maximum of $500. However, across years there have been several interruptions and other changes. After being in place during 2006 and 2007, the credits expired at the end of 2007 and were not available during 2008. Then as part of the American Recovery and Reinvestment Act, the credit was reinstated for two years at a higher level. Thus during 2009 and 2010, the credit was increased from 10% to 30%, and the maximum credit amount was increased from $500 to $1500.

The credit then continued at the standard 10% 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, and then remaining unchanged 2019-2022.[3] See Neveu and Sherlock (2016) and Crandall-Hollick and Sherlock (2018) for a complete legislative history.

With the Inflation Reduction Act of 2022 these credits became much more generous.[4] Starting January 1, 2023, the standard credit rate increased from 10% to 30%, and limits increased for most categories from $500 to $1200. For heat pumps, the maximum credit amount increased from $300 to $2000. Our analysis uses data from

[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 Inflation Reduction Act 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 Inflation Reduction Act 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 Internal Revenue Service, "Frequently Asked Questions about Energy Efficient Home Improvements and Residential Clean Energy Property Credits", December 2022.

2006-2021 and thus represents the period before the Inflation Reduction Act, but it will be interesting in future work to assess this later period.

2.2 Residential Solar

Tax credits for residential solar and other types of home renewable generation are known as "Section 25D" credits because they are described in section 25D of the internal revenue code, and known by the somewhat confusing name *Residential Energy Efficiency Property Credit* (REEPC). In practice, the REEPC credits go overwhelmingly to residential solar. During 2020, for example, 89% of the expenditures under this credit went to residential solar ("solar electric property" in IRS parlance), compared to 4% for solar water heating systems, 4% for geothermal heat pumps, 1% for small wind projects, and 1% 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% credit for qualified expenditures up to a maximum of $2000 for most categories. Notably, this $2000 maximum didn't 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% 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 $2000 maximum was removed starting in 2009 under the American Recovery

[5]Author's calculations based on IRS, Statistics of Income, 2020 Line Item Estimates, Form 5695, Part II, "Residential Energy Credits".

and Reinvestment Act. Residential solar systems typically cost tens of thousands of dollars, so removing the maximum 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]

The REEPC continued unchanged as a 30% credit for several years. Then, starting in 2020, the credit was decreased from 30% to 26%. The credit was 26% during 2020 and 2021, before being increased back to 30% under the Inflation Reduction Act. A household installing residential solar in early 2022 would likely have expected to receive a 26% credit but then the Inflation Reduction Act passed in August 2022 and restored the 30% credit for any installations made during 2022.[7] Under the Inflation Reduction Act, the REEPC is scheduled to remain at 30% through 2031, then decrease to 26% in 2032, and to 22% in 2034.

2.3 Electric Vehicles

The income tax credits for electric vehicles are known as "Section 30D" credits because they are described in section 30D of the internal revenue code, and known for much of this period as the *Qualified Plug-In Electric Drive Motor Vehicle Credit*, or PEDVC.

[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.

First available in 2010, the PEDVC is an income tax credit for 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 historically qualified for the full $7,500 credit, including all Tesla vehicles, Nissan Leaf, Chevrolet 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 with a 4 month delay compared to Tesla.

The PEDVC was then changed considerably with the Inflation Reduction Act. Vehicles purchased between August 16, 2022 and December 31, 2022 were required to have undergone final assembly on North America. Then, starting in 2023, several additional changes took effect: (1) the manufacturer phaseout was discontinued, making Tesla vehicles, for example, once again eligible for a $7,500 credit, (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, (4) vehicles must meet a series of increasingly stringent requirements for critical mineral and battery component requirements. Our analysis uses data from 2006-2021 so does not include this period of changes under the Inflation Reduction Act.

2.4 Other Related Credits

During this time period there were also a couple of smaller related tax credits that we do not examine in this paper. 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. By our calculations using IRS data, a total of $861 million went to the AMVC between 2006 and 2021, with a maximum annual expenditure of $185 million in 2007. See Sallee (2011), Gallagher and Muehlegger (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 to the others with only $96 million in total tax expenditure between 2005 and 2021, according to our calculations. 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 credit equal to 30% (up to maximum of $1000) for electric vehicle charging equipment. The AFVRPC was expanded and extended with the Inflation Reduction Act so will be worth examining closely in future research.

3 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. How does the use of these tax credits vary across income levels? How has the distributional pattern changed over time?

We first describe the IRS data used for this analysis (Section 3.1), and then use these data to summarize total tax expenditures (Section 3.2), calculate average credit amounts by income category (Section 3.3), construct concentration curves (Section 3.4), calculate concentration indexes (Section 3.5), and discuss additional results and limitations (Section 3.6).

3.1 Data Description

The information for the distributional analysis was compiled by the authors using data from the U.S. Department of Treasury, Internal Revenue Service (IRS). For this analysis we compiled information from two different sources from the IRS *Statistics of Income* program, a statistical organization that gathers, analyzes, and publishes information about U.S. income tax collection. A valuable feature of these data is that they are all publicly available and, upon completion of this project, we will post all data and code on our website.

The first data source is a series of annual reports from the IRS which publish summary statistics about the U.S. income tax system. Known as "Individual Income Tax Returns Complete Report (Publication 1304)" these statistics describe the number of returns filed, sources of income, exemptions, itemized deductions, and other features of the income tax system, as well as also providing information about how these features vary by adjusted gross income (AGI), marital status, age of tax payer, and other characteristics. For the distributional analyses which follow, we focus in particular, on "Table 3.3 All Returns: Tax Liability, Tax Credits, and Tax Payments".

These reports are 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 which claimed that credit as well as the total dollar value of all claims. Statistics are reported for 19 or 20 different income 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 underlying samples included, for example, 370,000+ returns in 2019 and 385,000+ returns in 2020. The IRS reports standard errors for all summary statistics, expressed as a percentage of the statistic being estimated. Throughout the analyses we use these standard errors to construct 95% confidence intervals. The IRS does not provide the entire variance-covariance matrix, so we are not able to formally test for differences between statistics.

In some cases it is possible for households to carry credits across tax years. For example, if a household installs solar panels, but is unable to use the entire tax credit, they may carry this credit forward to the following year. 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 tax credits in the year that they used, regardless of when the original credit was claimed. Thus, for example, the tax expenditures we report for 2020 mostly reflect investments made in 2020, but also, to a lesser degree, reflect investments made in 2019 and previous years, in cases for which the tax credit was then carried forward. This is not particularly problematic for our analyses, but is an intrinsic feature of these IRS data.

The second data source is annual reports from IRS known as "Individual Income Tax Returns: Line Item Estimates (Publication 4801)". These publications go line-by-line through the 1040 and accompanying schedules and forms, providing for each line item an estimate of the number of filers that included a nonzero number in the line and the sum of all values 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) from 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 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 dataset for our main results.

3.2 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 total expenditure of $17.3 billion, though over 60% comes from two years, 2009 and 2010, when this tax credit was temporarily increased from 10% to 30%. 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. As we described earlier, policymakers have frequently adjusted the generosity and even the availability of tax credits. In the case of the energy-efficiency, for example, not only were there the 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 ten largest tax expenditures in the United States. According to the Congressional Budget Office, total annual tax expenditures in the United States are $1.2

trillion (Congressional Budget Office, 2021). The exclusion for employment-based health insurance, for example, is $280 billion annually. Income tax credits like the child care credit and the earned income tax credit are also much larger, $118 billion annually and $70 billion annually, respectively.

The Congressional Budget Office finds that about half of the total benefits from income tax expenditures—tax reductions from exclusions, credits, and deductions—go to households in the top income quintile (Congressional Budget Office, 2021).[8] Part of the reason for the concentration among higher-income households is that many of the largest tax expenditures are tax *deductions* which require a filer to itemize deductions.[9] Among tax credits, there are some examples like the earned income tax credit that tend to go to lower-income filers but there are also other credits like the foreign tax credit that tend to go to higher-income filers. An important distinction with tax credits is whether they are refundable or non-refundable, a topic to which we return later.

3.3 Average Credit Per Return

Figure 1 plots the average credit per return by adjusted gross income (AGI). We focus on two categories of tax credits: Residential Energy Credits, and Electric Vehicle Credits. The first category is the combination of the NEPC (energy-efficiency credits)

[8]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).

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

and the REEPC (residential solar credits). Ideally, we would have liked to examine these credits separately but the IRS annual reports combine these two categories, as mentioned earlier.

For these figures we pooled data from across all years for which the credit was available; 2006-2021 for the top panel and 2009-2021 for the bottom 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. In 2021, for example, the six categories included 20%, 17%, 18%, 23%, 15%, and 7%, of all tax returns, respectively.

The y-axis in these figures is the average credit per return. We calculate this average over all tax returns, including filers who both did and did not claim these credits. Thus, for example, the far right observation in the first panel means that, among all filers with more than $200,000 in AGI, the average amount claimed in residential energy credits was $83.

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 for households in the bottom three AGI categories, compared to $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 among households with AGI below $100,000, compared to $7 for $100,000 to $200,000 and $27 for households with AGI above $200,000. Compared to 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. According to the Federal Reserve Bank of St. Louis, U.S. households spent on new vehicles an average of $300, $1000, $2100, $2600, and $5100, respectively, across income quintiles in 2021.[10] The electric vehicle credit, however, is even more concentrated among the highest income quintile than new vehicle spending overall.

3.4 Concentration Curves

Figure 2 plots concentration curves for both types of credits. The purpose of these figures is to provide a visual representation of the degree to which these tax credits are concentrated among high-income households. 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 figure 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%

[10]These statistics from FRED were compiled using data from the U.S. Bureau of Labor Statistics, Consumer Expenditure Survey.

of all income. The farther below the 45-degree line, the more concentrated income is among high-income filers. The figures show, in particular, that the bottom three quintiles receive about 20% of all AGI, and that the bottom four quintiles receive a bit more than 40% of all AGI.

The concentration curves for tax credits can be interpreted similarly. That is, these curves show the cumulative fraction of tax credits received by each percentile of taxpayers.[11] The curves are precisely estimated so we do not plot 95% confidence intervals.

The residential energy credits are highly concentrated among high-income filers. The bottom three income quintiles have received about 10% of all residential energy credits, while the top quintile has received about 60%. The credits are more concentrated than income for low and middle income levels, but then 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% of all electric vehicle credits, while the top quintile has received more than 80%. The concentration curve is nearly vertical at the top, with the top 5% of filers receiving about 50% of all electric vehicle tax credits.

[11] 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, though, generally, the Suits index is 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 filers; 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.

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 while the electric vehicle credits may have become somewhat less concentrated. We turn in the next subsection to an explicit comparison of how this concentration has changed over time.

3.5 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. We calculated the concentration index year-by-year for both types of credits.

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 energy credits, consistent with the results in the previous subsection, but 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.

At some risk of overinterpreting a subtle effect, we think there are reasonable 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.[12] 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.

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.

[12] One of the authors of Coyne and Globus-Harris (forthcoming) was an employee at U.S. 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).

3.6 Additional Results and Limitations

Additional results in the appendix 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% of filers with AGI below \$30,000 claim the credit, compared to 4%+ for filers with AGI above \$100,000. Similarly, the average credit per claimant is less than \$500 for filers with AGI below \$30,000, compared to almost \$2,000 for filers with AGI above \$200,000. Thus higher income households are both more likely to claim these credits, and tend to claim larger credit amounts.

As mentioned in the introduction, one limitation with 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 this is potentially a significant issue with solar panels and electric vehicles, both of which 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. For example, Forrester et al. (2023) shows 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% below \$50,000, 29% for \$50,000-\$100,000, 25% for \$100,000-\$150,000, 22% for \$150,000-\$200,000, and 17% above \$200,000.

Figure 4 plots lease shares for electric vehicles and residential solar. We compiled this information in order 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 suggests that leasing is unlikely to explain much of the patterns we observe (Borenstein, 2017; Muehlegger and Rapson, 2022; Forrester et al., 2023; Davis, 2024).

The tax data also do not include non-filers and the IRS statistics are weighted to reflect all filed income tax returns.[13] And, of course, non-filers are all non-claimers of the tax credits we study. Many analyses have suggested that low-income households are over-represented among non-filers. To the extent this is true, our analysis will understate the true concentration indexes for beneficiaries of these tax credits.

An important limitation of this analysis, as with all distributional analyses based on income, is that income may be a poor proxy for overall household well-being. This is an issue narrowly in the use of AGI which, by definition, reflects deductions including retirement contributions, health savings accounts, self-employed health insurance contributions, and other adjustments, that households adopt at different rates. There is also the broader challenge that annual income is a poor proxy for lifetime income

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

which most would argue is a better measure of a household's overall need. Students and retirees, for example, may have low annual income, even when their lifetime income is much higher.[14]

4 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?

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."*[15]

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 et al., 2010; Xing et al., 2021), energy-efficiency (Boomhower and Davis, 2014; Houde and Aldy, 2017), solar panels (Hughes and Podolefsky, 2015),

[14]Previous research has shown, for example, that distributional consequences of gasoline and carbon taxes tend to be more evenly distributed when viewed in a lifetime income framework (Poterba, 1989; Hassett et al., 2009).

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

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 U.S. 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 exploit state-level (rather than federal) tax credits (Dubin and Henson, 1988; Hassett and Metcalf, 1995).[16] This state-level approach has clear advantages from an identification perspective but is also somewhat 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 U.S. 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.

4.1 Heat Pump Shipments

Figure 5 plots U.S. heat pump shipments by year. These data come from the Air Conditioning, Heating, and Refrigeration Institute (AHRI), an industry organization

[16] 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.

representing 300+ member companies accounting for more than 90 percent of the air conditioning, space heating, and refrigeration equipment manufactured and sold in North America. The figure also highlights some of the major changes for the tax credit described in the previous section.

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 is no discernible decline in heat pump shipments during those years. Moreover, during 2009 and 2010 the credit increased from 10% to 30%, yet there is no pronounced increase in heat pump shipments those years. Finally, and perhaps most strikingly, the tax credit increased from 10% to 30% starting in 2023, but rather than increasing, shipments decreased by 16% between 2022 and 2023.

Of course, in each case there are other possible explanations for these patterns. For example, in 2009 and 2010 the United States was still 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.[17] 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 can cost $6,000 or more to buy and install a heat pump (Davis, 2024), so the tax credit during most years was equal only to about 5% of the upfront cost.

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

It is also worth emphasizing that our study does not take on the question of whether the incidence of these credits is on buyers or sellers. 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 manufacturer, sell, and install heat pumps. The economic incidence of a subsidy can vary across sectors and change over time, making this potentially important to consider for distributional consequences. Previous papers have tended to find that buyers bear most of the economic incidence of these types of subsidies (Sallee, 2011; Gulati et al., 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.[18] 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 to heat pump sellers. An empirical analysis could correlate transaction prices with year-to-year variation in credit generosity to measure economic incidence.

4.2 Residential Solar Installations

Figure 6 plots annual capacity additions for U.S. 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 seven gigawatts of new capacity added in 2023.

[18] See, for instance, https://electrek.co/2019/01/02/tesla-reduces-price-us-tax-credit-model-3/.

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), as well as 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 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 to heat pumps there are relatively few changes in the generosity of tax credits and no years in which the tax 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 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.[19]

[19] In related research, Hughes and Podolefsky (2015) estimate 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.

4.3 Electric Vehicle Sales

Figure 7 plots U.S. electric vehicle sales since 2010. Electric vehicle sales have grown dramatically throughout this period. 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. We do not want to overinterpret this evidence, but this loss of eligibility for both manufacturers was widely publicized and likely well understood by many potential electric vehicle buyers.[20] 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 not clear 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 there have been technological advancements and other changes over this time period which have benefited electric vehicles significantly. In particular, 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 the zero emissions vehicle (ZEV) mandate in California and nine other states (Armitage and Pinter, 2022).

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

Thus across all three technologies (heat pumps, solar panels, 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 a 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 on the basis of 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.

5 Conclusion

Economists have long argued that the most efficient approach to reducing externalities would be to price them directly, using, for example a tax or cap-and-trade program. Pricing externalities from fossil fuels would increase adoption of electric vehicles and other clean energy technologies, but 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 U.S. policies provide subsidies for zero carbon electricity generation, clean hydrogen, sustainable aviation fuel, and carbon capture and storage (Bistline et al., 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.[21] 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.

Our paper examines, in particular, the distributional effects of U.S. clean energy tax credits, which have provided more than $47 billion in subsidies to U.S. households since 2006. We find that during 2006-2021 these tax credits went predominantly to higher-income households, with about 60% 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% of U.S. households pay no federal income tax, so millions of mostly low- and middle-income filers are simply ineligible for these credits.[22] From the perspective of reducing negative externalities, there is

[21] 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.

[22] Tax Policy Center, "Tax Units with Zero or Negative Federal Individual Income Tax Under

no difference between filers with positive and negative tax liability so this highly asymmetric treatment is hard to rationalize. Indeed, some experts have argued that there has never been a compelling economic argument for making tax credits nonrefundable (Batchelder et al., 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 over one-third of homes are rented, so this is a significant omission, particularly given that owner-occupied and rental homes in the U.S. 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.[23]

Our paper also examines national-level data on adoption behavior. 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. Although there is some existing research in this area, we view better understanding the sensitivity of adoption behavior to subsidies as a key question for future work.

Current Law, 2011-2032", October 27, 2022.

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

In future work it will also be interesting to evaluate several significant changes to these tax credits under the Inflation Reduction Act. One of the biggest changes is a move toward point-of-sale subsidies. Starting in 2024, for example, the federal tax credit for electric vehicles has been available at the point-of-sale. This is potentially quite a significant change compared to before when a buyer needed to wait until filing income taxes to receive the credit, and many were ineligible due to the non-refundability of the credit. 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 impacts subsidy uptake and cost effectiveness.

Table 1: Annual Expenditures on U.S. 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 US Department of Treasury, Internal Revenue Service, "Statistic of Income, Individual Tax Returns," 2005-2021 and "Statistics of Income, Individual Tax Returns: Line Item Estimates" 2005-2021.

Figure 1: Average Credit Per Return, by Adjusted Gross Income

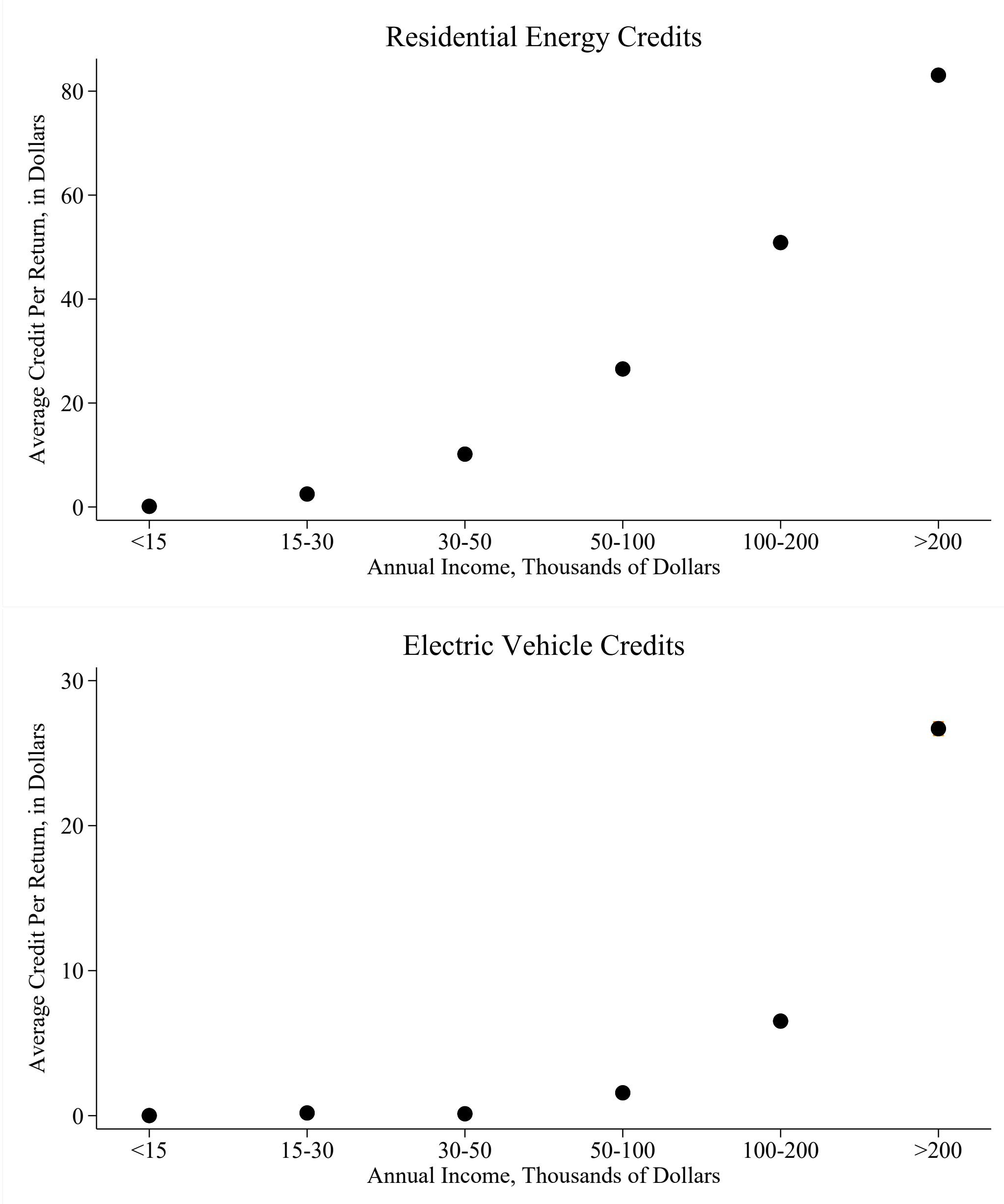
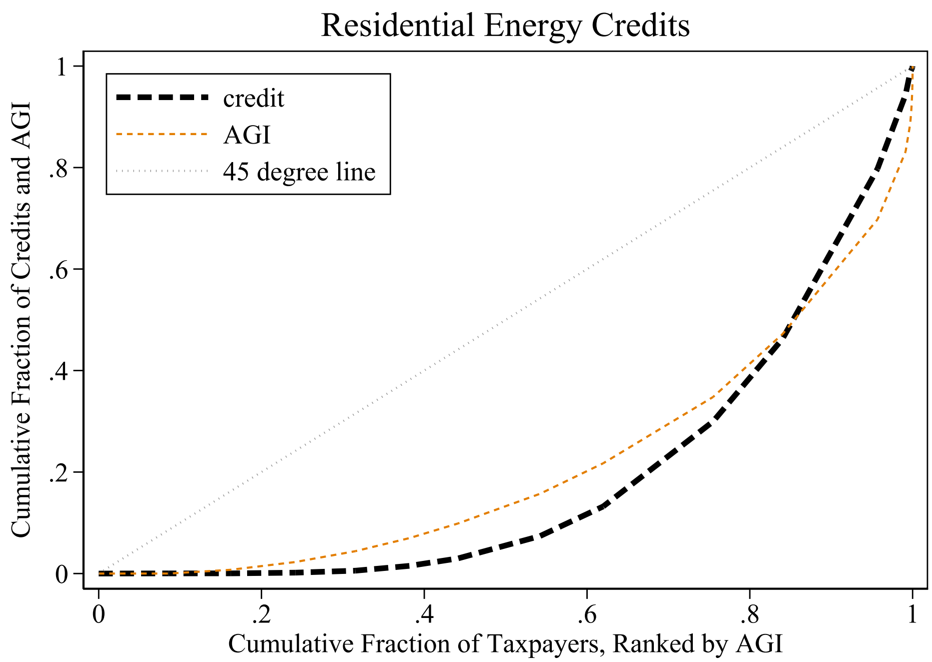


Figure 2: Concentration Curves



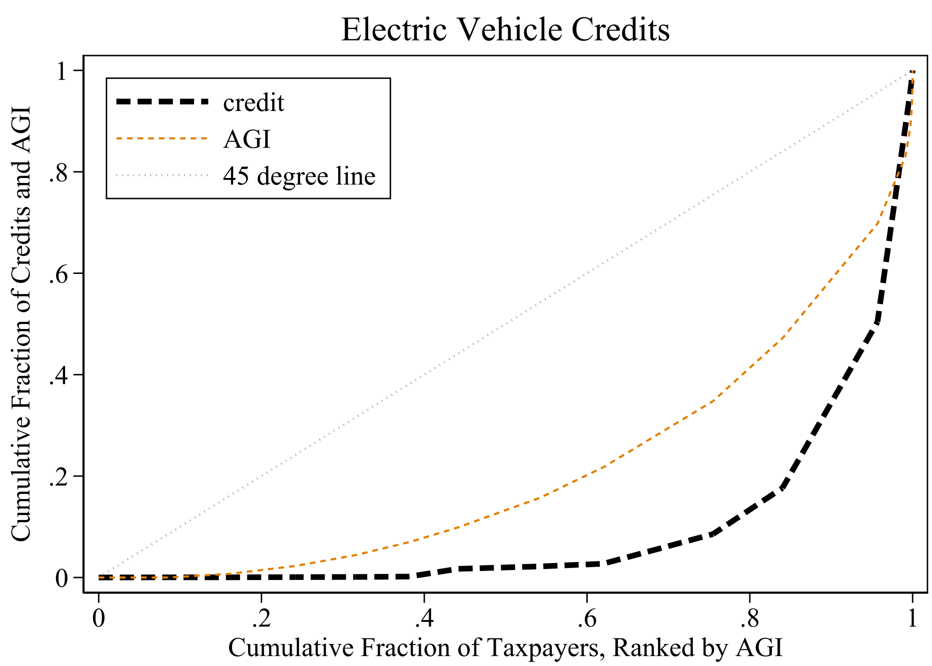


Figure 3: Concentration Index By Year

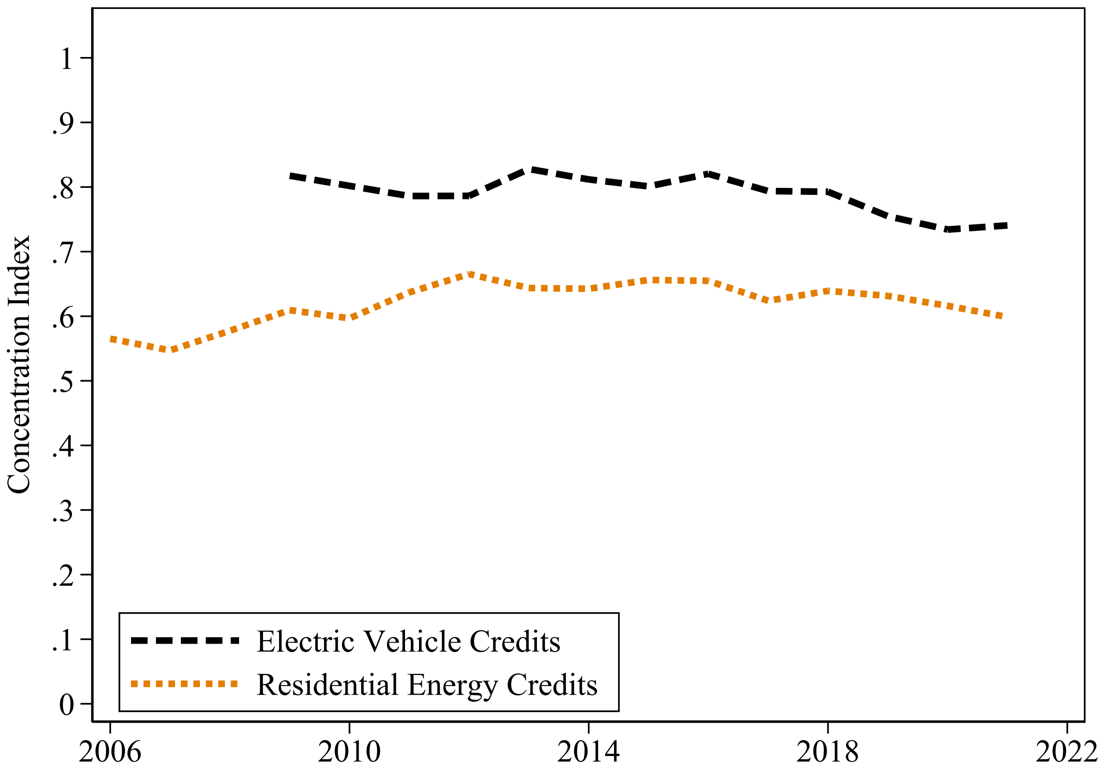
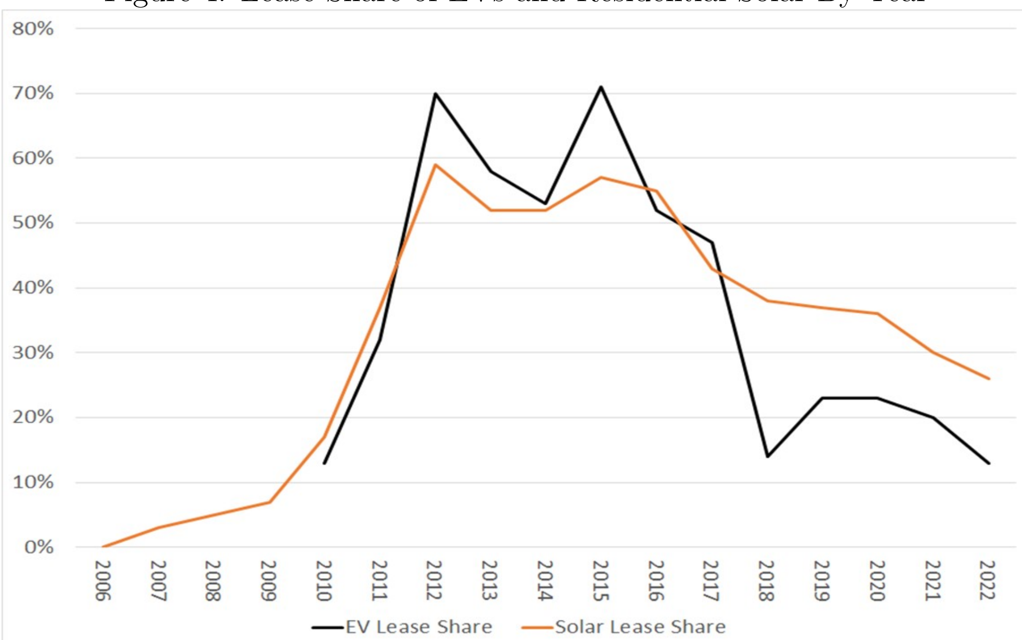
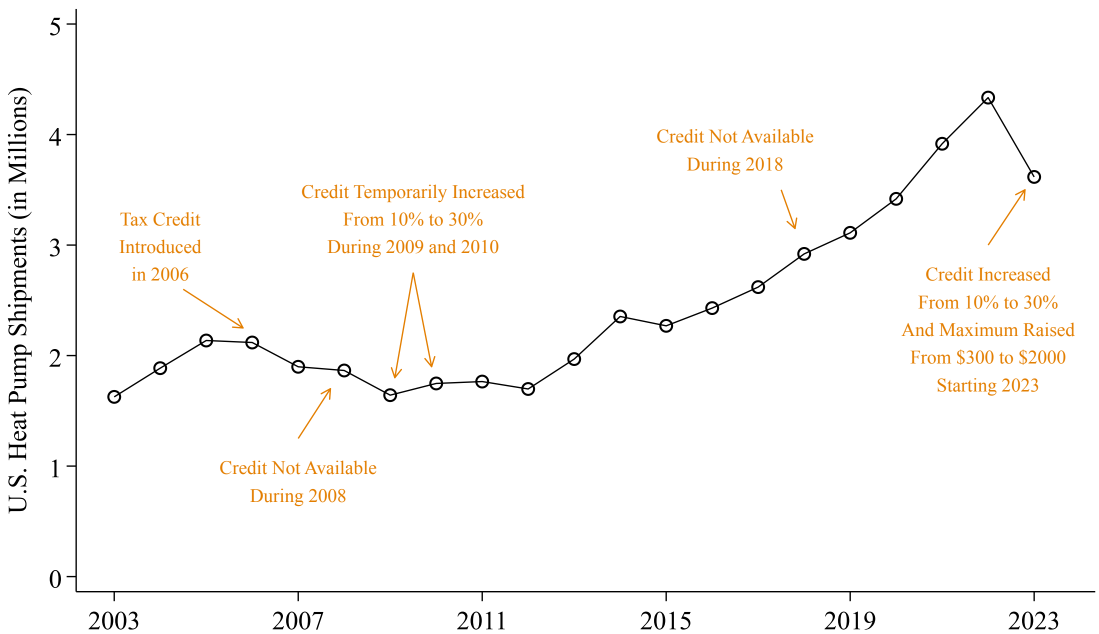


Figure 4: Lease Share of EVs and Residential Solar By Year



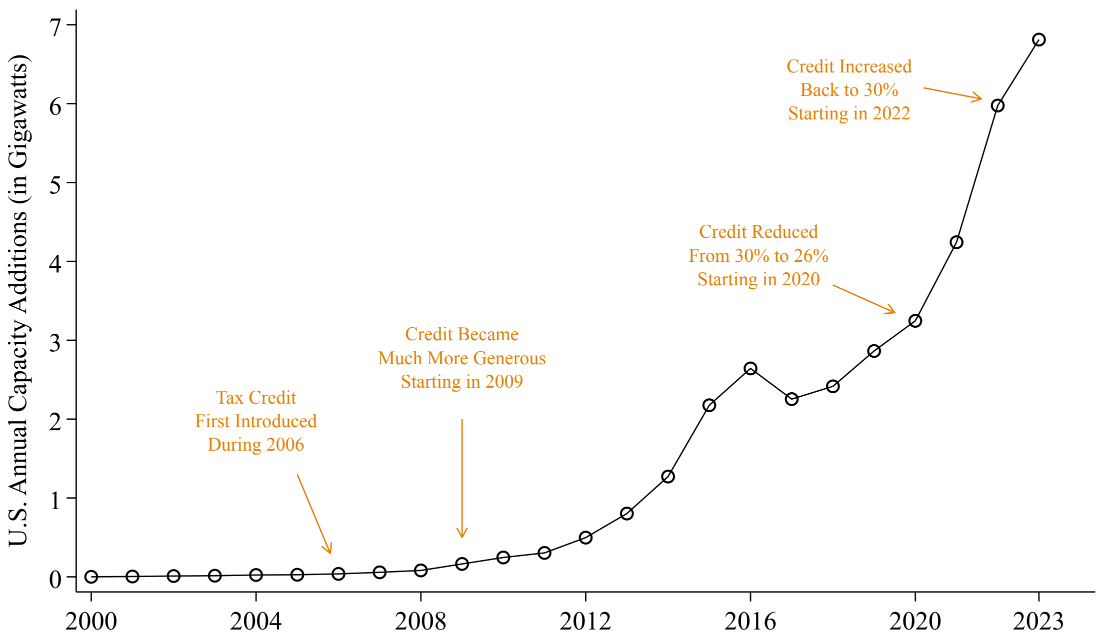
Notes: This figure was created by the authors using solar installation data from the Tracking the Sun database at Lawrence Berkeley National Laboratory (https://emp.lbl.gov/tracking-the-sun) and approximating the lease share of battery electric vehicles from figure 1 of Bognar and Klier (2023).

Figure 5: Do Tax Credits Matter for Heat Pump Adoption?



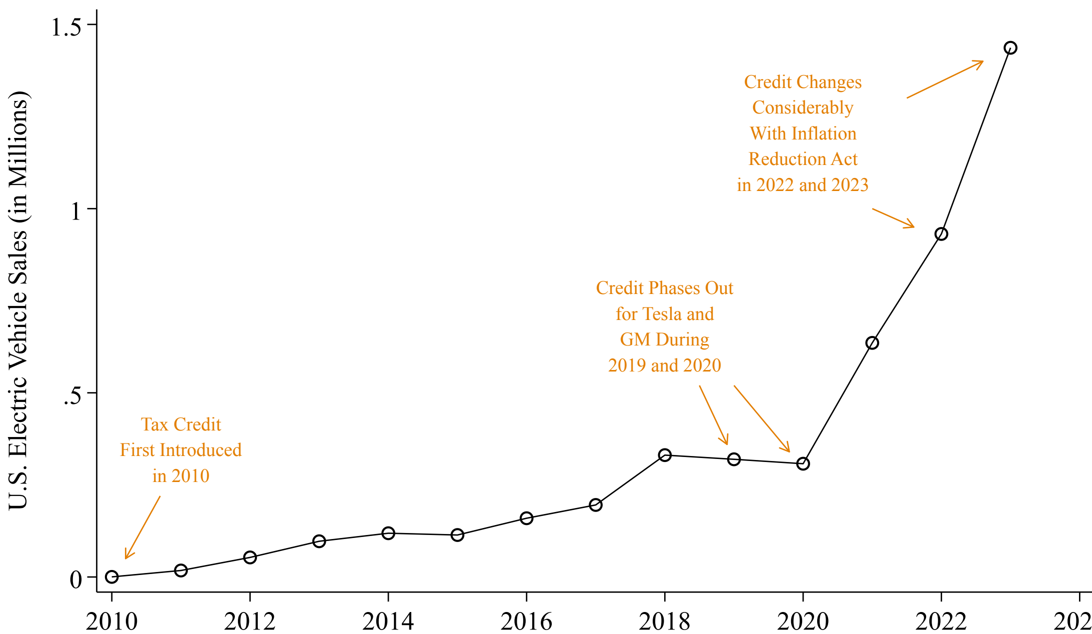
Notes: This figure was created by the authors using annual data on U.S. shipments of air-source heat pumps from the Air Conditioning, Heating, and Refrigeration Institute (AHRI).

Figure 6: Do Tax Credits Matter for Residential Solar Installations?



Notes: This figure was created by the authors using U.S. residential solar annual capacity from the Solar Energy Industries Association (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?



Notes: This figure was created by the authors using data on U.S. 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.

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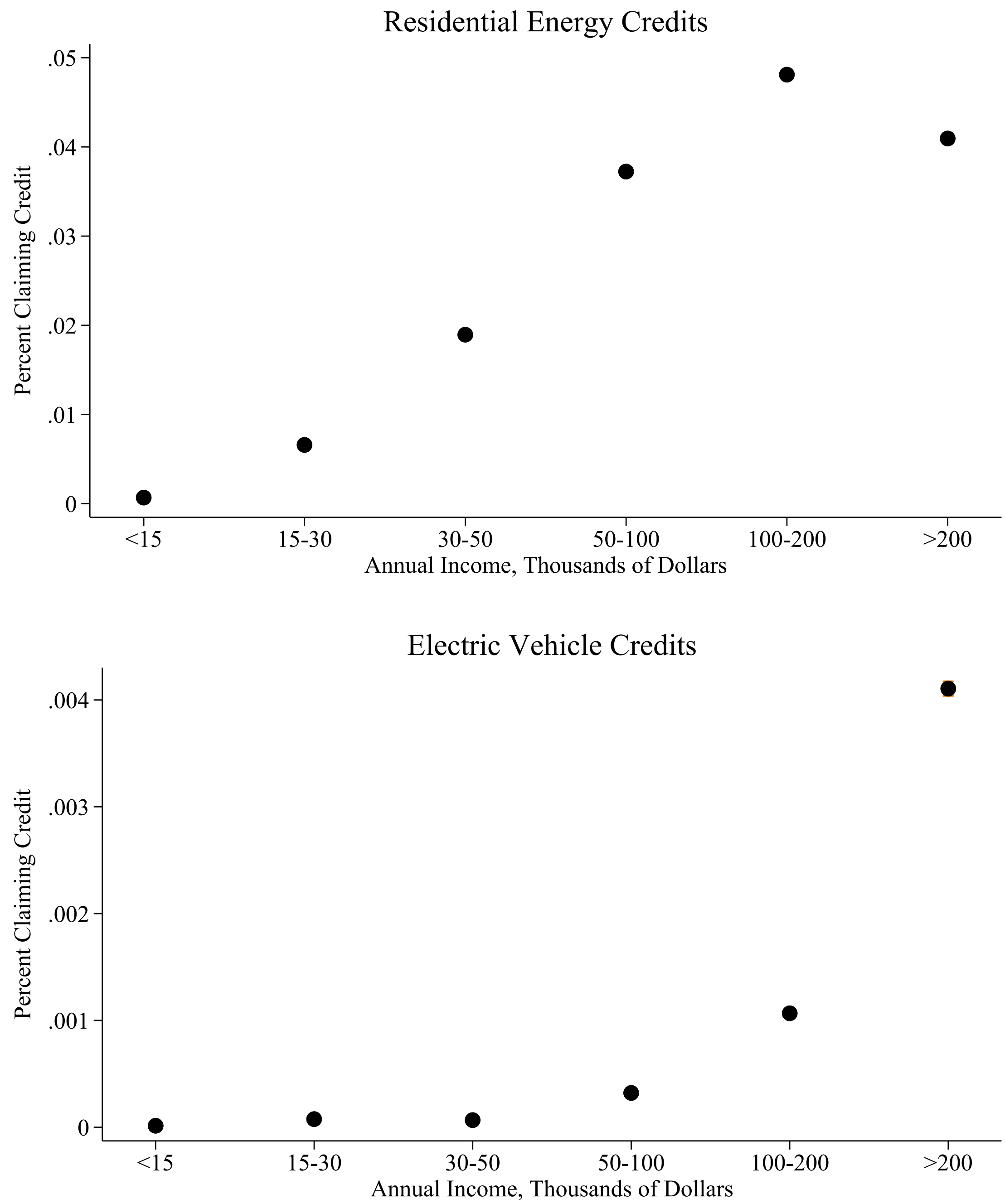
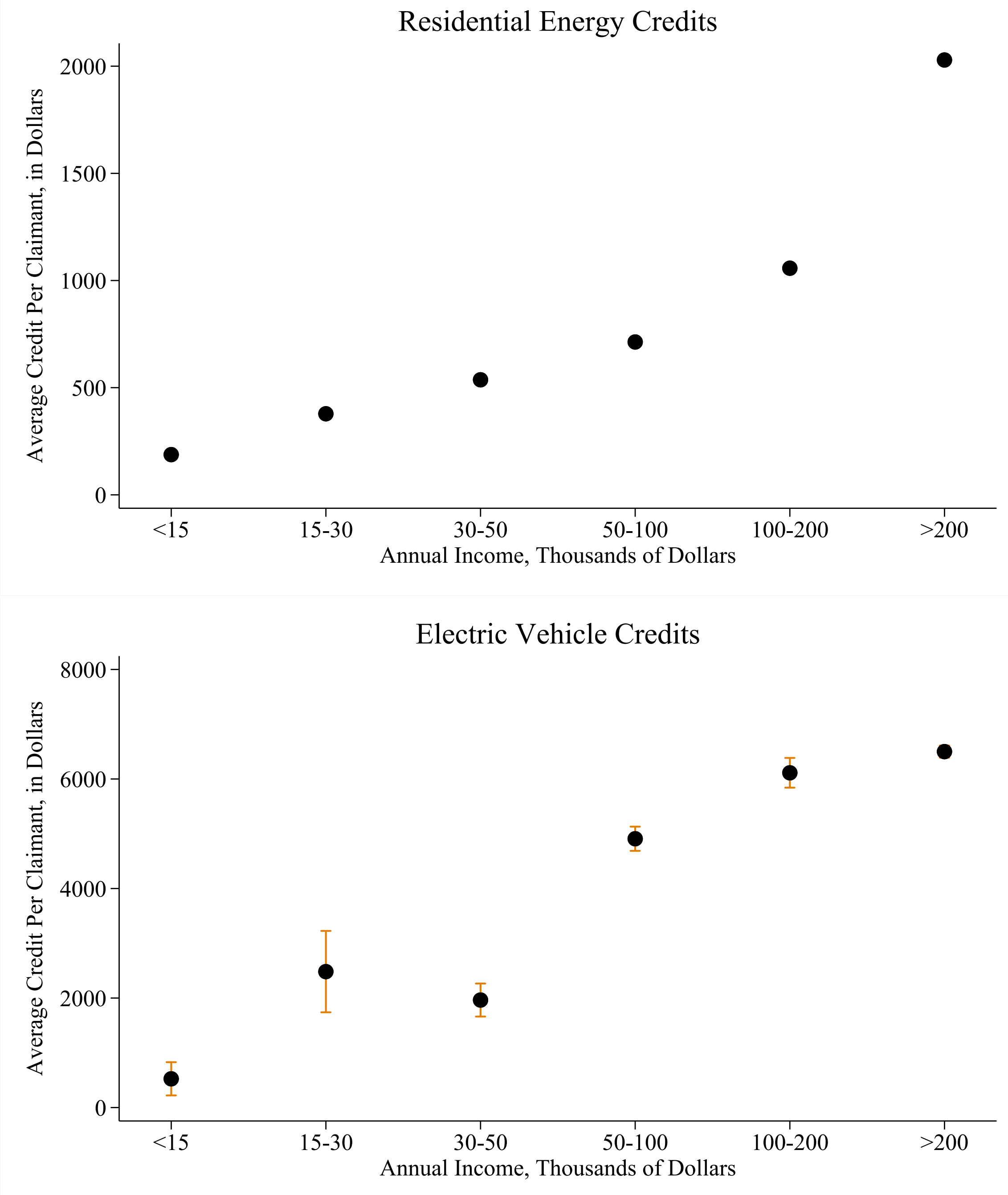
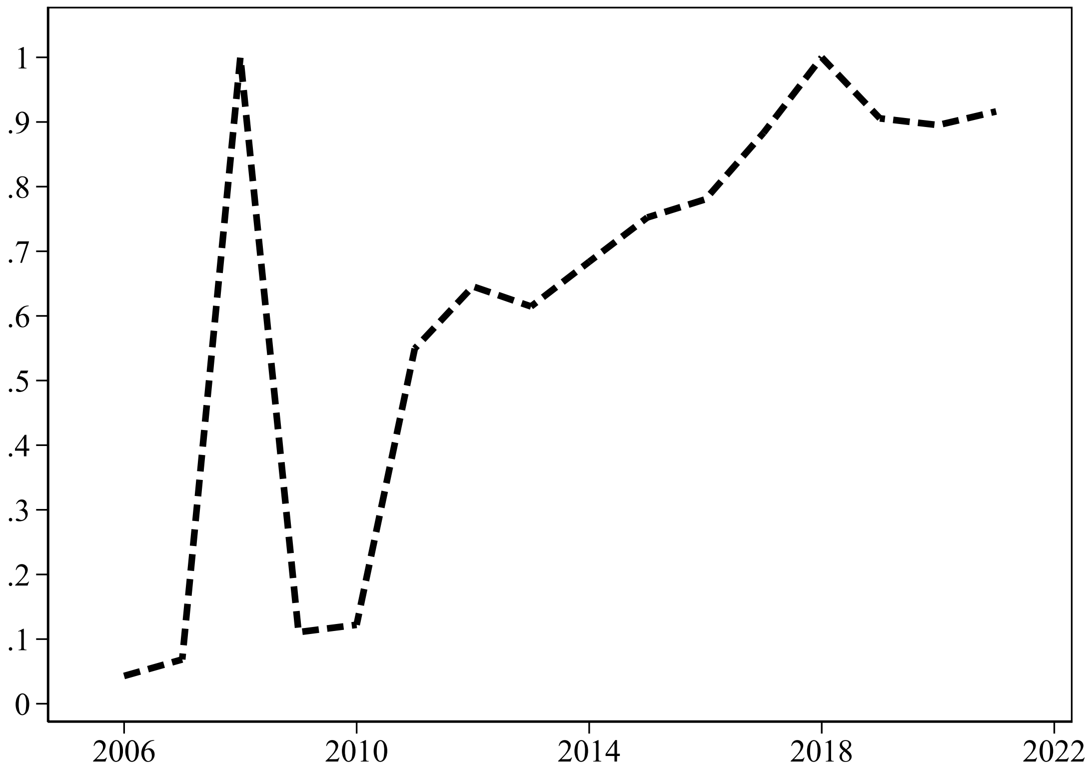
Appendix Figure 1: Percent Claiming Credit, by Adjusted Gross Income



Appendix Figure 2: Average Credit Per Claimant, by Adjusted Gross Income



Appendix Figure 3: Solar Panel Credits as a Fraction of Residential Energy Credits



Notes: The IRS Statistics of Income, "Individual Income Tax Returns Complete Report (Publication 1304)" used in the distributional analysis combines the REEPC (residential solar credits) and NEPC (energy-efficiency credits) into a single category "Residential Energy Credits". This figure plots the REEPC (residential solar credits) as a fraction of Residential Energy Credits, by year. The figure was created by the authors using information from IRS Statistics of Income, "Line Item Estimates, Residential Energy Credits, Form 5695" 2005-2021. As shown in Table 1 and discussed in the paper in Section 3.5, there has been a compositional shift over this time period toward rooftop solar with, for example, more than 75% of tax expenditures going to the REEPC since 2015. Also, notably, the concentration index for Residential Energy Credits plotted in Figure 3 is relatively constant across years despite large fluctuations in the fraction from REEPC, implying that the REEPC and NEPC have similar distributional effects.