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ECONOMIC IMPLICATIONS OF THE CLIMATE PROVISIONS OF THE INFLATION REDUCTION ACT

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ABSTRACT

The Inflation Reduction Act (IRA) represents the largest federal response to climate change to date. We highlight the key climate provisions and assess the Act's potential economic impacts. Substantially higher investments in clean energy and electric vehicles imply that fiscal costs may be larger than projected. However, even at the high end, IRA provisions remain cost-effective. IRA has large impacts on power sector investments and electricity prices, lowering retail electricity rates and resulting in negative prices in some wholesale markets. We find small quantitative macroeconomic effects including a small decline in headline inflation, but macroeconomic conditions–particularly higher interest rates and materials costs–may have substantial negative effects on clean energy investment. We show that the subsidy approach in IRA has expansionary supply-side effects relative to a carbon tax but, in a representative-agent dynamic model, is preferable to a carbon tax only in the presence of a strong learning-by-doing externality. We also discuss the economics of the industrial policy aspects of the act as well as the distributional impacts and the possible incidence of the different tax credits in IRA.

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1 Introduction

President Biden described the climate provisions of the Inflation Reduction Act (IRA) as "the most aggressive action ever, ever, ever to confront the climate crisis."[1] Other observers similarly describe it as "the most ambitious funding ever for tackling climate change" and "the largest climate legislation in U.S. history."[2] Consistent with preliminary analysis, modeling suggests that IRA puts the U.S. on track to reduce greenhouse gas (GHG) emissions 32% to 42% below 2005 levels in 2030 (Bistline et al., Under Review), which is 6 to 11 percentage points lower than without IRA (per the analysis in Section 3), closing the gap toward its Nationally Determined Contribution under the Paris Agreement to halve economy-wide GHG emissions by 2030. The problem IRA confronts is massive – re-orienting the way the U.S. and global economies produce and consume energy. IRA's incentives span the entire energy sector, from producers of raw materials to end-use consumers, and will set considerable new forces in motion.

IRA is vast, and the economics profession will likely devote considerable attention over the next decade to analyzing the impacts of many of the individual programs embodied in this important piece of legislation. We offer a broad-stroke analysis of the law, summarizing the major climate-related provisions and noting some of the possible economic impacts. We focus on several major themes.

First, we discuss the possible fiscal implications of the act and note a wide range of uncertainty in the extent to which firms and households will take up the different tax credits. The Congressional Budget Office (CBO), using inputs from the Joint Committee on Taxation (JCT), estimates that over two-thirds of the fiscal costs of the climate-related provisions of IRA ($271 billion) will be tax credits, which target clean electricity production and investment, new and used electric vehicle purchases, and investments in clean energy and energy efficiency by individuals (Table 1 in Section 2). The remaining fiscal costs ($121 billion of the $392 billion total), per CBO/JCT, will be direct expenditures on forestry and agriculture, energy loans and other financial investments, and other items. Most of the tax credits are uncapped and are a function of individual firm investment decisions and individual household consumption decisions.

We summarize evidence from the Electric Power Research Institute's U.S. Regional Economy, Greenhouse Gas, and Energy (EPRI's US-REGEN) model in Section 3 suggesting that initial estimates of the fiscal costs may be understated in several areas due to greater deployment of IRA-supported technologies such as clean electricity and electric vehicles. Central and higher-end estimates of tax credit expenditures range from $780 to $1,070 billion over the 10-year budget window, which are 2.9-4.0 times higher then the CBO/JCT score for comparable credits. When

[1] See the White House (2022), "Remarks by President Biden on the Passage of H.R. 5376, the Inflation Reduction Act of 2022" (available here).

[2] See Nature Conservancy, available here and U.S. Green Building Council, available here.

these tax credits are combined with direct expenditures, total budgetary effects of IRA's climate provisions are \$900 to \$1,200 billion cumulatively through 2031 (Table 2 in Section 3). Even at the higher end of fiscal costs, IRA tax credits reduce CO_2 emissions at an average abatement cost of \$36-87 per metric ton for the power sector—considerably less than recent estimates of the social cost of CO_2 (with central values between \$120-400/t-CO_2 in 2030 per Rennert et al. (2022)), even before accounting for avoided air pollution damages and other co-benefits. On the other hand, IRA's fiscal costs may be considerably lower. We document that the costs for clean electricity generating plants, for whom IRA includes large subsidies, are more sensitive to interest rates than conventional fossil fuel generators. In addition, continued supply constraints, permitting delays, and other factors may increase costs and reduce the pace of clean energy deployment, depressing take-up for IRA incentives. Our lower-end estimates of tax credit expenditures are about \$240B in a scenario with higher interest rates and technology costs, where total fiscal costs are slightly lower than with CBO/JCT estimates but more limited economy-wide CO_2 reductions.

Second, we highlight potential market impacts of IRA incentives, including negative prices in wholesale electricity markets (Section 4). Electricity generation technologies that collect production-based tax credits will have strong incentives to operate even when wholesale prices are low and even negative (which are more common during hours when output from these resources is highest) to receive these credits. For example, a wind project may be willing to pay -\$33 per megawatt-hour (MWh) (suppliers make payments when prices are negative), because it could receive as much as \$33 per MWh in tax credits. Some areas of the country are already seeing negative prices, but their prevalence will likely increase with IRA, which can alter economic signals for market entry and exit of generators, shift incentives for locational decisions and balancing resources (e.g., energy storage, transmission), and change the economics of end-use electrification and new loads (e.g., hydrogen production, cryptocurrency mining).

Third, we discuss distributional impacts and the possible incidence of the different subsidies in IRA. We note the extent to which IRA may drive down retail prices for energy due to subsidies for electricity generation and investment, reflecting transfers from the federal government to consumers and clean electricity providers. In addition to potentially decreasing retail electricity prices, IRA could lower expenditures on fossil fuels due to its incentives for end-use electrification, especially petroleum for transportation. We describe patterns in energy expenditures by income. We also present results from US-REGEN under a counterfactual scenario without IRA subsidies to inform the extent of inframarginal transfers to firms and households that would have adopted these technologies anyway.

Fourth, we consider the relationship between IRA and the macroeconomy. To elucidate the potential macroeconomic impacts of IRA, we develop a representative agent model of the economy which features subsidized clean energy as an input in Section 5. We show how clean energy subsidies function as a supply-side policy that boosts output, investment, wages, and labor productivity while reducing the price of electricity. These dynamic effects work to partially offset the static fiscal cost of the policy. Along the transition path, increased investment demand raises interest rates and lowers private consumption. Bottlenecks lower real clean energy investment but may raise investment expenditures and fiscal cost of the investment tax credit as the relative price of investment in clean energy capital rises. However, the slower pace of investment under bottlenecks mitigates the rise in the real interest rate. We show how elastic labor supply and learning-by-doing externalities increase the clean energy capital stock in steady state under a subsidy policy. Even labor and domestic sourcing requirements as structured in IRA would increase the steady state clean energy capital stock. We also show that clean energy investment may crowd out non-energy investment in the short-run but increases non-energy capital in the long run.

Fifth, we turn to a normative analysis in Section 6 and compare the subsidies approach in IRA to carbon pricing. Our comparison is both conceptual and quantitative, as we derive a carbon price that would yield comparable emissions reductions over a similar timeframe. Conceptually, while both policies lower the relative price of clean to fossil fuel power generation, a carbon tax raises energy prices, encouraging energy conservation but carrying negative supply-side implications for output, investment, and wages. The conservation margin means that a carbon tax results in a larger decline in emissions. In the context of our model, we define optimal policy and show that, despite its positive supply-side effects, optimal climate policy generically involves a positive carbon tax and a zero clean-energy subsidy. The case for an approach centered on clean energy subsidies relies heavily on strong learning-by-doing externalities.

We describe further dimensions along which carbon taxes and subsidies differ that are not captured in our model including fuel switching, differential carbon intensity, and impacts from usage along the intensive margin. We also compare subsidies and carbon pricing in terms of the incentives created for innovation. In this section, we also discuss the economics of some of the industrial policy aspects of IRA, which offers higher tax credits for firms that adopt certain labor practices and buy inputs manufactured in the U.S. In addition, some of the electric vehicle tax credits are only available if the vehicle meets battery sourcing requirements and North American assembly. We explain how these provisions may be addressing market failures, but if not, they may raise costs.

Lastly, we use inputs from the US-REGEN model in Section 7 in the Federal Reserve's FRBUS model to provide quantitative evidence on the possible macroeconomic impacts of IRA. Consistent with this, we show that the new investment under IRA, while large relative to the current level of investment in the energy sector, are comparatively small as both a share of overall investment and overall economic activity. Increases in clean power investment and household transfer income for EVs and other household equipment initially increase demand before raising the capital stock and output. The movements in interest rates and unemployment are very small owing to the small size of electric power investment relative to the overall economy. Although we find that IRA investments in the baseline case are not likely large enough to meaningfully influence macroeconomic aggregates, Section 8 quantifies how the macroeconomic environment – including higher interest rates and rising costs of labor and materials – could have meaningful negative impacts on clean energy investment.

2 Summary of IRA's Climate Provisions

Table 1 summarizes the major energy- and climate-related provisions in IRA and the accompanying fiscal score (Congressional Budget Office, 2022).[3] The fiscal score reflects estimates made by the Congressional Budget Office and Joint Committee on Taxation of the costs to the U.S. government over the 10-year budget window, i.e., 2022-2031. The top panel of the table reflects tax credits, which CBO/JCT estimate will account for about $271 billion in lost tax revenues in total through 2031. The bottom panel reflects direct expenditures, which are estimated to be $121 billion.[4] As discussed in Section 3, the CBO/JCT score is an initial estimate of budgetary effects of IRA, and actual tax expenditures could be significantly larger, given how many of the tax credits are uncapped.

2.1 Tax Credits

Production and Investment Tax Credits. The production and investment tax credits for clean electricity and energy storage account for more than one-third of the estimated costs of IRA's climate provisions (Table 1). The production tax credit (PTC) is awarded per megawatt-hour of electricity output for the first ten years of production from qualifying low-emitting resources, while the investment tax credit (ITC) is awarded as a percentage of the investment cost.

There are two phases to each tax credit. For the first several years, until January 1, 2025, the law lists tax credit amount by type of resource (e.g., over $5/MWh[5] for wind and solar renewable projects that do not meet labor requirements). For projects that are placed into service after December 31, 2024, the law is broader and compensates any clean electricity generation capacity, defined as one with zero GHG emissions. The tax credit is 5 times higher (about $27.5/MWh) for projects that meet certain labor requirements on prevailing wages and apprenticeships, as shown in

[3] For more details on the climate-related provisions of IRA, see "Building a Clean Energy Economy: A Guidebook to the Inflation Reduction Act's Investments in Clean Energy and Climate Action," produced by the Biden Administration (available here). See also,"Tax Provisions in the Inflation Reduction Act of 2022 (H.R. 5376)," produced by the Congressional Research Service (available here).

[4] Much of the reporting on IRA has cited a total figure of $369 billion for the climate provisions, which is apparently from the initial press release on IRA released by Leader Schumer and Senator Manchin's offices. See "Joint Statement From Leader Schumer and Senator Manchin Announcing Agreement to Add the Inflation Reduction Act of 2022 to the FY2022 Budget Reconciliation Bill and Vote in Senate Next Week," July 27, 2022, available here.

[5] All values are shown in 2022 USD unless otherwise noted. The base PTC level is listed in the bill text as 0.3 cents per kilowatt-hour, which is expressed in nominal terms from when the wind PTC was first applied to projects built in 1993. Many IRA tax credits include inflation adjustments over time.

Table 1: Fiscal score of the climate-related provisions of IRA by major category. Values are based on the September 7, 2022 CBO score (available here).

	Fiscal Score ($ B)
TAX CREDITS	
Investment and Production Tax Credits for Clean Electricity Generation and Storage	$131
Production Tax Credit for Carbon Capture and Sequestration	$3
Nuclear Power Production Tax Credit	$30
Clean Fuels	$19
Clean Energy and Efficiency Incentives for Individuals	$37
Clean Vehicles	$14
Clean Energy Manufacturing	$37
SUBTOTAL	**$271**
DIRECT EXPENDITURES	
Agricultural & Forestry Conservation and Sequestration Projects	$21
Energy Loans	$17
Energy Efficiency	$11
Industrial Decarbonization	$5
Other (e.g., Green Bank)	$66
SUBTOTAL	**$121**
TOTAL	**$392**

Figure 1. There is also a 10% increase in the PTC and a 10-percentage point boost to the ITC for projects that use domestically produced steel and other materials, assuming they comply with the labor requirements. Similar bonuses are available for projects that are sited in energy communities, which meet specified criteria. Many of the provisions include incentives to meet similar labor, domestic content, and location-based requirements, so we describe the specifics in the subsection below.

Qualifying electricity facilities are allowed to choose whether to take the PTC or the ITC, and the relative value of each credit could vary by location (e.g., due to variation in wind and solar resource quality), technology, bonus credit eligibility, and assumed capital costs. In many locations, land-based wind and solar PV have higher lifetime credit values with the PTC with the labor bonus, while offshore wind and new nuclear have higher values with the ITC (Xu et al., 2022). However, if a project is eligible for both the energy communities and domestic content bonuses, then the ITC could be more valuable for developers, given the higher incremental value of these bonuses under the ITC.

Production Tax Credit for Carbon Capture and Sequestration. The IRA also expands the tax credit available to facilities that capture carbon dioxide (45Q). With the IRA, facilities above a minimum size threshold that meet labor requirements are eligible for $85/ton of CO_2 stored or $60 for CO_2 utilization (Figure 1, bottom panel). The provision applies for industrial or power generating facilities that capture carbon dioxide from their production processes, as well as direct air capture plants built solely to capture and sequester carbon, which receive $180 per ton of captured and stored CO_2.

Although the CBO estimates that the tax credit for carbon capture and sequestration (CCS) will only cost the government $3.2 billion over the budget window (i.e., about 1% of the tax expenditures in Table 1), some external modelers see substantial investment.[6] Among those modelers that project investments in CCS, major applications include both the industrial sector and the electric power sector, though relative sequestration in each varies by model.

Nuclear Power Production Tax Credit. The IRA adds a production tax credit through 2032 for existing nuclear power plants that meet labor and wage requirements. This credit provides up to $15/MWh for plants, though the magnitude of the subsidy depends on electricity revenues and whether plants already receive credits from other Federal or State zero-emission credit programs. For example, the Infrastructure Investment and Jobs Act, signed into law in November 2021, created a $6 billion program to auction grants to nuclear power plants that remain in service.

Clean Fuels. The IRA also extends and expands credits for clean transportation and industrial

[6] See Jenkins et al. (2022), "Preliminary Report: The Climate and Energy Impacts of the Inflation Reduction Act of 2022" (available here); Zhao, et al. (2022), "An 'All-In' Pathway to 2030: The Beyond 50 Scenario" (available here); Bistline, et al. (2023), "Impacts of Inflationary Drivers and Updated Policies on U.S. Decarbonization and Technology Transitions" (available here).

fuels. As with the PTC and ITC, the legislation extends targeted tax credits for biodiesel, renewable diesel, and alternative fuels for the first several years and then replaces those with a technology neutral credit. The technology-neutral credit begins in 2025 and is available through the end of 2027. The credit value is $1/gallon if labor requirements are met and can be increased depending on the emissions intensity of the fuel. The CBO projects the largest expenditures in this category will be a new credit for clean hydrogen (45V), which can be used in transportation, industrial, and power generation applications, and the magnitude of these hydrogen subsidies depends on the emissions intensity of production.[7] The IRA also adds a tax credit for sustainable aviation fuels of $1.75/gallon with the labor bonus, although CBO estimates, consistent with those of outside modelers, reflect relatively low take-up of this credit. Unlike the power sector PTC, the tax credits apply to all qualifying fuels produced that year, whether from a new facility or not.

Clean Energy and Efficiency Incentives for Individuals. CBO estimates that individuals will make use of almost $40 billion in tax credits for clean energy and energy efficiency investments (Table 1).[8] Individual taxpayers can receive credits for their investments in equipment, including home solar; battery storage; solar water heating; small wind energy; energy efficient insulation, windows, and doors; electric heat pumps; and home energy audits and electric panel upgrades necessary for other efficiency improvements. The amount of rebate can vary based on the energy savings, building type, and household income. There are caps on the amounts an individual taxpayer can claim for specific investments (e.g., $150 for a home energy audit and $2,000 for a heat pump) and on total annual credits, but there are no caps on the total amount of credits. Unlike the more commercially oriented credits discussed thus far, there are no adders for using a particular category of labor.

Clean Vehicles. The IRA allows a taxpayer credits up to $7,500 for the purchase of a new electric or hydrogen fuel cell vehicle if several conditions are met. The conditions include: The final assembly of the vehicle must take place in North America, a share of both the critical minerals and the battery components must come from North America (or, in the case of critical minerals, a country with which the U.S. has a free-trade agreement), and the share escalates over time after 2024, and both the vehicle MSRP and the taxpayer's income must be below specified limits. $3,750 of the credit is tied to meeting the battery components requirement, and $3,750 to the critical minerals requirement. Treasury guidance issued in March 2023[9] confirmed that companies leasing vehicles to consumers may claim the commercial clean vehicle credits, which can provide $7,500 without stringent requirements on battery sourcing or caps on MSRP or income eligibility. More broadly, the commercial clean vehicle tax credits provide up to $7,500 for vehicles less than 14,000

[7]Credits for electrolytic hydrogen may be combined with PTC and ITC incentives for clean electricity production, which is an input to hydrogen production.

[8]Less than $0.5 billion of this line item is for energy efficiency investments in commercial buildings.

[9]https://home.treasury.gov/news/press-releases/jy1379

pounds and $40,000 for larger vehicles (or 30% of the purchase price or incremental cost of an internal combustion engine replacement, whichever is lower).

IRA also introduces a $4,000 credit (or 30% of the vehicle price, whichever is smaller) for the purchase of a previously owned electric vehicle as long as the vehicle as more than two years old, the buyer meets income requirements, and the sales prices is below $25,000. Both the income and sales price thresholds are considerably lower than for new electric vehicles. Finally, IRA extends tax credits for individual taxpayers, who can, regardless of income, deduct up to 30% or $1,000 for home charging. Businesses can also claim tax credits for EV charger installations of 30% (as long as they satisfy labor requirements) up to $100,000.

Clean Energy Manufacturing. The IRA extends and expands tax credits for retrofits or new construction of certain energy manufacturing facilities, such as facilities that produce energy storage systems or electrolyzers. There is a 30% credit capped at $10 billion that applies to a range of clean energy technologies and an uncapped credit per unit of production for several specific wind, battery, and solar components (for example, $12 per square meter of photovoltaic wafer or $3 per kilogram of solar grade polysilicon). The CBO estimates that the bulk of the tax expenditures will be through the uncapped provision, though analysis by Credit Suisse indicates that manufacturing credits could be many times the CBO/JCT estimate.[10]

2.2 Common Features of the Tax Credits

Most of the IRA tax credits are not capped, so the CBO/JCT estimates summarized in Table 1 are subject to considerable uncertainty. In Section 3, we present examples of models that have come up with widely varying estimates of the fiscal costs of the credits. In some cases, such as production-based credits for low-carbon electricity, carbon capture, and clean hydrogen, lower fiscal costs would be driven by lower-than-anticipated deployment, meaning that emissions would not come down as quickly as hoped. For the ITC, however, lower budgetary effects could also be driven by lower-than-expected investment costs, for example if the costs of renewable or storage technologies fell faster than expected. Budgetary effects of the tax credits also could be lower if bonus credit uptake is limited.

The IRA does two things to make the tax credits easier to use: It makes some of them direct pay and some of them transferable.[11] Direct pay essentially transforms the tax credit into a grant and means that entities such as nonprofits and state and local governments are eligible to receive them. If a tax credit is transferable, a taxpayer can transfer the credit to an unrelated party in

[10] See Credit Suisse (2022), "US Inflation Reduction Act: A Tipping Point in Climate Action" (available here).

[11] Some credits are transferable but not eligible for direct pay, such as the personal electric vehicle credit. Some are eligible for direct pay but not transferable, such as the credit for commercial clean vehicles. Many are both, including the PTC and ITC for renewable electricity. Credits for alternative fuels are neither eligible for direct pay nor transferable.

exchange for cash. This means that if a provider (e.g., a solar power project developer) has a tax bill that is too small to absorb the credits, they can transfer the credits to a taxpayer that can use them, i.e., whose tax bill is larger than the value of the credits. This transferability provision did not exist before IRA, so for example, renewable developers had to form partnership with taxpayers that had the ability to absorb the credits (so-called "tax equity" investors). As another example, the IRA specifies that beginning in 2024, the taxpayers may elect to transfer the electric vehicle credit to the dealer, meaning that the credit works like a point-of-sale rebate.

Almost all the credits include substantial adders for projects that use domestic content, are located in low-income or energy communities, and meet certain labor requirements (Figure 1). Companies can comply with the labor requirements if they pay prevailing wages during construction and repair and if qualified registered apprentices provide more than a threshold share of labor hours, where the threshold increases over time. This bonus is lucrative for projects eligible for the PTC and ITC, increasing values by five times relative to the base rate. The domestic content provisions typically increase over time, presumably to allow U.S. manufacturers the opportunity to scale production capacity.

The energy communities bonus provides an additional 10% for the PTC or 10 percentage points for the ITC if any of three criteria are met related to brownfield sites, employment and tax revenue from fossil fuels,[12] or coal mine or plant closures. Eligibility for energy communities bonuses could affect bonus uptake, siting decisions for projects, and the ability to direct IRA funds toward areas most acutely impacted by lower fossil fuel consumption and production. The broad geographical coverage of statistical areas and census tracts under energy communities definitions likely means that large land areas may be eligible for these bonuses, covering 42% to 50% of U.S. land area according to initial estimates (Raimi and Pesek, 2022), which is consistent with Treasury and IRS guidance[13], even areas that are geographically distant from communities that are dependent on fossil fuels for employment and government revenue. This coarse geographical targeting means that IRA benefits also go to regions with limited fossil fuel dependence, while at the same time, the unemployment criterion may exclude areas with some of the highest dependence on fossil fuels, including Colorado, Louisiana, North Dakota, West Texas, and Wyoming (Raimi and Pesek, 2022). Additionally, the binary eligibility rule for the energy communities bonus ignores the heterogeneity of fossil fuel dependence, which lowers the cost-effectiveness of these provisions in achieving "just transition" objectives. The modeling in Section 3 illustrates that the eligibility for the energy communities bonus can increase the deployment of wind, solar, and other IRA-qualified resources, though the geographical allocation of this capacity does not necessarily align

[12] IRA specifies that "0.17 percent or greater direct employment or 25 percent or greater local tax revenues related to the extraction, processing, transport, or storage of coal, oil, or natural gas" and an "unemployment rate at or above the national average unemployment rate for the previous year" (117th Congress, 2022).

[13] https://home.treasury.gov/news/press-releases/jy1383

with fossil-fuel-dependent communities.

The credits are available over different time periods. The production and investment tax credits begin to phase down either in 2032 or when power sector emissions reach 25% of their 2022 emissions, whichever is later. This emissions-based eligibility threshold is a novel feature of IRA and could imply that qualifying clean electricity resources may receive tax credits well into the 2030s and potentially longer, which has associated budgetary impacts. Production-based tax credits for hydrogen and electricity apply to projects placed in service through at least 2032 and continue for 10 years after the project begins claiming the credit. Credits for CO_2 capture continue for 12 years after the project begins claiming the credit. The electric vehicle tax credits are generally available through 2032, which is the end of the 10-year budget reconciliation period.

2.3 Direct Expenditures

Agricultural & Forestry Conservation and Sequestration Projects. The IRA provides over $20 billion for agricultural and forestry conservation programs. Much of the agricultural funding flows through existing conservation programs, though expands funding for them significantly. For instance, $8.45 billion is directed to the Environmental Quality Incentives Program (EQIP) for practices that improve carbon storage in soil or decrease greenhouse gas emissions. Funding for forestry programs would target hazardous fuel reduction projects, vegetation management projects, inventories of old-growth forests, and other measures.[14]

Energy Loans. IRA increases existing loan program authority of the U.S. Department of Energy's Loan Program Office by about $100 billion and creates a new Energy and Infrastructure Reinvestment Program, which aims to accelerate retooling and replacing emissions-intensive energy infrastructure. The IRA also increases funding for several existing programs that aim to encourage farmers and rural landowners to purchase renewable energy systems. It also provides almost $10 billion to encourage rural electric cooperatives to invest in renewables and other low-carbon energy projects.

Energy Efficiency. The IRA includes over $10 billion in direct expenditures for energy efficiency programs, including a new Department of Energy program to award grants to state energy offices to develop whole-house energy saving retrofits programs. It also increases funding for energy efficiency under an existing Department of Housing and Urban Development affordable housing programs.

Industrial Decarbonization. The law funds a new program at the Department of Energy to support industrial facilities in emissions-intensive industries that complete demonstration and deployment projects to reduce emissions. Although projections before IRA suggest that the industrial

[14]See Mahajan et al. (2022) (available here) for analysis of these provisions. They project that these provisions lead to CO_2 emissions from land-use change and forestry in 2030 of -744 Mt-CO_2/yr (i.e., net removals) instead of -707 Mt-CO_2/yr in the counterfactual reference without IRA. See CRS for more details on the agricultural and forestry programs.

sector will be responsible for over one-quarter of emissions by 2030, IRA allocates only $5 billion for emissions reductions in the sector. Some models suggest that clean hydrogen and carbon capture and sequestration will be useful in the industrial sector, so the total subsidies for the sector may be larger than $5 billion, but still considerably smaller than subsidies for the electric power and transportation sectors.

Other. Notable expenditures in the "Other" category include $27 billion for the Environmental Protection Agency to run the Greenhouse Gas Reduction Fund, which will award competitive grants with an emphasis on clean energy projects that benefit low-income and disadvantaged communities. (This is sometimes described as the U.S. government's "Green Bank" as much of the funding will support nonprofit organizations that provide financial or technical assistance to local clean energy projects.) IRA includes a Methane Emissions Reduction Program to establish a charge on methane emissions from specified sources, beginning at $900 per ton of methane and increases to $1,500 after two years. This fee equates to about $36 and $60 per metric ton of CO_2 equivalent,[15] although the precise number depends on the assumed CO_2-equivalence of methane. The fee will not be assessed if all 50 states adopt EPA regulations.

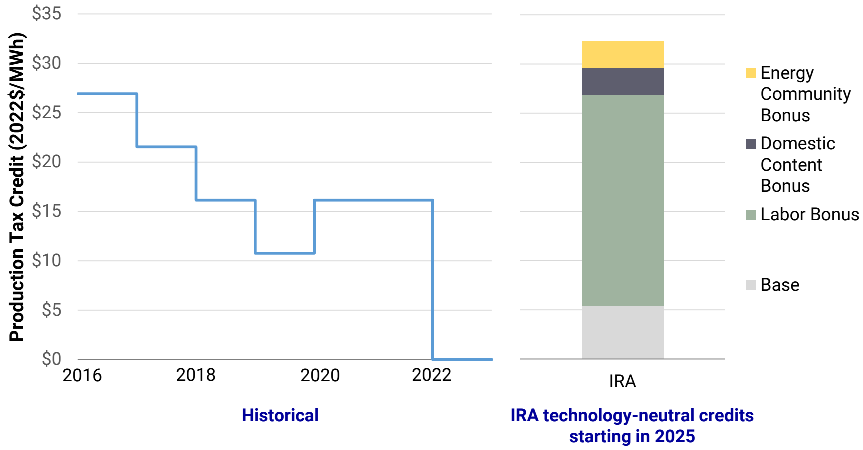
2.4 Comparing IRA to Pre-2022 Programs

In many cases, IRA extended and expanded existing programs. In some cases, IRA introduced entirely new programs.

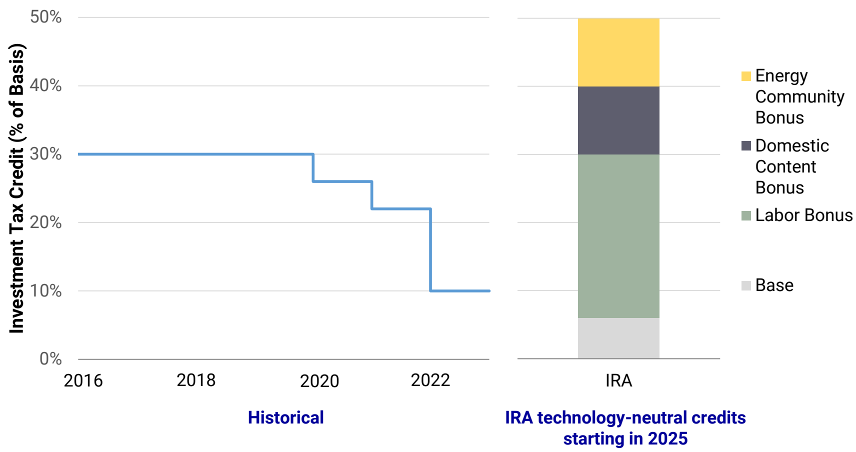
As an example of enhancements to existing tax credits, Figure 1 depicts the production and investment tax credits that existed for wind, solar, and carbon capture and sequestration before IRA. The top panel summarizes the credits available to wind generators through the production tax credit, which had been as high as $27/MWh in 2016 (2022$) but had expired on December 31, 2021. Before the IRA, solar projects were eligible for the ITC but not the PTC. The bars on right break down the IRA credits, showing the large bonus credits available for plants that meet the labor requirements. The middle panel of Figure 1 compares historical ITC values with IRA ones. Finally, the bottom panel summarizes credits available for captured CO_2. Before the IRA, industrial and power generating facilities were eligible for $50/ton for CO_2 storage and $35 for utilization. The updated IRA credits for CO_2 capture also include higher credit levels for direct air capture, which can be up to $180/t-$CO_2$ for projects with the labor bonus.

The longevity of the tax credits under IRA also provides renewable project developers with more certainty than they had in the past. For example, the Union of Concerned Scientists noted in 2015 that, since its inception with the Energy Policy Act of 1992, the production tax credit expired six times. Though it was subsequently extended by Congress each time, they conclude that, "[t]his 'on-again/off-again' status has resulted in a boom-bust cycle of development. In the years following

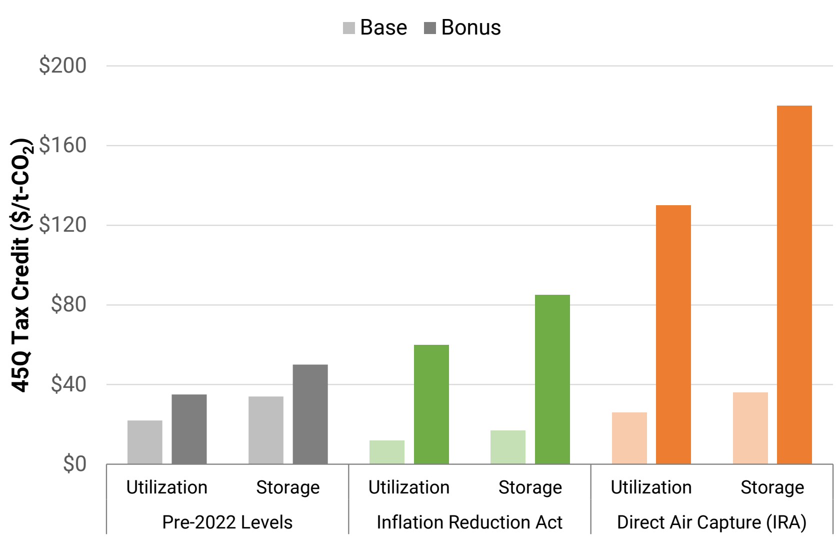
[15] https://crsreports.congress.gov/product/pdf/R/R47206



(a) Production tax credit



(b) Investment tax credit



(c) Captured CO_2 credit

Figure 1: Production, investment, and carbon capture credits under IRA relative to pre-IRA. Note that the right-hand side of Panels A and B reflects the technology-neutral credits starting in 2025, but the wind and solar-specific credits available in 2023 and 2024 are identical.

expiration, installations dropped between 76 and 93 percent."[16] Timing projects to ensure that they qualify for tax credits may increase costs and risk for renewables developers.

Examples of expansions under the IRA include extending the investment tax credit to standalone energy storage projects, which previously were only eligible if they were co-located with solar power facilities.

In some cases, IRA introduced brand new programs, including the Green Bank, tax credits for advanced manufacturing of clean energy inputs, and tax credits for commercial vehicles. And, many of the labor market, domestic content, and energy community credits are new.

3 Fiscal Implications

3.1 Initial CBO/JCT Score

Initial estimates by the Congressional Budget Office and Joint Committee on Taxation (Congressional Budget Office, 2022) indicate that the entire climate and non-climate provisions of IRA would increase federal tax revenue by $58B on net over the 10-year budget window (i.e., through 2031).[17] Increases in fiscal costs from tax credits and direct spending would be more than offset by increases in revenues from alternative minimum taxes on large corporations, excise taxes on stock buybacks, and increased enforcement of extant taxes. According to this CBO/JCT estimate, costs to the U.S. government for energy- and climate-related tax credits are $271B and $121B for direct expenditures through 2031 (Table 1).

As discussed in Section 2, large shares of spending are allocated for IRA provisions where tax credits are uncapped, which are investment- or production-based. This means that actual federal tax expenditures and budgetary effects might be significantly more than initially estimated.

3.2 US-REGEN Score

Here, we use the energy-economic model US-REGEN[18] to estimate the budgetary effects of core energy-related IRA provisions. US-REGEN brings technological, temporal, spatial, and cross-

[16] https://www.ucsusa.org/resources/production-tax-credit-renewable-energy

[17] CBO/JCT estimates are summarized here. An overview of CBO's general approach to preparing cost estimates is available here, and JCT's approach is described here. These quick turnaround analyses of proposed legislation estimate changes to federal spending and revenues for most bills approved by committee in the House or Senate. For IRA's power and transport provisions, JCT revenue estimates come from baseline projections, often based on U.S. Energy Information Administration (EIA) projections, combined with tax data and assumed elasticities.

[18] EPRI's U.S. Regional Economy, Greenhouse Gas, and Energy (US-REGEN) model features regional disaggregation and technological detail of the power sector and linkages to other economic sectors. Recent peer-reviewed articles and reports can be found here and detailed model documentation here. For descriptions of IRA implementation, see Bistline et al. (2023). The analysis was conducted in February 2023 and does not consider changes in policy or guidance after that time.

sector detail, which can influence the economics of supply- and demand-side resources in the energy system and consequently the budgetary effects of IRA provisions. The electric sector model is an intertemporal optimization of capacity planning and dispatch with simultaneous investments in generation, energy storage, transmission, hydrogen production, and carbon removal.[19] Demand for electric vehicles, heat pumps, and other building equipment come from separate logit models that translate relative costs of ownership across technologies into equilibrium market shares.[20]

This analysis suggests that government expenditures under IRA may be significantly larger than initial estimates based on higher tax credit uptake and deployment of clean electricity, carbon capture, and electric vehicles (Figure 2). Total fiscal costs of tax credits in US-REGEN are estimated to be over $780B by 2030 – over three times the CBO value for comparable credits. Figure 2 compares total fiscal costs (i.e., cumulative expenditures) of IRA tax credits in the US-REGEN analysis with the CBO/JCT score for select IRA provisions over time. When these tax credits are combined with direct expenditures, total budgetary effects of IRA's climate provisions total $900B through 2031.

Tax credits in the electric sector are projected to be $320B cumulatively through 2031 by US-REGEN. 45Q credits for captured CO_2 are one of the largest differences between CBO/JCT and US-REGEN estimates. The CBO/JCT score indicates a total of $3.2B in 45Q credits through 2031 (and just $0.3B annually in 2031). In contrast, credits for captured CO_2 in US-REGEN total $100B through 2031.[21] US-REGEN estimates could be conservative, since they only reflect credits used in the power sector. BloombergNEF estimates cumulative 45Q credits could be over $100B, as carbon capture and sequestration (CCS) could become economical for several point-source CO_2 applications outside of the power sector, including natural gas processing, ethanol, ammonia, and cement.[22]

Note that the CBO/JCT score only examines effects across a 10-year budget window, and most IRA incentives are available for 10 years based on their construction date (i.e., a project constructed

[19]US-REGEN uses a unique approach for selecting intra-annual segments to more accurately characterize the economics of variable renewables, energy storage, and dispatchable capacity (Blanford et al., 2018). This algorithm allows the model to capture features such as diminishing marginal returns for higher wind and solar deployment, the value of firm low-emitting technologies under deep decarbonization, and chronological system operations for short- and long-duration energy storage options.

[20]The model includes segmentation of firms and consumers to capture differences that are relevant to technology choice, including household location, vehicle ownership, driving intensity, building type, and charging access for passenger vehicle decisions. Hourly electricity profiles for vehicle charging are based on exogenous charging patterns that vary by driver type, day type, temperature, and location and include flexibility through deferrable charging (Bistline, Roney and Blanford, 2021). US-REGEN assumes perfectly competitive markets, meaning that tax credits and taxes are passed through to consumers.

[21]Note that US-REGEN is typically run in five-year timesteps. However, for comparability with the CBO/JCT score, we interpolate results to show 2026 and 2031 values.

[22]See BloombergNEF (2022), "Carbon Capture Could Get $100B in Credits from US Climate Bill" (available here).

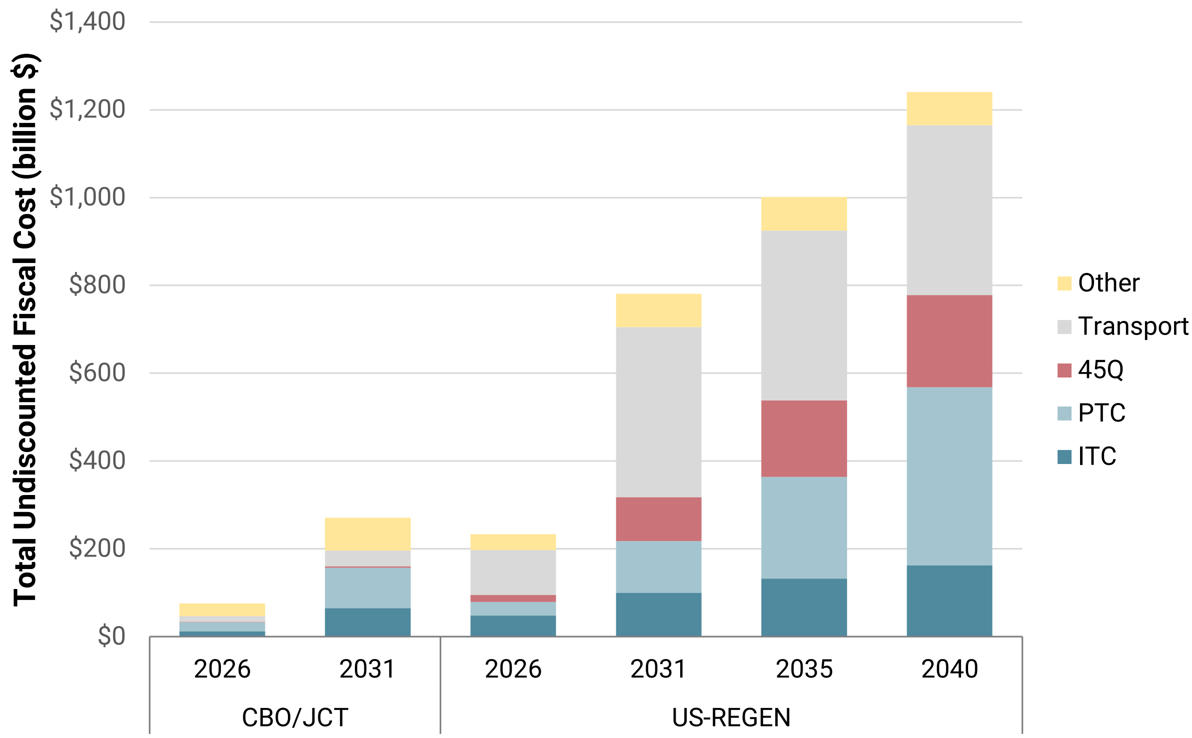


Figure 2: Estimates of cumulative (undiscounted) fiscal costs from IRA tax credits by provision. CBO/JCT scores are based on September 7, 2022 estimates (available here) and look at budgetary effects from 2022-2031. Values are shown in nominal terms. The Other category includes additional end-use incentives (e.g., credits for heat pumps) and manufacturing. 45Q credits are for captured CO_2.

in the early 2030s may receive credits into the 2040s). US-REGEN estimates that the electric sector tax credits will sum to $780B through 2040, 63% of the total (Figure 2). Cumulative credits for captured CO_2 are estimated to be $210B by 2040. For a hypothetical budget window from 2031-2040, electric sector tax credits would be $460B, nearly three times the comparable CBO/JCT values for the initial 10-year period (about $160B).

59% of aggregate spending through 2031 in US-REGEN comes from demand-side credits for electric vehicles, heat pumps, and energy efficiency upgrades. In particular, subsidies to promote electric vehicle sales dominate end-use credits and are significantly higher than initial estimates. Total fiscal costs of clean vehicle credits in US-REGEN are $390B through 2031, which is more than an order of magnitude greater than CBO estimates of $14B. If U.S. EIA's estimates are used for electric vehicle deployment,[23] the CBO/JCT score suggests that the average eligible share of vehicles for the full credit is 12%. On the other hand, if all new electric vehicles in 2030 are assumed to be eligible for the full credit, the CBO/JCT score implies an electric vehicle sales share of 1%.

Because electric vehicles can have lower total costs of ownership for many households before tax credits (Argonne National Laboratory, 2021), 73% of electric vehicles sold in 2030 would have occurred in the counterfactual without IRA incentives in US-REGEN (Figure 3),[24] which reduces the efficiency of these tax credits. Figure 3 indicates that IRA increases the electric vehicle share of new vehicle sales by 12 percentage points in 2030 from 32% to 44%. There is considerable uncertainty about the fiscal cost of consumer tax credits for electric vehicles, since as Section 2.1 describes, magnitudes of these credits are tied to battery components and critical minerals requirements, various eligibility restrictions, and domestic manufacturing incentives. These factors depend on Treasury guidance, firm responses to passenger clean vehicle credits and manufacturing tax credits, as well as consumer purchasing decisions.[25]

Tax expenditures increase over time, especially in the electric sector. Figure 2 illustrates how fiscal costs of tax credits in 2031 total $780B but reach over $1.2 trillion by 2040. End-use incentives are larger in 2031, but since these credits generally expire around 2031, power sector credits lead cumulative spending by 2040. The power sector PTC and ITC could last longer until electricity emissions reach 25% of 2022 levels,[26] which could mean that credits could remain in place for

[23]U.S. EIA's Annual Energy Outlook 2022 projects that electric vehicle sales shares are 6.6% in 2030, declining from a 6.7% sales share in 2022 (Figure 3).

[24]Electric vehicles shares account for range anxiety, household heterogeneity, preferences for internal combustion engine vehicles, and other factors in US-REGEN's logit model of passenger vehicles, as described in the model documentation here.

[25]For US-REGEN scenarios, new light-duty vehicle sales are assumed to have an increasing average incentive value for clean vehicle credits (30D) and advanced manufacturing production credits (45X) over time. Assumptions about battery assembly, critical materials sourcing, income and sales price eligibility, final vehicle assembly, and battery manufacturing credits lead to an average incentive value for new electric vehicles of $3,750 in 2025 and $7,500 in 2030, which are similar to the Moderate scenario in Slowik et al. (2023).

[26]This threshold is approximately 380 Mt-CO_2/yr based on preliminary Rhodium estimates of 2022 emissions

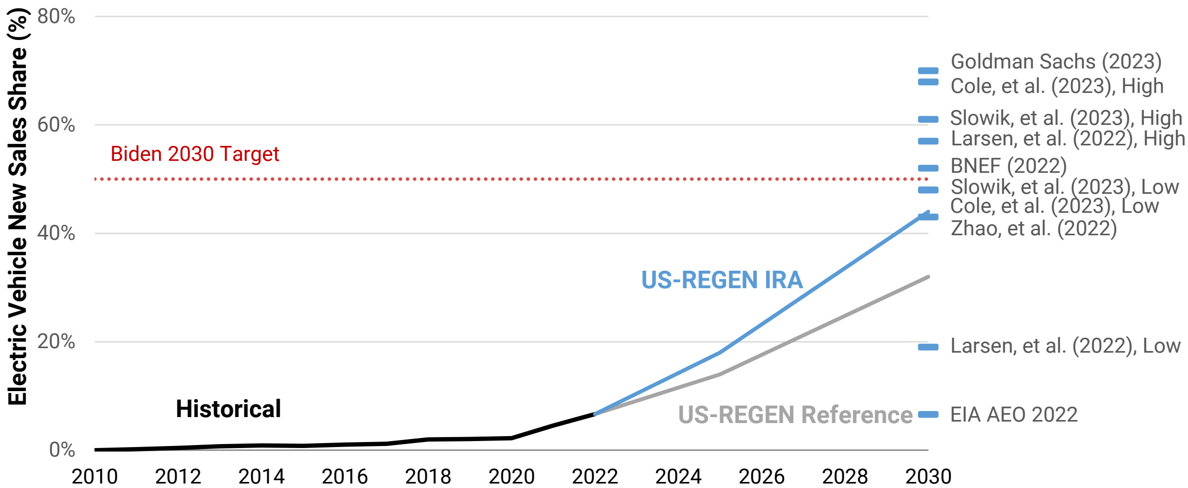


Figure 3: Electric vehicle share of new passenger vehicle sales. Electric vehicles include battery electric and plug-in hybrid electric vehicles. Historical values come from the International Energy Agency's "Global EV Outlook 2022" (available here). US-REGEN scenarios with and without IRA are compared with recent estimates of electrification shares of new vehicle sales under IRA.

over two decades and that fiscal implications of IRA credits are largest after the initial 10-year window. Projections for tax expenditures over time can vary based on uptake of ITC vis--vis PTC (i.e., where the former are frontloaded and the latter are payouts over time), bonus eligibility, and timing of investments.

3.3 Comparisons with Other Estimates of IRA's Fiscal Costs

This finding that fiscal costs under IRA are uncertain and may be much larger than initial CBO/JCT estimates is reflected in other studies:

- An analysis by Credit Suisse points to greater climate spending in several areas, especially for advanced manufacturing credits. They project tax expenditures of $250B for these credits supporting solar, wind, and battery supply chains, which is eight times higher than CBO estimates (Credit Suisse, 2022).[27]

- An analysis by Goldman Sachs estimates that government spending could be nearly $1.2 trillion over the next decade, including $393B for transport electrification and $274B for clean electricity.[28]

(available here). IRA scenarios in US-REGEN generally do not reach emissions levels below this threshold until after 2040.

[27] See Credit Suisse (2022), "US Inflation Reduction Act: A Tipping Point in Climate Action" (available here).

[28] See Goldman Sachs (2023), "Carbonomics: The Third American Energy Revolution."

- Cole et al. (Forthcoming) estimate cumulative federal tax expenditures for light-duty vehicles to be $451B through 2031, comparable to the $390B in US-REGEN, which are more than an order of magnitude greater than the $14B CBO value. They also estimate that 40-57% of this spending would be inframarginal transfers to consumers who would have purchased in counterfactual without IRA incentives. Figure 3 compares the Cole et al. (Forthcoming) estimates for new sales of electric vehicles under IRA with US-REGEN values and several other estimates from the literature (Slowik et al., 2023; Alicia Zhao, 2022; McKerracher and Grant, 2022; John Larsen and Herndon, 2022). These shares span a wide range – from 19-70% – though many are above the US-REGEN value of 44%, which suggests that the budgetary effects in Figure 2 could be conservative.

- Power sector capacity additions vary based on IRA implementation and scenario assumptions (e.g., projections of capital costs, fuel prices, other policies and incentives). Figure 4 compares US-REGEN additions of low-emitting capacity (including renewables, nuclear, CCS-equipped fossil, and energy storage) with other public estimates of IRA's impacts (Roy et al., 2022; Levin and Ennis, 2022; BloombergNEF, 2022; O'Boyle, Esposito and Solomon, 2022; Jenkins, 2022; John Larsen and Herndon, 2022). Average annual capacity additions under IRA range from 34 GW/yr to nearly 120 GW/yr, which suggests that the US-REGEN estimates in earlier sections could underestimate fiscal costs of IRA provisions.

The comparison of electric sector additions in Figure 4 also illustrates how, although IRA tax credits accelerate clean electricity deployment, there are still considerable additions of solar, wind, and energy storage in the counterfactual without IRA. Technological change has led to rapid cost declines for solar power, wind power, and battery storage over the past decade (Figure 18), and the expectation of future declines in costs of these resources (Figure 8) implies that a portion of the power sector tax credits will be inframarginal transfers to firms that would have adopted these technologies even without IRA (similar to clean vehicle credits), which aligns with qualitative insights from earlier tax credit analysis (Stock and Stuart, 2021). Average annual additions of low-emitting capacity in US-REGEN is 51 GW/yr with IRA and 27 GW/yr in the counterfactual reference, indicating that over half of these additions would have occurred without IRA tax credits. Nonetheless, US-REGEN modeling suggests that the IRA incentives are highly cost-effective, as we discuss below.

Figure 4 also illustrates the broad range in possible electric sector additions under IRA, even across models with similar IRA implementations (Bistline et al., Under Review). These cross-model differences in power sector outcomes are tied to model structure, input assumptions, and IRA representations. In particular, temporal resolution (i.e., the number of intra-annual periods represented for investment and dispatch decisions) and assumed discount rates (Section 4.1) alter

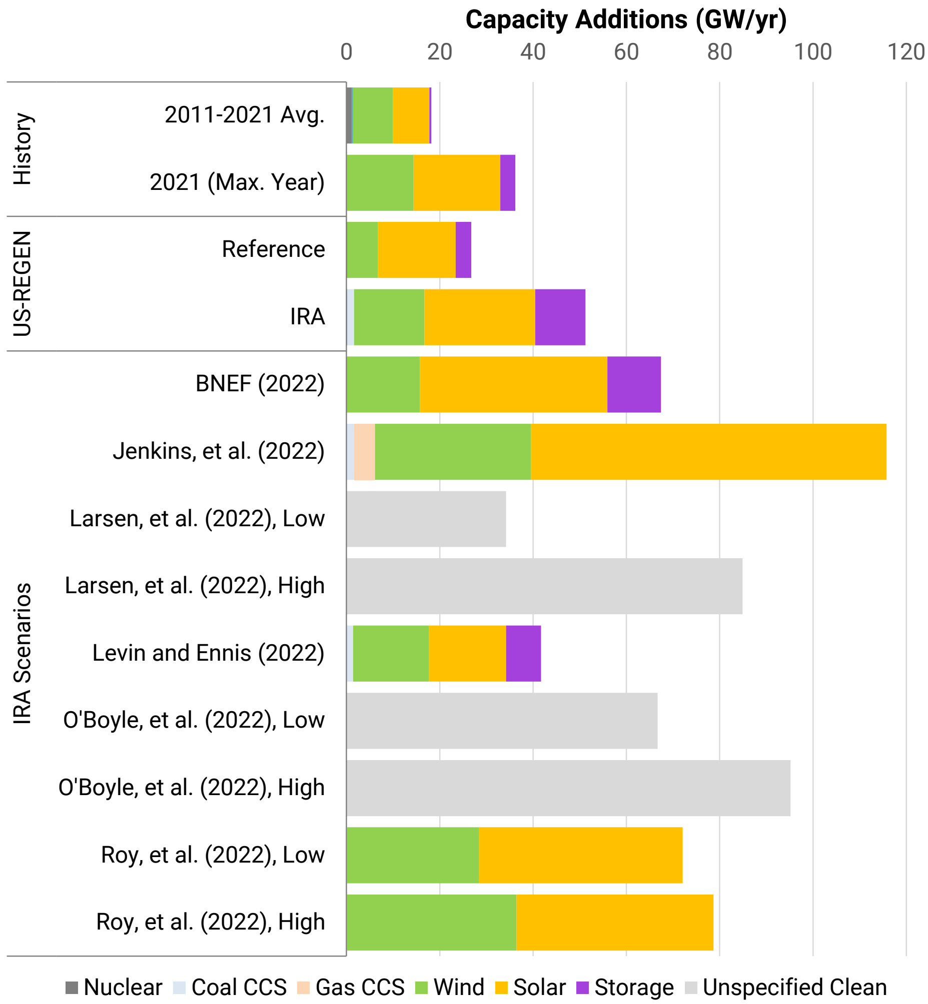


Figure 4: Average annual capacity additions by low-emitting generation and energy storage technologies. Historical values come from Form EIA-860 data (available here) and show average additions over the past decade and the year of maximum deployment to date (2021). US-REGEN model outputs show build rates with and without IRA through 2035. These scenarios are compared with estimates in the literature for deployment under IRA through 2035, where available. Note that several studies do not report energy storage capacity or technology-specific capacity additions (aggregate values are shown in gray).

the economics of low-emitting resources (Bistline, 2021; Lonergan et al., 2023).[29]

3.4 IRA Emissions Impacts and Implied Abatement Costs

Although the CBO/JCT score does not provide carbon reduction estimates, the initial announcement of IRA indicated that it would "reduce carbon emissions by roughly 40 percent by 2030" (Senate Democrats, 2022). Figure 5 shows CO_2 emissions over time for the US-REGEN scenarios, indicating economy-wide reductions of 35% by 2030 (from 2005 levels) with IRA and 41% by 2035 (compared to 29% and 33%, respectively, in the reference scenario without IRA).[30] Large shares of IRA-induced emissions reductions beyond reference levels come from the electric sector, which decreases its emissions 64% by 2030 (compared to 54% in the reference). If 40% reductions in economy-wide emissions were reached by 2030, fiscal costs of the tax credits would exceed the US-REGEN estimates in Figure 2, making them even higher than initial CBO estimates (the sensitivity in the next subsection indicates that tax credit expenditures would be $1,100B through 2031 if 40% reductions are reached).

We also conduct a sensitivity in US-REGEN to evaluate emissions reductions if fiscal costs over the 10-year budget window are constrained to the CBO/JCT score values for power sector tax credits (Table 1). In that case, Figure 5 shows how economy-wide emissions reductions only reach 30% below 2005 by 2030.[31]

We calculate emissions reductions in the U.S. economy and do not model impacts on the rest of the world. All of the models summarized in Figure 4 take a similar approach. This implicitly assumes that reductions in the U.S. will not lead to increased emissions outside the U.S. (i.e., that there will not be meaningful emissions "leakage"). The existing empirical estimates and model-based studies suggest that emissions leakage is limited (Grubb et al., 2022), and these studies are based on climate-mitigation approaches that impose costs on domestic industry, such as carbon pricing. Since IRA will subsidize clean production, emissions leakage is likely to be even more limited. We discuss possible technological and/or policy spillovers to the rest of the world below.

Our estimated emissions reductions can be used to calculate implied abatement costs associated with IRA tax credits. In particular, the cost per metric ton of CO_2 reduced from IRA tax credits in the power sector are based on changes in total system costs over time (including all private

[29]For instance, US-REGEN has one of the highest temporal resolutions of the models represented in Figure 4 but lower deployment, whereas one of the models with highest deployment has a single annual timeslice (Energy Innovation, 2021).

[30]This six percentage point reduction in energy CO_2 emissions is comparable to the U.S. EIA's Annual Energy Outlook 2023 (?) reductions between its reference case with IRA and its no IRA scenario, which is seven percentage points (from 26% below 2005 by 2030 to 33% with IRA).

[31]Power sector emissions in a scenario with IRA incentives that are capped at the CBO values exceed reference levels, since renewables and CCS deployment are lower than in the IRA scenario but overall generation is higher than the reference case due to the additional end-use electrification from IRA incentives.

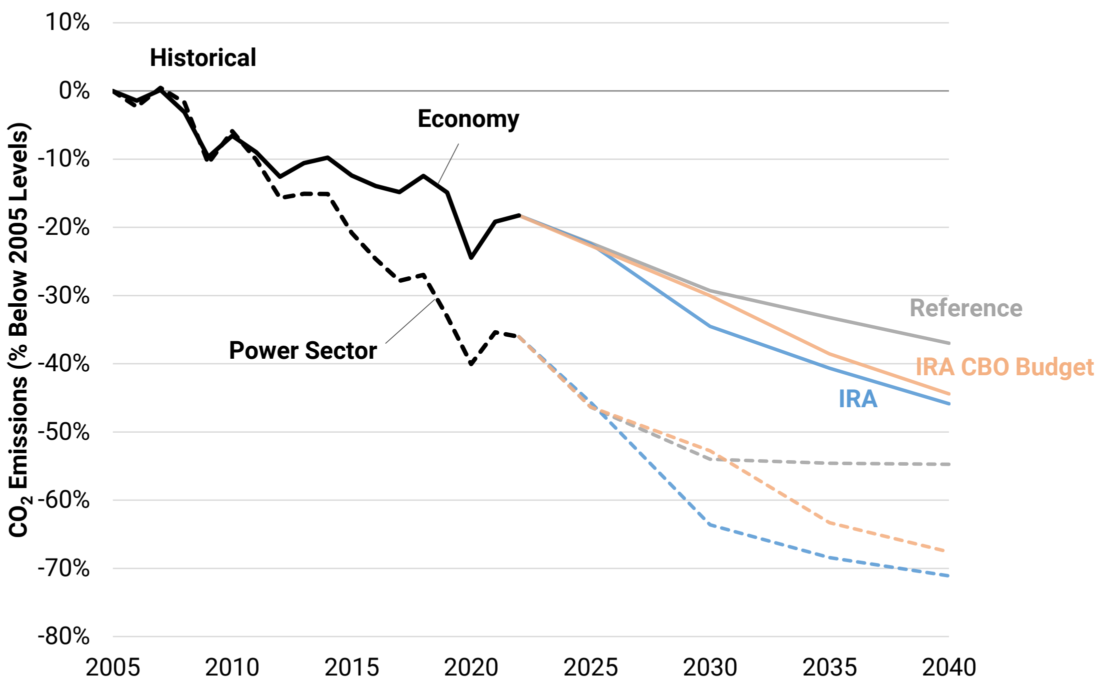


Figure 5: Economy-wide and electric sector CO_2 emissions over time. Values are based on US-REGEN modeled scenarios with IRA incentives (blue), a counterfactual reference without IRA (gray), and an IRA scenario with a constraint that fiscal costs match CBO values through 2030 (yellow). Historical values come from U.S. EPA's "Inventory of U.S. Greenhouse Gas Emissions and Sinks" (available here).

sector and government costs that would not have been borne without IRA[32]) divided by emissions impacts from IRA (which is the difference between the IRA and reference scenarios in Figure 5).[33] Cumulative incremental costs under IRA are $420-570B across the model's time horizon depending on the discount rate—ranging from 1.5% to 3%—with cumulative reductions of 9.4 billion metric tons of CO_2. As shown in Figure 6, IRA tax credits reduce CO_2 emissions at an average abatement cost of $45-61 per metric ton for the power sector—considerably less than recent estimates of the social cost of CO_2 (with central values between $120-400/t-$CO_2$ in 2030 per Rennert et al. (2022), depending on the near-term discount rate), even before accounting for avoided air pollution damages and other co-benefits.[34] The finding that IRA's average abatement costs are likely below updated social cost of carbon estimates holds even with the higher abatement costs in Section 3.5 and inframarginal transfers noted in Section 3.3.

3.5 Lower and Higher Fiscal Cost Sensitivities

Given uncertainties in the planning environment, we include two sensitivities to investigate the potential range[35] of IRA's fiscal costs, in addition to the central case presented earlier:

- A *Lower Fiscal Costs* scenario assumes higher supply-side costs, higher interest rates, and lower eligibility of electric vehicles for credits. Scenario assumptions are discussed in Section 8, which provides a deep dive into how the assumed macroeconomic environment can alter the effects of IRA.

- A *Higher Fiscal Costs* scenario uses the same technology and market assumptions as the central case but adds additional policies, including higher credit values for clean hydrogen under IRA, IRA bonus credits for energy communities and domestic content for all power sector projects, as well as new and existing source performance standards for power plants.[36]

[32]Similar to Stock and Stuart (2021); Greenstone et al. (2022), this definition includes incremental expenditures on capital costs (including generation, energy storage, transmission, and distribution), fuel costs, and maintenance costs, and includes both public and private expenditures.

[33]Abatement costs include changes in cost and emissions through the model horizon of 2050, since incentives can shift cash flows far into the future, given the long-lived nature of many assets and the potential for capital-intensive low-emitting resources to lower operational costs over time. Comparisons use discounted costs and undiscounted emissions, due in part to the comparability with emissions-equivalent carbon price in Section 6.5, where the shadow price on the annual emissions cap constraint is implicitly using discounted costs (since the objective function is the net present value of system costs) and undiscounted emissions. If costs and emissions are both discounted, average abatement costs are $88-94/t-$CO_2$.

[34]Note that average abatement costs would be higher if distortions associated with financing the incentives were included (Finkelstein and Hendren, 2020).

[35]These illustrative scenarios should not be interpreted as bookends of possible scenarios or as predictions of likely outcomes.

[36]IRA hydrogen credits are assumed to provide $3/kg-$H_2$ for all electrolytic hydrogen in this scenario (unlike the central scenario that assumes more stringent implementation guidance). The central case assumes that only a fraction

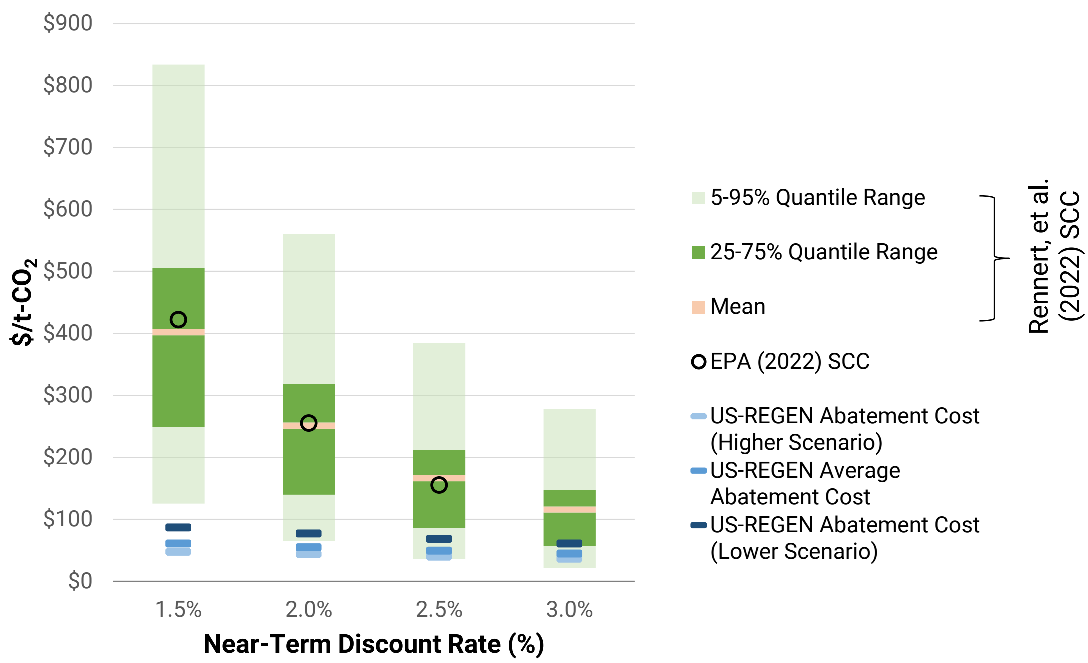


Figure 6: Comparison of social cost of CO_2 estimates and average abatement cost of IRA tax credits in the power sector from US-REGEN. Social cost of CO_2 values come from EPA (2022) and Rennert et al. (2022), which reflect damages from sea-level rise, building energy expenditures, temperature-related mortality, and agriculture only. Scenario results from US-REGEN are summarized in Table 2.

Table 2: Comparison of key metrics across lower, central, and higher fiscal cost sensitivities in US-REGEN. Total fiscal costs include all tax credits and direct expenditures. Abatement costs show ranges across different discount rates (1.5% to 3%).

Metric	Lower	Central	Higher
Total Tax Credit Expenditures to 2031 ($B)	244	781	1,070
Expenditures Relative to CBO/JCT	0.9	2.9	4.0
Total Fiscal Costs to 2031 ($B)	365	902	1,190
Economy-Wide CO_2 in 2030 (% from 2005)	-28%	-35%	-40%
Power Sector CO_2 in 2030 (% from 2005)	-51%	-64%	-75%
Abatement Cost ($/t-$CO_2$)	$61-87	$45-61	$36-49
Electric Vehicle Sales Share in 2030 (%)	33%	44%	60%
Clean Capacity Additions to 2035 (GW/yr)	34.7	51.3	75.9

These sensitivities expand the range of tax expenditures through 2031 from $781B in the central case to $244B to $1,070B, which is similar to the CBO/JCT score at the low end of the range and four times higher than the CBO/JCT estimate at the high end (Table 2). Total fiscal costs of IRA's climate provisions, inclusive of tax credits and direct expenditures, range from $365B to $1,190B through 2031 (compared with $902B in the central case). This sensitivity with lower fiscal costs also leads to more limited emissions reductions (similar to reference levels in Figure 5) because of lower electric vehicle and clean electricity capacity deployment (Table 2). The higher fiscal costs sensitivity reaches 40% economy-wide CO_2 reductions by 2030 relative to 2005 levels and 75% reductions in power sector CO_2, which entails power sector investments increasing by 50% over the central case.

Figure 7 shows IRA fiscal costs by provision across these three sensitivities. Tax credit expenditures quadrupling through 2031 under the higher fiscal costs scenario are due to higher power sector credit uptake vis--vis the central case and about $100B in hydrogen credits. Fiscal costs of these tax credits approach $2 trillion through 2040 in the higher scenario.

3.6 Caveats

There are several uncertainties associated with the fiscal implications of IRA. First, specific guidelines about IRA provisions still await clarifications from Treasury and the IRS, including about

of projects receive the energy communities bonus for the PTC and ITC, which is consistent with updated Treasury and IRS guidance, though this guidance is not explicitly modeled. Model implementation of the new and existing source performance standards for power plants under Sections 111(b) and (d) of the Clean Air Act come from the analysis in Bistline (2023), specifically the scenario with plant-level cofiring-based standards for coal and natural gas combined cycle units.

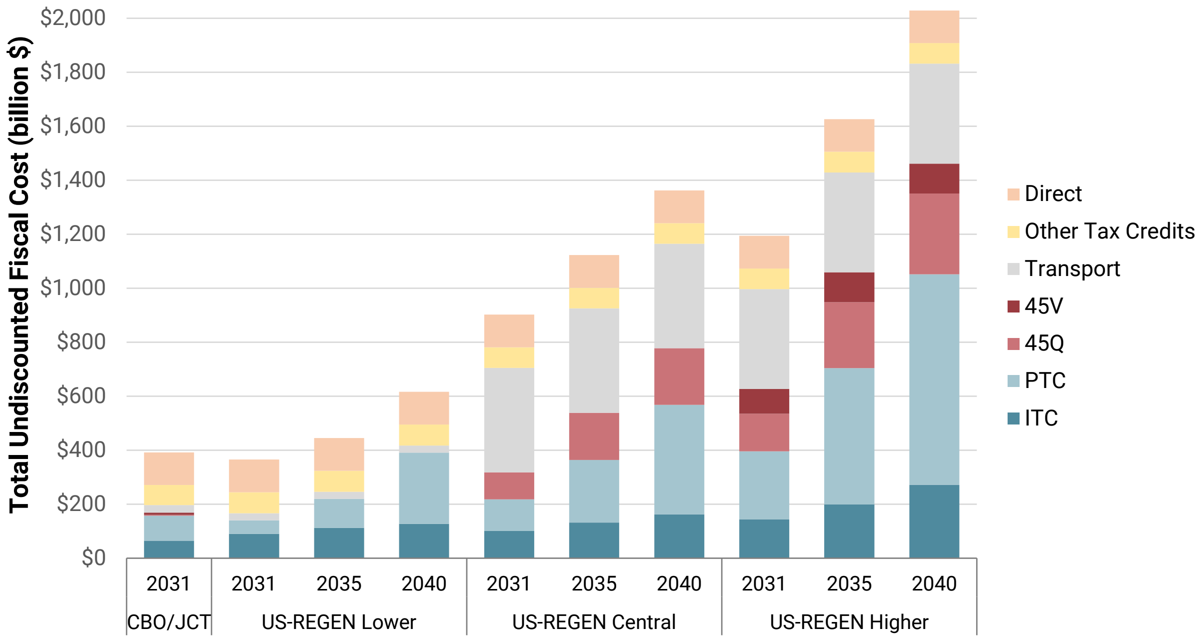


Figure 7: Estimates of cumulative (undiscounted) fiscal costs from IRA tax credits by provision across low, central, and high fiscal cost sensitivities in US-REGEN. CBO/JCT scores are based on September 7, 2022 estimates. Values are shown in nominal terms. The Other category includes additional end-use incentives (e.g., credits for heat pumps) and manufacturing. 45Q credits are for captured CO_2, and 45V credits are for clean hydrogen.

bonus credit eligibility, qualifying resources for the technology-neutral PTC and ITC in power sector, emissions accounting for several credits, and others. Second, forthcoming policy and regulatory changes may affect uptake of tax credits, especially since the timing and stringency of such policies could be influenced by the presence of IRA incentives. For instance, EPA is scheduled to release proposed performance standards for new and existing power plants under Sections 111(b) and (d) of the Clean Air Act in early 2023. If these standards are based on carbon capture or hydrogen at coal- and gas-fired plants, increased deployment of these IRA-subsidized resources could increase and accelerate fiscal impacts (Bistline, 2023). Third, there are general uncertainties as with any projection. For example, US-REGEN assumes that the levelized cost of electricity from utility-scale solar will decline by about 44% with IRA relative to current unsubsidized levels (see Figure 8), though there is considerable uncertainty about the pace of future technological change (Bistline et al., 2022; Way et al., 2022). These unknowns about technologies, markets, and policies mean that IRA incentive uptake (Figure 4) and budgetary impacts are uncertain.

4 Energy Production Analysis

This section describes results from the US-REGEN model (described in Section 3) that shed light on costs and market implications of IRA. Our focus here is on the impact of IRA on the cost of different generating technologies and implications for the price of electricity.

4.1 Levelized Cost of Electricity

Analysts often reference the levelized cost of electricity (LCOE) for different types of electricity generation. The LCOE is the discounted sum of costs associated with building and operating a power plant over its lifetime divided by the discounted sum of future electricity production:

$$LCOE = \frac{\sum_{t=1}^{T} (I_t + OM_t + FC_t)/(1+r)^t}{\sum_{t=1}^{T} E_t/(1+r)^t} \tag{1}$$

where I are investments in period t (including financing costs, minus subsidies), OM are operations and maintenance costs, FC are fuel costs, r is the discount rate, and E is electricity production.

Figure 8 plots estimates of the levelized costs of electricity through 2035 for several prominent generating technologies. The estimates are based on capital cost assumptions from EPRI's US-REGEN model used for the analysis in other sections.[37] Without IRA, costs for renewable technologies, including solar and wind, are generally projected to decline (24% for solar, 16% for onshore wind, and 18% for offshore wind by 2030). These projections are based on a combination

[37] Values are discussed in Bistline et al. (2023). Capital cost assumptions in 2030 are similar to the National Renewable Energy Laboratory's Annual Technology Baseline (moderate technology innovation scenario), which is the primary source for many models that have informed policy discussions about the impacts of IRA (see Bistline et al. (Under Review)); however, near-term costs have been adjusted to reflect observed 2022 costs.

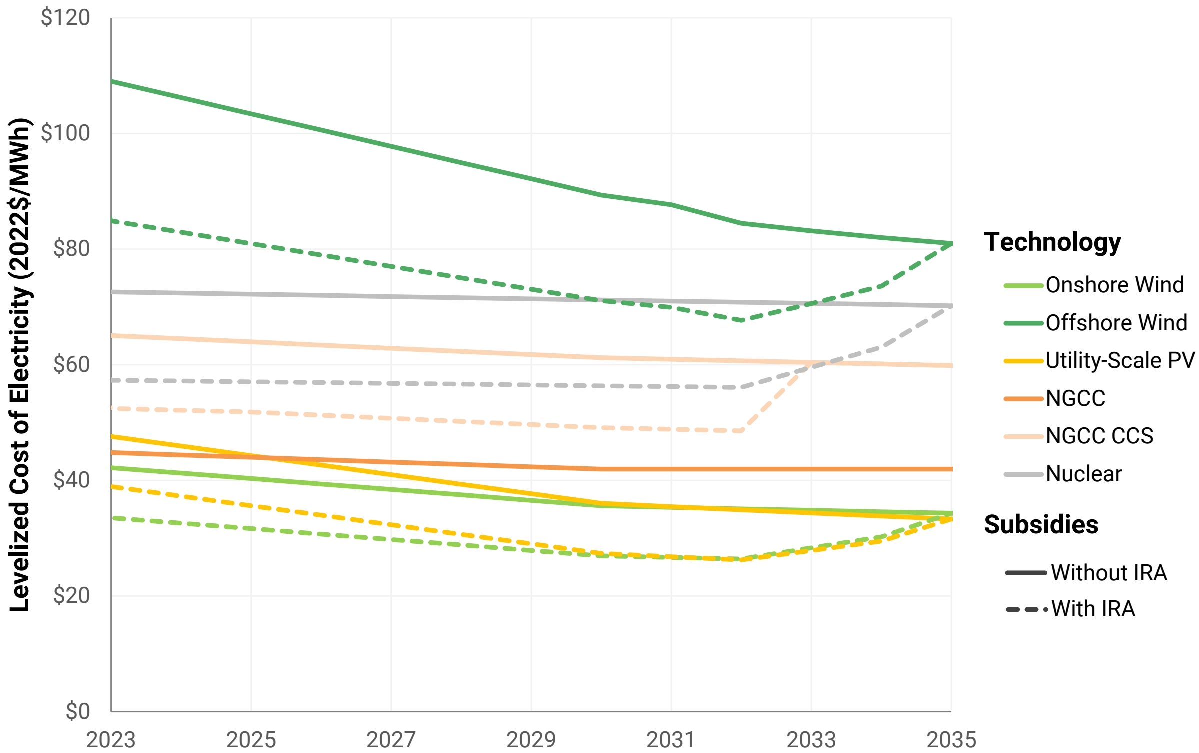


Figure 8: Levelized cost of electricity by technology over time without and with IRA subsidies (solid and dashed lines, respectively). Capital costs underlying these estimates are based on Bistline et al. (2023). Estimates assume 30-year financial lifetimes and 7% discount rates (weighted average cost of capital). Onshore wind and utility-scale solar PV are assumed to take the PTC under IRA, nuclear and offshore wind take the ITC, and natural gas combined cycle (NGCC) with CCS takes CO_2 capture credits. Labor bonuses are included but not bonuses for energy communities or domestic content.

of factors, including assumptions about learning curves, technological progress (e.g., larger rotors for onshore wind), and estimates from the literature.[38]

Figure 8 also highlights the impact of IRA subsidies on the estimated costs for all the eligible technologies. Only the NGCC without CCS is ineligible for subsidies. The calculations behind Figure 8 assume that the technology-neutral production and investment tax credits begin to phase down in 2032 for illustrative purposes, though these could continue afterward if power sector CO_2 emissions have not reached 25% of their 2022 levels.

While LCOE estimates can be a useful summary statistic to make high-level comparisons, especially for time trends of individual technologies, they also have well-known limitations. The statistic does not account for the value of the electricity provided to the grid. LCOE does not distinguish

[38]This figure does not show variability in LCOE estimates based on regional labor costs, resource quality (e.g., for wind and solar generation), or capacity factors (which can vary by scenario and time period), though these features are accounted for in the US-REGEN modeling in other sections.

between resources that primarily produces electricity when demand and wholesale prices are low and resources whose output aligns with higher-priced periods, including dispatchable resources. Joskow (2011) details these issues, highlighting the extent of the problem by noting that, "the difference between the high and the low hourly prices over the course of a typical year, including capacity payments for generating capacity available to supply power during critical peak hours, can be up to four orders of magnitude" (p. 239). The value to production at different times of the day and over the course of the year will also vary as more renewable resources are added to the system.[39] Models that minimize system costs (such as US-REGEN) simultaneously account for power system investments and operational dynamics, including endogenous representations of how the costs and value of different resources change as the system evolves (Bistline et al., 2021).

With those limitations in mind, Figure 8 highlights how, particularly with IRA tax credits, the LCOE of onshore wind and solar PV installations are below other resources. Firms will have strong incentives to build these resources. Offshore wind, even with IRA subsidies, is considerably more expensive than other resources, but several states have resource-specific mandates for these resources, which are represented in many models including US-REGEN. Finally, the impact of tax credits on the LCOE is a function of the assumptions about how long the subsidies will persist. As discussed above, we illustrate LCOEs with credits that begin declining in 2032, but extended tax credits would reduce LCOEs across longer horizons, potentially across multiple decades.

LCOE estimates, including those reflected in Figure 8, incorporate assumptions about the interest rate faced by a project developer. Figure 9, Panel A plots LCOEs under different interest rates, highlighting how various technologies respond to increases in the cost of borrowing (across an illustrative range of rates). Low-carbon technologies are all more sensitive to increases in interest rates, reflecting the large upfront investments required and relatively low operating costs, including a lack of fuel costs (except in the case of CCS-equipped capacity). Figure 9, Panel B plots LCOEs under different assumptions about labor costs. Nuclear plants are the most sensitive to increases in labor inputs, and labor's share of total plant costs range from 17% (for onshore wind) to 44% (nuclear). Section 8 below explores the sensitivity of IRA fiscal costs and emissions impacts under different assumptions about interest rates and other input costs.

4.2 Electricity Market and Price Impacts of Tax Credits

In addition to encouraging the construction of new electricity generating resources, IRA tax credits will impact how new and existing resources are operated. IRA incentives can have large impacts on electricity markets, since credits can lower wholesale prices and increase the prevalence of negative-priced periods. Generation technologies that collect production-based tax credits will have strong

[39]In particular, wind, solar, and other resources exhibit diminishing marginal returns, where the economic value of additional capacity decreases as their deployment increases (Bistline, 2017; Hirth, 2013). Metrics like LCOE neglect declining value and increasing system costs.

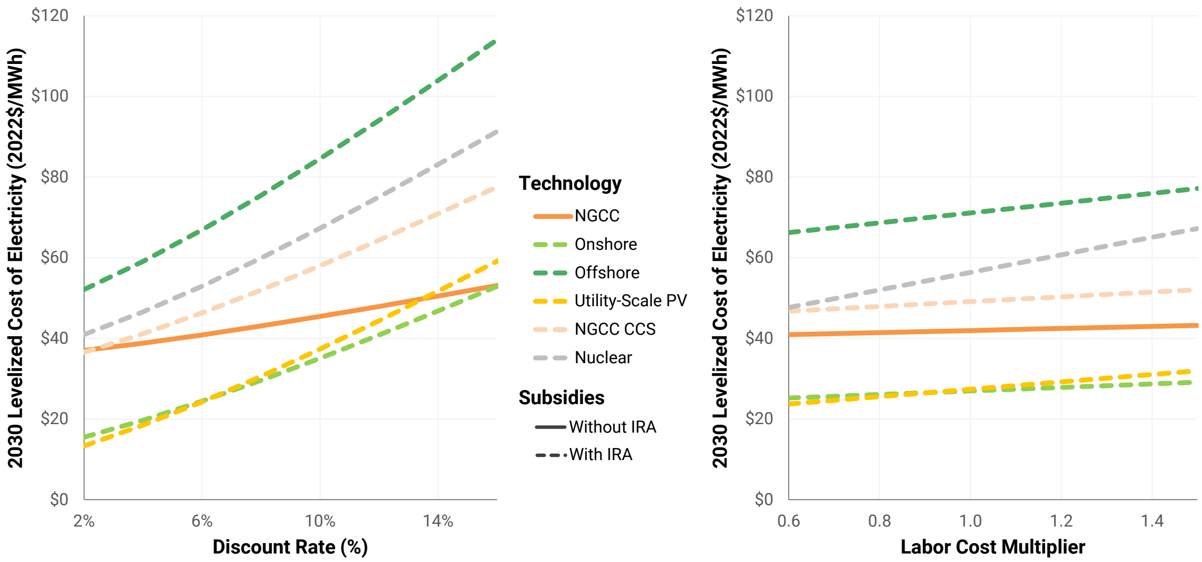


Figure 9: Levelized cost of electricity by technology in 2030 for various assumptions about discount rates (left panel) and labor costs (right panel). All other parameters are held constant from the comparisons in the earlier figure. Costs for technologies are shown after accounting for IRA subsidies, except for NGCC capacity, which is not eligible for tax credits.

incentives to operate even when wholesale prices are low and even negative (which are more common during hours when output from these resources is highest) to collect credits.[40] For example, the variable costs of operating a wind turbine are negligible, and the operator could receive as much as $33 per MWh in subsidies. As long as wholesale prices are above -$33 per MWh, it is profitable for the wind plant to generate electricity.[41] Negative prices alter economic signals for market entry and exit of generators, shift incentives for locational decisions and balancing resources (e.g., energy storage, transmission), affect system operations, and change the economics of end-use electrification and new loads (e.g., hydrogen production, cryptocurrency mining).

Electricity markets have already experienced periods of negative wholesale prices, in large part driven by subsidized renewables.[42] For example, California and Texas, areas with significant renewable capacity, experienced the most periods with negative wholesale electricity prices in 2021 and the first half of 2022.[43] Energy storage can play important roles in shifting electricity from periods

[40]Output-based tax credits under IRA include the technology-neutral PTC, credits for captured CO_2, and credits for clean hydrogen.

[41]These negative offer prices can be as low as -$70-90 per MWh for coal with CCS taking 45Q credits for captured CO_2 (Bistline et al., 2023).

[42]Negative bids from subsidized resources are not the only cause of negative prices in current markets. Local transmission congestion and system-wide oversupply (e.g., due to flexibility constraints) also play roles (Seel et al., 2021).

[43]Malik, Naureen. "Negative Power Prices? Blame the US Grid for Stranding Renewable Energy," Bloomberg, August 30, 2022 (available here).

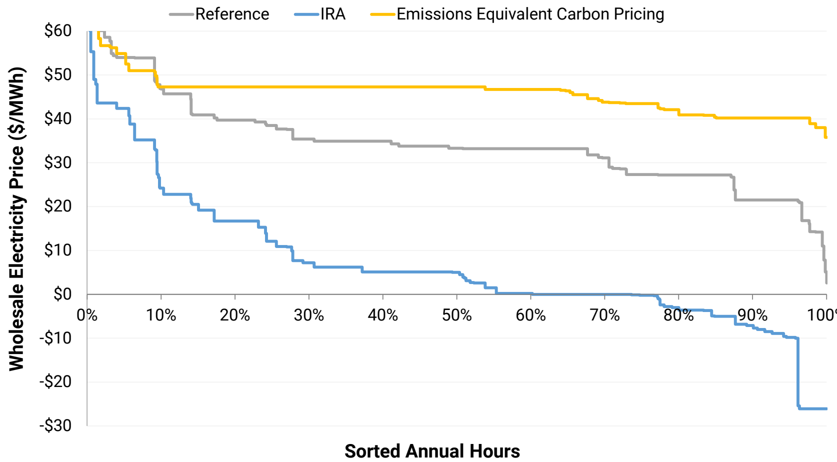


Figure 10: Wholesale electricity price duration curves for the reference, IRA, and carbon price scenarios. Curves are shown for the Southwest Power Pool (SPP) region in 2050, which includes South Dakota, Nebraska, Kansas, and Oklahoma.

with low prices to periods with higher prices. Since IRA extends tax credits to standalone energy storage, deployment of these resources could be significant: Comparisons in Section 3 illustrate how deployment of storage technologies could total over 10 GW per year (compared with about 7 GW of energy storage installed cumulatively as of 2022).

Even with storage deployment, Figure 10 shows how IRA tax credits increase the frequency of zero- and negative-priced hours, which comprise nearly half of all hours in the wind-dominant SPP region. Ultimately, the frequency of negative-priced periods depends on: 1. The fraction of generators taking different tax credits (since negative-priced periods are more likely the more generators take the PTC rather than the ITC); 2. The extent of generator entry and exit (which affects shares of IRA-subsidized resources); 3. Regional supply-demand balances (which influences supply curves and ultimately which technologies are on the margin).[44] In contrast, emissions equivalent carbon pricing, as presented in Table 3, increases wholesale prices relative to the reference. In terms of policy, there are different perspectives on the importance of wholesale and retail market changes for deeply decarbonized energy systems, which may be dominated by resources with zero/negative short-run marginal costs, energy-limited devices such as storage, and cross-sector interactions and subsidized resources, which may exacerbate "missing money" problems and out-of-market payments for resource adequacy and reliability (Ela et al., 2021; Mays, Morton and O'Neill, 2019; Hogan, 2019; Conejo and Sioshansi, 2018).

While the analysis of price pressures has focused on the production-based incentives in the elec-

[44]There are many hours with positive clearing prices, even with significant deployment of zero-marginal-cost resources—energy storage bids at its opportunity cost, gas-fired capacity is on the margin in many hours, and not all subsidized resources are incentivized to make negative bids (e.g., those electing to take the ITC).

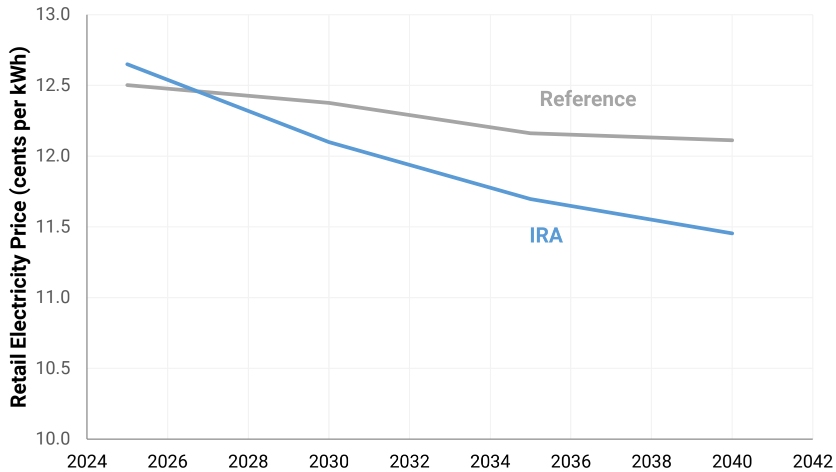


Figure 11: Load-weighted national average of residential retail electricity prices over time. Values are based on US-REGEN modeled scenarios with IRA incentives (blue) and a counterfactual reference without IRA (gray). Note the truncated vertical axis.

tricity market, similar incentives will exist in the manufacturing sector, where IRA offers subsidies per unit produced (e.g., solar panel). These subsidies will put downward pressure on market prices for all suppliers.

Annual retail electricity price impacts of IRA incentives are shown in Figure 11. Modeled prices in US-REGEN[45] illustrate how IRA incentives lower long-run retail prices by 2.2% in 2030 nationally and 5.4% in 2040 relative to a counterfactual scenario without IRA incentives, which already indicates a trend of declining prices over time.[46] These changes are consistent with other studies of IRA (Roy, Burtraw and Rennert, 2022), which also depend critically on assumed fuel price trajectories. Beyond lowering household and firm electricity costs, an advantage of retail electricity price declines is that they can further encourage end-use electrification, which is a central decarbonization strategy in many studies (DeAngelo et al., 2022).

4.3 Distributional Implications

Households across the income distribution will experience different impacts from IRA. Lower-income households spend a slightly larger share of their income on electricity than higher income households (see Figure 12), so by reducing the costs of electricity, IRA will provide greater benefits for many

[45]Retail prices in US-REGEN are built up from modeled generation prices. These regional prices are calibrated to observed base year prices, including a mark-up to reflect sunk costs built into the rate base. Future retail mark-ups are scaled based on projected changes to transmission and distribution costs as function of the changing load and resource mix.

[46]Note that prices increase in 2025 under IRA due to the assumption in the reference case that solar and wind tax credits maintained their previous step-down schedule, which leads forward-looking firms to frontload investment in these resources to take advantage of expiring credits.

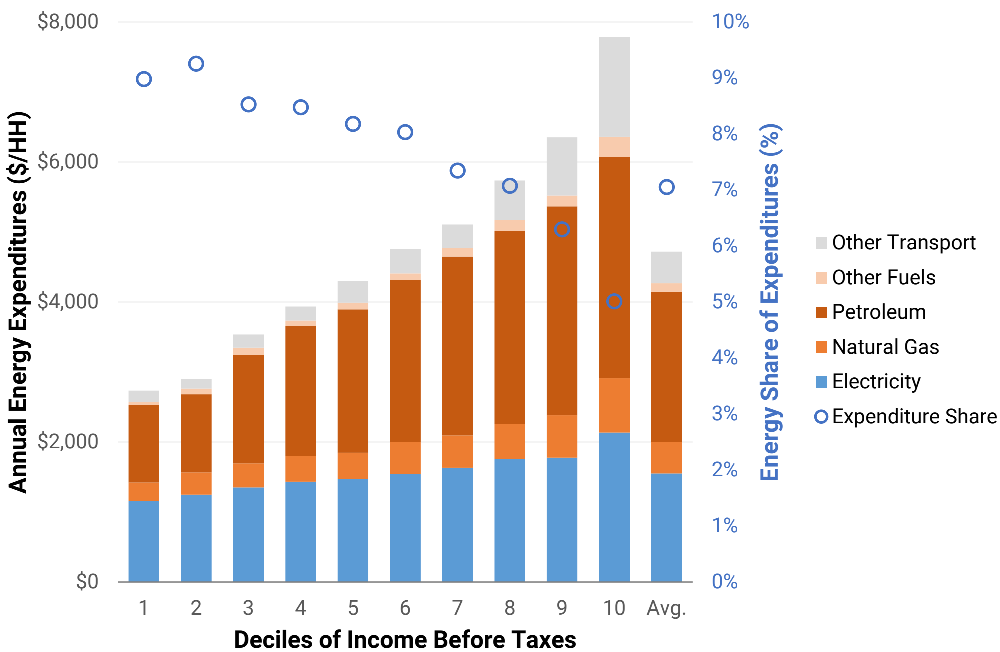


Figure 12: Annual household energy expenditures across income deciles. Data are from 2021 Consumer Expenditure Survey data (available here) for deciles of income before taxes. Energy shares of expenditures on the secondary axis are based on average annual expenditures for consumer units within the decile.

lower-income households. The relationship between income and consumption shares is stronger for petroleum (primarily gasoline for transport), so the means-tested tax credits for electric vehicles in IRA can help lower-income households that buy an electric vehicle reduce these expenditures. For example, Burnham et al. (2021) find that even at gasoline prices of less than $2.63 per gallon, fuel costs for electric vehicles are about half the fuel costs for a comparably sized vehicle with an internal combustion engine. Impacts over the next decade-plus will depend heavily on expected electricity and gasoline prices. Burnham et al. (2021) also suggest that maintenance costs are significantly lower for electric vehicles. Finally, Linn (2022) describes how electric vehicle subsidies may lead to lower prices for gas-powered vehicles by interacting with existing fuel economy standards and state-level zero-emission vehicle programs. Since low-income households are more likely to buy gas-powered vehicles, this effect is progressive.[47]

The economic incidence of the tax credits will also factor into the distributional outcomes. US-REGEN assumes perfectly competitive markets, meaning that the tax credits are passed through to consumers. In electricity markets, this assumption means that wholesale electricity buyers pass on the full benefits of the subsidies to end-use consumers. The second step involves assumptions about the political and regulatory processes that determine regional retail rates. Most other IRA

[47] US-REGEN captures many of these effects and in ongoing work, we quantify the expected impacts of IRA by region and income level.

analyses make the same assumption that the full values of the tax credits are passed through to consumers.[48] In reality, electric vehicle manufacturers, clean electricity producers, and other firms and their shareholders may capture some of the tax credits. As described in Appendix B, an index of clean energy stocks fell relative to the market on December 19, 2021 when Senator Manchin, the pivotal 50th Democratic vote, went on television to say he was done negotiating on the bill then known as Build Back Better, which contained many of the same climate provisions as IRA, and increased on July 27, 2023 when the Senate deal on IRA was announced. These movements suggest that producers could gain from the tax credits and that they will not be fully passed through to consumers. Particularly if the domestic content and labor provisions change behavior (i.e., are marginal), non-energy firms and their workers may also gain from the tax credits. In the case of electric vehicles, the incidence of the credits, and perhaps even the market structure for vehicle sales, will depend crucially on whether the Treasury guidance stands exempting leased vehicles from requirements on battery sourcing and eligibility caps. Sorting out the incidence of different IRA provisions and measuring it empirically will be useful tasks for future research.

4.4 Electrification Implications

IRA alters electricity demand through two channels—by directly subsidizing the adoption of electric end-use technologies (e.g., the electric vehicle and heat pump tax credits discussed in Section 2.1) and by lowering electricity prices (as discussed in the previous subsection). Technological change and consumer choice lead to transport, industrial, and buildings electrification and to a 12% increase in electricity demand by 2035 in the reference scenario without IRA (Figure 13). IRA incentives increase load growth by 4 percentage points to 16% from current levels by 2035.

To isolate the impact of lower prices on electricity demand, we include a scenario with only IRA's power sector tax credits, which reach similar prices as Figure 10. Demand for electricity increases in this scenario by 14% from current levels by 2035, which is midway between the reference without IRA (12%) and the IRA scenario (16%), as shown in Figure 13, with most of these increases relative to the reference coming from industry. Since there are more limited IRA tax credits that directly incentivize industrial electrification, electricity growth in industry under IRA is primarily attributed to lower electricity prices, which is reflected in high industrial electricity demand even with power sector IRA credits only in Figure 13 (96% of growth in industrial demand under IRA from the reference persists with only power sector credits). In contrast, incremental passenger vehicle electrification under IRA is largely from the clean vehicle credits, as less than 2% of growth in passenger vehicle electricity demand from the reference occurs with power sector provisions alone in Figure 13. There are several reasons for this muted demand elasticity, even with lower wholesale

[48] The Cole et al. (Forthcoming) analysis, which presents several scenarios that vary the share accruing to the consumer, is the lone exception of which we are aware.

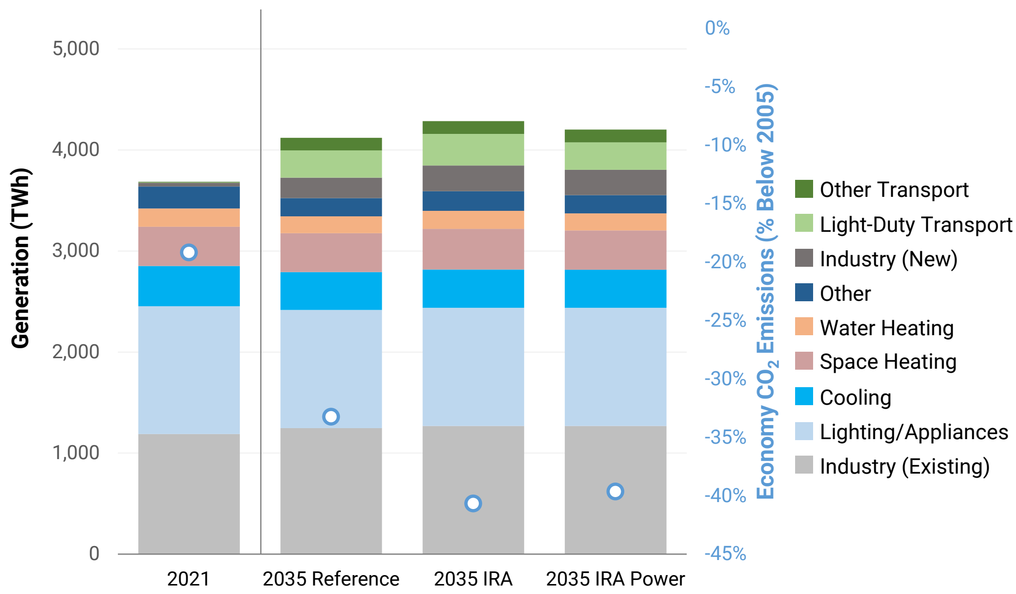


Figure 13: Electricity demand by end use. 2035 values are based on US-REGEN scenarios without IRA (Reference), one with all IRA incentives (IRA), and one with power sector IRA incentives only (IRA Power).

electricity prices (Figure 10), including stock turnover dynamics, limited effects of fuel costs in purchase decisions, and wholesale electricity prices only being one component of retail prices (i.e., unsubsidized transmission and distribution costs could comprise large shares of retail prices).

5 Macroeconomic Framework

In this section, we consider the macroeconomic impacts of the climate provisions of IRA. We present a conceptual framework for understanding the macroeconomic impacts of clean power tax credits. Using a neoclassical growth model with clean energy capital, we show both the long-run and short-run macroeconomic impacts of investment and production tax credits on macroeconomic variables: interest rates, wages, output, and consumption. We show how macroeconomic outcomes vary depending on labor market conditions, bottlenecks in clean energy investment, reductions in the price of capital due to learning-by-doing, and domestic sourcing requirements. The model details are presented in Appendix A.

5.1 Impact of Tax Credits

We start by characterizing how increases in clean energy tax credits impact macroeconomic aggregates. For simplicity, assume that household electricity demand is inelastic and fixed at $\bar{E}^h$. Then changes in power generation only impact electricity prices and demand via industrial demand.

Model equilibrium can be reduced to the following three equations:

$$p_t^c \left(1 - \tau_t^{inv}\right) u_c\left(C_t\right) = \beta u_c\left(C_{t+1}\right)\left[\left(F_e\left(E_{t+1}^f, \bar{N}\right) + \tau_{t+1}^p\right) G_c\left(K_{t+1}^c\right) + p_{t+1}^c\left(1 - \tau_{t+1}^{inv}\right)\left(1 - \delta_c\right)\right] \tag{2}$$

$$C_t = F\left(E_{t+1}^f, \bar{N}\right) - p_t^c\left(K_{t+1}^c - \left(1 - \delta_c\right) K_t^c\right) \tag{3}$$

$$G\left(K_t^c\right) = E_t^f + \bar{E}^h \tag{4}$$

which jointly determine the equilibrium path of electricity supplied to industry E_t^f, household consumption C_t, and clean energy power generation K_{t+1}^c as a function of underlying parameters and the exogenous path of capital prices p_t^c and fiscal policy.

In steady state, the level of clean energy capital is defined implicitly by following condition:

$$p_c\left(\frac{1}{\beta} - 1 + \delta_c\right)\left(1 - \tau_{inv}\right) = \left(F_e\left(G\left(K_{ss}^c\right), \bar{N}\right) + \tau_p\right) G_c\left(K_{ss}^c\right) \tag{5}$$

The left-hand side of this equation is just the steady state user cost of capital while the right hand side is the marginal product of capital taking into account both the effect of power generation capital on electricity production and electricity production on overall output. Under mild conditions for the production function F and the power generation function G (see Appendix A), the steady state level of capital K_{ss}^c is increasing in both the investment tax credit and the production tax credit. Figure 14 shows the user cost of capital (LHS of steady state condition, in blue) and the marginal product of capital (RHS of steady state condition, in orange) which pin down the steady state level of clean energy capital. The shift in user cost and marginal product under an investment and production tax credit are shown.

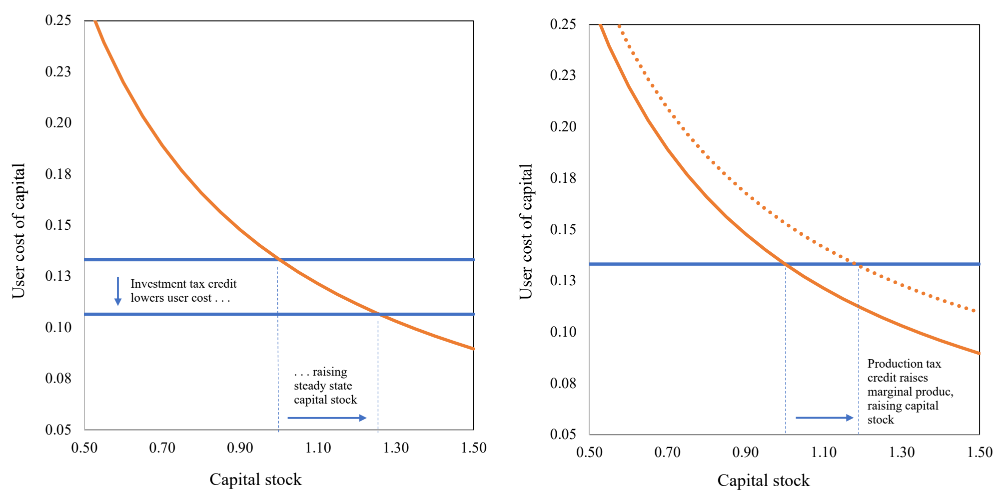


Figure 14: Steady state capital after an increase in investment tax credit (LHS) and increase in production tax credit.

An increase in the clean energy capital stock increases other macroeconomic quantities in steady state; the increase in electricity supplied to industry raises output and investment. Labor productivity and wages also rise due to increase in industrial electricity supply. Assuming that the subsidies are not too large, consumption also increases in steady state. On the price side, the price of electricity falls while the real interest rate is unchanged ($r = \frac{1}{\beta} - 1$), which is unaffected by fiscal policy.

Effectively, production and investment subsidies are a negative capital tax, raising the capital stock and productivity. To the extent that the weight of energy in the aggregate production function is low or the marginal product falls sharply with higher electricity supply, the tax credits have only marginal benefits in terms of productivity, output, wages, and consumption. However, the price of electricity would fall more sharply in this case. Like other supply-side tax policies with dynamic effects, the fiscal burden would be tempered somewhat by higher output (relative to a static analysis).

The transition path to this new steady state can also be characterized. An increase in the investment or production tax credit lowers consumption on impact while raising investment. The real interest rate rises initially before gradually falling back to its long-run level. Labor productivity, wages, and electricity prices inherit the dynamics of the capital stock, with wages and productivity rising gradually along the transition path to their higher steady state level. On the fiscal side, the increase in interest rates would raise debt-servicing costs on impact, with higher output mitigating the impact on the debt-to-GDP ratio over time.

Given that output, consumption, investment, wages and productivity ultimately rise over the long-run (along with a fall in the price of electricity), a natural question to ask is if a strictly positive subsidy is welfare-improving. So far, we have not considered the impact of the policy on emissions or in mitigating damages from climate change, so the question is solely about whether the macroeconomic benefits are welfare-improving. The answer is no. For the planner, the aggregate resource constraint binds and the optimal allocation for clean energy capital would be implemented only if both the ITC and PTC are set to zero.

5.2 Alternative Macroeconomic Conditions

In the baseline model, we assumed a fixed, inelastic supply of labor. Supporters of the Inflation Reduction Act have argued that, by subsidizing construction and manufacturing, the legislation may help create jobs by increasing the labor force and by creating jobs in communities/regions that have seen structurally weaker labor markets. Power generation would likely stimulate labor demand in less urbanized regions and upstream labor demand for raw materials and equipment are also likely to be in regions that have seen less robust labor markets.

One way to incorporate this channel is to assume that there exists a pool of labor that is currently outside the labor force but has a relatively low reservation wage. If aggregate labor supply is given by an upward sloping labor supply curve (i.e., $w_t = N_t^{\phi}$), then the investment or production tax credit increases employment as a higher capital stock boost the marginal product of labor and labor supply adjusts to meet higher labor demand. In steady state, the increase in the clean energy capital stock is larger than in the case of an inelastic labor supply. Steady state consumption, output and labor productivity all increase by more than in the baseline case. This case also sees a larger level of subsidies, but a sharper decline in the price of electricity and possibly a decline in subsidy cost as a share of GDP.

However, a more elastic labor supply results in a *larger* increase in interest rates and decline in consumption (relative to the baseline case) as the initial demand impact dominates; an elastic labor supply implies a larger increase in investment given a larger increase in the desired capital stock. Along the transition path, as the capital stock rises, employment rises to keep the marginal product of labor constant at $\bar{w}$ and the real interest rate gradually converges back to its long-run value $1/\beta - 1$.

Given supply chain disruptions and dislocations during the pandemic, another relevant departure to consider is presence of bottlenecks that constrain the ability to ramp up construction of clean energy facilities or the manufacturing of equipment for those facilities. Domestic content requirements or delays in siting or transmission access could function to either raise the cost or outright prevent investment in new clean power generation despite the financial incentives provided in IRA. Bottlenecks are classified as either a "market" or "non-market" bottleneck; the former shows up as an increase in the relative price of capital p_t^c when a (possibly time-varying) investment constraint is reached, while the latter is simply a constraint on investment that does not impact price. "Market" bottlenecks could be thought of as inelastic supply of a key material (like lithium or copper) while "non-market" bottlenecks could be thought of as prohibitions on the siting of new solar or wind projects.

Our model can be generalized to account for "non-market" bottlenecks by simply introducing a constraint on investment: $I_t^c \leq \bar{I}$. The intertemporal optimality condition for investment is now:

$$\begin{aligned} p_t^c \left(1 - \tau_t^{inv}\right) \lambda_t + \mu_t = \beta \lambda_{t+1} \left[\left(F_e \left(E_{t+1}^f, \bar{N} \right) + \tau_{t+1}^p \right) G_c \left(K_{t+1}^c \right) + p_{t+1}^c \left(1 - \tau_{t+1}^{inv}\right) (1 - \delta_c) \right] \\ + \beta \mu_{t+1} (1 - \delta_c) \end{aligned} \tag{6}$$

where μ_t is the Lagrange multiplier on the investment constraint in period t.

If the constraint is binding in steady state, then investment is constrained at its upper bound $\bar{I}$, and the user cost of capital is above the level that would obtain absent any bottlenecks. Relative to the baseline case, the capital stock is lower, as is output. The price of electricity is higher and subsidies paid are lower. Even when the constraint does not bind in steady state, bottlenecks may constrain investment along the transition path. In this case, the path of investment is below the baseline case until the desired investment rate falls below the constraint. Since investment is lower initially, the rise in the interest rate and decline in consumption are muted in the case where bottlenecks initially bind. Bottlenecks *mitigate* the macroeconomic impact since the rise in investment is attenuated and the required decline in consumption to meet desired investment is lessened.

Market bottlenecks that manifest as a higher price of investment carry the same implications for the steady state capital stock and transition dynamics. Indeed, the Lagrange multiplier in the "non-market" bottlenecks case is effectively a shadow price. For concreteness, assume that the $p_t^c = p_c$ if $I_t^c < \bar{I}$ - that is, the price of investment is constant at its steady state value p_c so long as the investment constraint is slack. Then, we can define a market price p_t^c when $I_t^c = \bar{I}$ that satisfies the investment Euler equation above:

$$p_t^c = p_c + \frac{\mu_t}{\lambda_t \left(1 - \tau_t^{inv}\right)} \tag{7}$$

Substituting for μ_t into the Euler equation above returns the same Euler equation that delivers the same equilibrium path of consumption and investment as the "non-market" bottlenecks case. Likewise, the steady state level of the capital stock would also be depressed (relative to baseline) because the ITC/PTC are offset by a rise in the user cost of capital.

The distinction between "market" and "non-market" bottlenecks is not relevant for investment, but it does carry implications for the fiscal cost. With both types of bottlenecks, less clean energy investment is deployed, lowering fiscal cost. But"market" bottlenecks carry a counteracting effect on prices. Despite lower real investment, a higher price of investment may be sufficient to raise the fiscal cost of an investment tax credit. This issue is unique to the ITC since the PTC is tied to quantity of clean energy produced. In the extreme case that investment is already against its constraint, the tax credit is fully offset by a rise in the price p_t^c and the government subsidy generates no new investment. Indeed, there may a Laffer curve for ITC fiscal cost where fiscal cost is non-monotonic in the level of investment; with extreme bottlenecks no investment occurs so fiscal expenditure is zero, but very high prices due to bottlenecks keep fiscal expenditure high even for low levels of real investment.

5.3 Learning by Doing

Proponents of the subsidies approach to clean energy transition have emphasized the dramatic decline in solar and wind production costs over the last decade and the potential for further declines in clean energy production costs. The Inflation Reduction Act includes a host of incentives to support the supply chain for clean energy and generous incentives for technologies that are not yet cost competitive like carbon capture and clean fuels. To the extent that higher production spurs learning by doing and cost reductions, how might that impact the clean energy transition?

A classic formulation of learning-by-doing is Wright's law, which expresses marginal cost as a function of cumulative production (see Wright (1936) and Way et al. (2022)).[49] Accordingly, we

[49]The presence of credit constraints or locally increasing returns to scale would generate similar results.

model learning by doing by making the price of capital a decreasing function of the current stock of clean energy capital: $p_t^c = p_c(K_t^c)$.[50] For modest levels of learning by doing, the user cost of capital falls as more clean energy capital is produced. Relative to the baseline model, this implies a larger increase in the clean energy capital stock in steady state for a given subsidy policy. Clean energy subsidies now lead to a larger increase in output, labor productivity and wages and a larger decline in the price of electricity.[51] Figure 15 shows how the user cost becomes downward sloping with learning-by-doing, magnifying the impact of either the ITC or PTC.

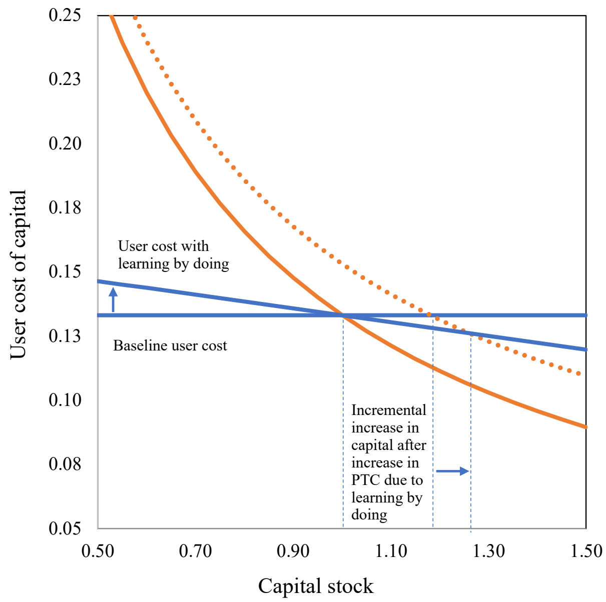


Figure 15: Learning-by-doing results in larger increases in steady state capital after an increase in PTC.

5.4 Domestic Sourcing

As noted earlier, IRA's investment tax credit is eligible for bonuses based on whether labor standards and domestic sourcing requirements are satisfied. The labor and domestic sourcing requirements have two distinct impacts on the equilibrium level of investment that is eventually realized. One way to model domestic sourcing is to assume two distinct prices for investment: $p_t^{c,low}$ and $p_t^{c,high}$ with associated investment tax credits of $\tau_t^{c,low}$ and $\tau_t^{c,high}$. The households' budget constraint becomes:

$$C_t + p_t^{c,low}\left(1 - \tau_t^{c,low}\right) I_t^{c,low} + p_t^{c,high}\left(1 - \tau_t^{c,high}\right) I_t^{c,high} = F\left(E_t, \bar{N}\right) \tag{8}$$

[50]Modulo of depreciation, which is low for power structures, the current capital stock is equal to cumulative production.

[51]If the price of capital is sufficiently sensitive to production, multiple steady states are possible. In particular, if over some region, the price of capital drops faster than the marginal product of electricity, multiple steady states will obtain.

In steady state, the household chooses whichever option delivers the lowest user cost of capital. Importantly, the higher relative cost of investment may be chosen if the labor/domestic sourcing bonus is sufficiently generous. In this sense, the labor and domestic sourcing bonuses *raises* the clean energy capital stock, since the lowest user cost option (inclusive of the tax credit) is chosen in equilibrium. That the domestic bonus may lead to higher clean energy capital is a function of the tax credit and does not mean it is optimal. Absent some other benefit or externality, the planner would always choose the lower cost investment $p_t^{c,low}$ to minimize the cost of achieving some given level of emissions.

Domestic sourcing has another distinct element - the use of imports to meet increased clean energy investment demand. Suppose that domestic and foreign producers both sell at a relative (domestic) price of p_t^c and are eligible for the same ITC. Then, the absence of domestic sourcing would allow for a faster increase in investment with less crowding-out of domestic consumption. The steady state level of clean energy capital would be unchanged (relative to baseline), but the real interest rate would rise by less and decarbonization of electricity production would be faster. From an emissions perspective and given conditions of full employment, the inability to import and slowdown in investment is likely to be the most important impact of domestic sourcing requirements.

5.5 Crowding Out and Capital Taxation

Our model so far has abstracted away from the funding mechanisms of IRA and possible impacts on the non-energy capital stock. It is straightforward to add non-energy capital to the production function and characterize the effect of the clean energy subsidies on non-energy capital. As before, the subsidies increase the steady-state clean energy capital stock but also increase the non-energy capital stock. A lower price of electricity increases the rate of return and demand for non-energy capital in the same way as it increases labor demand. There is no long-run crowding out; private non-energy capital is *crowded in*. Output, consumption, wages and labor productivity all rise in the long-run by more than in the baseline model.

However, in the short-run, investment in clean energy capital competes with non-energy capital and consumption. Depending on the elasticity of intertemporal substitution, non-energy investment and consumption may fall while clean energy investment crowds out these other uses. For sufficiently large crowding out of non-energy capital investment, it is possible, in the short run, that output, wages and labor productivity initially decline before rising to their higher steady state values.

The IRA is estimated to reduce deficits through a combination of reductions in prescription drug spending in Medicare and increased revenue from tax enforcement and increase in corporate taxation. So far, we assume that the tax credits in the IRA are funded via a lump sum tax levied on the representative household that does not distort behavior.[52] However, the corporate tax and

[52] The macroeconomic impact would be identical if, instead, the policy were fully deficit financed (assuming that

tax enforcement provisions in IRA may have impact closer to a rise in the marginal tax rate on capital. In standard macroeconomic models, corporate tax increases can have substantial effects on investment and the capital stock.

Depending on the magnitude of the capital tax, the steady state increases in output, wages, and labor productivity may be reversed if the long-run crowding out for non-energy capital is large enough. However, in the short-run, the rise in capital taxation would mitigate the crowding out and interest rate effects of the clean energy subsidies. A higher capital tax, by lowering non-energy investment demand, would free output for consumption or clean energy investment, mitigating or reversing the increase in real interest rates. To the extent that the capital taxation effects dominate, output, consumption and non-energy investment would gradually fall along the transition path to their lower steady state values.

6 Clean Energy Subsidies versus Carbon Pricing

Subsidy-based approaches and emissions pricing are two widespread policy instruments to reduce emissions, each with tradeoffs across economic, environmental, and political dimensions. While the U.S. does not have a federal price on carbon emissions, 55% of the greenhouse gas emissions in the rest of the OECD are subject to an explicit Pigouvian carbon price, either in the form of a carbon tax or cap-and-trade system (OECD, 2022; Timilsina, 2022). Several U.S. states have carbon pricing covering varying shares of their carbon emissions, ranging from under 20% in Massachusetts to almost 75% in California. In total, explicit carbon pricing covers 6% of U.S. GHG emissions.

It is instructive to compare the subsidy-based approach to carbon pricing.[53] At a high level, both subsidies and carbon pricing change the relative prices of non-emitting and emitting fuels. Some of the provisions of IRA are output-based credits, which directly subsidize production of zero-carbon energy. If every unit of subsidized production offset the same amount of carbon emissions (for example, if all non-subsidized energy was generated by the same fossil-fired technology with the same emissions per unit of energy), then the production tax credits would be identical to a carbon price. In other words, subsidizing a clean MWh of electricity at $10 per MWh would displace as much carbon from the electricity sector as taxing an emitting MWh of electricity at $10 per MWh, assuming inelastic demand.

taxes eventually rise to stabilize the debt-to-GDP ratio).

[53]Most sources describe policies as carbon pricing, although many of the policies cover GHG emissions in addition to CO_2. As noted above, IRA introduces a price on methane emissions from specified entities in the oil and gas sector. These GHG emissions are not included in the 6% figure, which was based on programs through April 2022.

6.1 Comparison to a Carbon Tax

To place more structure on the question of subsidies versus carbon pricing, we extend our macroeconomic framework from the previous section to allow for fossil fuel power generation. We now allow for both fossil fuel and clean energy capital, with relative price of investment p_t^f and p_t^c. Electricity generated from fossil fuel capital is given by the generation function $G^f(\cdot)$ with capital as the only factor of production; electricity generated from clean energy capital is given by the generation function $G^c(\cdot)$. Total electricity production is simply the sum of electricity generated from fossil fuel and clean energy capital (i.e., perfect substitutes). The details of the model extension are shown in Appendix A.

Relative to the baseline model, households now may invest in both clean energy and fossil fuel capital. Clean energy is eligible for both an investment tax credit and production tax credit. Fossil fuel energy instead faces a carbon tax where τ_t^f is a carbon tax and κ is a technological constant relating electricity generated from fossil fuels to carbon emitted. It's worth noting that a carbon tax is identical to an appropriately scaled negative production tax credit. Revenues raised from a carbon tax are rebated lump sum.

The households' choice for clean energy and fossil fuel investment are now given by two Euler equations:

$$p_t^c\left(1-\tau_t^{inv}\right)\lambda_t = \beta\lambda_{t+1}\left[G_1^c\left(K_{t+1}^c\right)\left(p_{t+1}^e+\tau_{t+1}^p\right)+p_{t+1}^c\left(1-\tau_{t+1}^{inv}\right)\left(1-\delta_c\right)\right] \tag{9}$$

$$p_t^f\lambda_t = \beta\lambda_{t+1}\left[G_1^f\left(K_{t+1}^f\right)\left(p_{t+1}^e-\tau_{t+1}^f\kappa\right)+p_{t+1}^f\left(1-\delta_f\right)\right] \tag{10}$$

where λ_t is the household's marginal utility of consumption. In steady state, the fossil fuel and clean energy capital stocks are jointly determined by conditions equating the user cost of capital to its marginal product, analogous to the case with just clean energy capital:

$$p_c\left(1-\tau_{inv}\right)\left(r+\delta_c\right) = G_1^c\left(K_c\right)\left(p_e+\tau_p\right) \tag{11}$$

$$p_f\left(r+\delta_f\right) = G_1^f\left(K_f\right)\left(p_e-\tau_f\kappa\right) \tag{12}$$

If both generation functions G^f and G^c are constant return to scale, then the marginal increase in electricity production is constant for each unit of labor. In that case, only one of the steady state conditions can hold in equilibrium (we are implicitly assuming that K_c and K_f are positive in steady state). In effect, a corner solution obtains in the long-run and only clean or fossil fuel technology is utilized. Increases in carbon tax and ITC/PTC would only impact this choice if the unsubsidized (utilization-adjusted) user cost for fossil fuel generation was lower than the user cost and the carbon tax and/or ITC/PTC are large enough to make the relative utilization adjusted user cost for clean energy lower. However, to the extent that clean energy has a lower user cost, further increases in the carbon tax or ITC/PTC do not impact the steady state level of capital stock. The level of capital stock is pinned down by the price of electricity p_e which falls as the power generation capital stock rises.

If the generation functions G^f and G^c exhibit decreasing returns to scale, then both technologies can be utilized in steady state. In this case, incremental increases in either the carbon tax and the ITC/PTC will shift the energy mix toward clean energy. Nevertheless, the policies are not fully interchangeable so long as we rule out negative carbon taxes or negative subsidies. While either policy could achieve a given target for the mix of clean and fossil fuel generation, the overall level of electricity production rises under an ITC/PTC policy and falls under a carbon tax policy. The emissions reduction is, hence, greater under a carbon tax, but output, consumption, productivity and wages all fall relative to the ITC/PTC policy.

The emissions difference between a clean energy subsidy policy and a carbon tax depends on the price elasticity of electricity demand. Relative to a carbon tax, subsidies encourage electricity consumption and discourage conservation. If household and industrial demand for electricity is sensitive to price, a carbon tax would have a relatively large effect on electricity consumed and hence emissions. By contrast, a subsidy policy – by encouraging electricity consumption – would partially undo the switch from fossil to clean energy by raising overall electricity consumption (see (Holland, Hughes and Knittel, 2009)).

One argument against carbon taxes is that these taxes adversely impact poor households with inelastic energy consumption and whose energy consumption is a larger share of household expenditure. So long as *absolute* energy consumption is increasing in household income (see Figure 12), a carbon tax distributed as lump sum dividend provides poor households sufficient resources to both maintain their pre-tax energy consumption *and* increase non-energy consumption.

6.2 Optimal Policy

The difference in subsidy versus carbon tax policy in terms of electricity prices and electricity consumption begs the question of whether a subsidy policy is economically preferable to a carbon tax. Is there a case for a clean energy subsidy in lieu of a carbon tax? To address this question, we modify our baseline model to include damages from emissions and consider the planner's problem. As before, we assume only emissions from electricity production, ignoring transportation or land use. The details of the planner's problem are available in Appendix A.

The planner's choice from clean energy and fossil fuel capital are given by:

$$\begin{aligned} p_t^c &= \frac{1}{1+r_t}\left[p_{t+1}^e G_c'\left(K_{t+1}^c\right) + p_{t+1}^c\left(1-\delta_c\right)\right] \\ p_t^f &= \frac{1}{1+r_t}\left[p_{t+1}^e G_f'\left(K_{t+1}^f\right) + p_{t+1}^f\left(1-\delta_f\right)\right] - \underbrace{\mu_{t+1}\kappa G_f'\left(K_{t+1}^f\right)}_{\text{time-varying carbon tax}} \end{aligned}$$

where μ_{t+1} is the multiplier that implicitly prices the damages from cumulative carbon emissions.

It is clear that the optimality condition for clean energy capital is the same as what would obtain with zero subsidies; that is, even in the presence of fossil fuel damages, the planner's allocation for clean energy capital is unchanged relative to the household. The condition that is distorted is the choice of fossil fuel capital, with the planner taking into account that additional fossil fuel capital increases damages from emissions. To implement the planner's allocation, the fiscal authority would need to levy a carbon tax that enters into the Euler equation for fossil fuel capital (shown in red). Note that we have made no assumptions on the elasticity of electricity demand or the relative price of clean v. fossil fuel capital.

Since emissions are cumulative and production exhibits diminishing returns in electricity, the (asymptotic) steady state features zero fossil fuel capital and a carbon tax high enough to ensure that only clean energy capital is utilized. The price of electricity will rise to incentivize increases in clean energy capital investment along with reductions in electricity demand.

Why does the planner rely exclusively on the price of electricity to incentivize a switch to clean energy power generation? The intuition is that subsidies do not change the underlying resource cost of clean energy capital. The incentive to choose power generation via clean v. fossil fuel capital depends only the relative technological cost (i.e. p_t^c v. p_t^f). The only externality comes from damages generated by reliance on fossil fuel power generation. The main benefit is fossil fuels is power generation and this benefit must be weighed against damages from emissions; a single instrument is sufficient for correcting that externality.

6.3 Learning by Doing Externality

In the context of our model, introducing a learning-by-doing externality can restore scope for a clean energy subsidy (in addition to a carbon tax). Now, households do not internalize the impact of their investment on the price of capital and, therefore, underinvest relative to a social planner. This can be seen by comparing the household's Euler equation for clean energy investment (in the baseline case where the price of capital is exogenous) in comparison to the planner who internalizes that faster investment results in faster decline in price of capital. Indeed, a subsidy could be warranted even if the unsubsidized price is low enough today or expected to be low enough in the future such that clean energy capital is the only power generation source in the long-run.

The Euler equation for investment from the planner now differs from the private optimality condition that does not take account of the learning-by-doing externality:

$$p\left(K_t^c\right)u_c\left(C_t\right) = \beta u_c\left(C_{t+1}\right)\left[p_{t+1}^e G_c\left(K_{t+1}^c\right) + p\left(K_{t+1}^c\right)\left(1-\delta_c\right) - p_c\left(K_{t+1}\right)I_{t+1}^c\right] \tag{13}$$

Under learning by doing, there is an additional marginal benefit to an added unit of clean-energy capital - a lower price of future investment (shown in red). The marginal benefits from increasing capital are the discounted sum of the added electricity generated, the market value of the undepreciated capital stock, and the decrease in the cost of new investment. This last term is given by the change in the price of the capital stock multiplied by next period expected investment. This last term does not appear in the household's private Euler equation and justifies a time-varying investment credit to internalize the learning-by-doing externality.[54]

6.4 Efficiency Impacts of Tax Credits versus Carbon Pricing

Our model abstracts from many dimensions of difference between subsidies and carbon pricing. One important difference is that pricing carbon, depending on how it is implemented, could generate revenue for the government. These revenues could be used to offset other distortionary taxes (Barron et al., 2018; Goulder, 1995), address equity concerns (Goulder et al., 2019), or be directed toward other policy objectives. A subsidy-based approach costs the government the subsidy amounts and imposes the marginal cost of raising government funds on the economy.

Our model also abstracts from differences in carbon emissions between unsubsidized energy resources. In practice, these can vary considerably, meaning a single clean energy subsidy does not reflect the fact that the benefits of zero carbon power sources will vary depending on which unsubsudized energy resources they displace. For example, hydropower plants generate electricity without emitting CO_2, while coal plants emit over a ton of CO_2 per MWh, meaning that at a social cost of carbon of approximately \$200 per ton, carbon emissions raise the cost of coal-fired electricity by several multiples. Coal and natural gas generation have different emissions intensities, and even within a fuel type, there is considerable heterogeneity in emissions rates (Kotchen and Mansur, 2014). In the transportation sector, emissions are a function of vehicle fuel economy, which also varies considerably. Under IRA, clean energy that displaces zero-carbon energy such as hydropower is subsidized at the same rate as clean energy that displaces the dirtiest resources.

In principle, this issue could be addressed by adjusting production tax credits based on regional or temporal characteristics that are correlated with the emissions rates of the unsubsidized energy (Abrell, Rausch and Streitberger, 2019). For example, EIA shows that the electricity grid has about eight times higher emissions in Wyoming compared to Washington state, so the PTC could be increased for clean energy producers that locate near Wyoming and reduced in the Pacific Northwest. In practice, it may be difficult to legislate accurate adjustment factors given changing conditions on the electricity grid.[55] Further, it may be politically challenging to reward investments in some politicians' constituencies more than others.

Other provisions of IRA subsidize the energy-using or energy-producing asset, irrespective of how much it is operated. The investment tax credit for zero-carbon electricity subsidizes the construction of the facility rather than its operation. Relative to the PTC, the ITC provides a lower incentive to produce clean energy once the facility is constructed, and thus a lower incentive

[54] For a steady state to exist, it must be the case that $p_c(K) = 0$ for sufficiently large levels of capital (i.e. there must be some diminishing returns to learning).

[55] Note that efficiency gains from differentiated subsidies across technologies may be limited in practice (Abrell, Rausch and Streitberger, 2019).

to locate in areas with the highest production potential (Aldy, Gerarden and Sweeney, 2018). With lower capital costs for relatively mature technologies like wind and solar that are expected to deploy with IRA, many developers could opt for the production tax credit, which could minimize such distortions. Similarly, the electric vehicle tax credits subsidize vehicle purchases without regard to how much they are driven. Electric vehicles that are used as second cars and driven less will offset fewer emissions than vehicles that replace a household's only car.[56]

Overall, a shortcoming of fixed tax credit rates for supply- and demand-side resources is that they are relatively inflexible as technology and market conditions change (Peñasco, Anadón and Verdolini, 2021).[57] Carbon pricing enables households and businesses to select their preferred approaches to lower emissions, which can help to reduce costs and account for other welfare-relevant considerations that vary across individuals and firms. Carbon pricing also can enable coordination across sectors and geographies. When policy stringencies differ across sources and locations, emissions leakage can occur, though there are several policy options to mitigate leakage when policies are not harmonized (Böhringer et al., 2022).

Another potential rationale for policy instruments that lower electricity prices could be that retail prices exceed social marginal costs. Borenstein and Bushnell (2022) argue that residential electricity rates are higher than the full social marginal costs in many locations across the U.S., including the Southwest and Northeast. However, their estimates for external marginal costs are based on older values of the social cost of carbon and marginal damages of criteria pollutants, which are considerably lower than more recent estimates (Rennert et al., 2022; Shindell et al., 2021). In addition, federal tax credits are relatively blunt instruments to correct for retail pricing distortions that dominate only in a few regions, especially since tax credit uptake and retail rate impacts are not necessarily correlated with areas with retail price distortions. Also, the Borenstein and Bushnell (2022) analysis only looks at residential electricity rates, and marginal rates for other sectors are generally lower.

In addition to the negative externalities from emissions, climate change is also associated with positive innovation-related externalities, particularly since carbon emissions are unpriced in many parts of the world (van den Bergh and Savin, 2021; Gillingham and Stock, 2018; Acemoglu et al., 2012; Popp, Newell and Jaffe, 2010). Carbon pricing and subsidies are both aimed not only at addressing negative externalities from emissions but also positive innovation-related externalities. Induced innovation, economies of scale, network effects, and learning-by-doing effects can be altered by subsidies, carbon pricing policies, and other instruments, which can lower costs of low-emissions technologies and of energy services more broadly, though impacts depend on policy design. For

[56] Burlig et al. (2021) use EV charging data to show that vehicles in California through 2019 were driven substantially less than vehicles with internal combustion engines.

[57] On the other hand, features in IRA such as the qualifying emissions threshold for the power sector PTC and ITC illustrate how dynamic elements could be incorporated into subsidy design.

example, subsidies for nascent technologies, like electric vehicles, may push producers down a learning curve. Or, with more electric vehicles on the road, the economics of installing and operating charging stations improve and the number of mechanics with expertise working with electric vehicles will increase. Future research should elaborate on the advantages of subsidies versus carbon pricing for incentivizing innovation. It is plausible, for example, that subsidies involve less uncertainty for investors in clean technology and are therefore better at addressing liquidity constraints.

6.5 Estimates Comparing Tax Credits with Carbon Pricing

Several modelers have simulated the reductions achieved with a carbon price and compared them to tax credits. For example, Roy, Burtraw and Rennert (2021) find that even relatively modest carbon fees reduce emissions more than the types of tax credits that were included in IRA, and that the two policies together can achieve greater emissions reductions at a lower fiscal cost, while also insulating household from increased costs.

Here, we use the energy-economic model US-REGEN to investigate how electric sector outcomes vary between a scenario with IRA incentives and another that matches annual electricity CO_2 emissions without IRA (implicitly assuming a cap-and-trade policy approach). Table 3 compares electricity generation shares by technologies across these scenarios along with emissions, electricity prices, and abatement costs. This comparison illustrates how carbon pricing leads to lower coal generation relative to a subsidy-focused approach, since the latter does not distinguish between the carbon intensity of unsubsidized generation, which has implications for associated air quality co-benefits. These lead to 68% reductions in power sector CO_2 emissions from 2005 levels by 2035. Average abatement costs in the CO_2-equivalent policy are relatively low (\$10/t-CO_2[58]), given the low incremental costs of coal-to-gas switching and renewables deployment at these levels. Table 3 also confirms that tax credits lead to lower electricity prices relative to carbon pricing with equivalent CO_2 emissions. These lower prices are due to the prevalence of subsidized resources that put downward pressure on electricity prices and shift costs from ratepayers to the federal government (i.e., taxpayers).

While these estimates pit the subsidies against an idealized alternative policy, another useful comparison is between the IRA subsidies and the social cost of carbon, which essentially measures whether the subsidies pass a cost-benefit test. Several analyses estimate the cost-effectiveness of components of IRA, permitting this comparison. Analyzing a suite of tax credits for the power sector like the ones include in IRA (the credits were included in the Build Back Better Act passed by the House in Fall 2021), Greenstone et al. (2022) estimate that the credits would reduce emissions at a cost of \$33-50/ton of CO_2, substantially below the most recent estimates of the social cost

[58] Average abatement costs are presented for comparability between the IRA and carbon pricing scenarios. Marginal abatement costs under the carbon pricing scenario are \$12-15/t-CO_2 between 2030 and 2035, which are the shadow prices on the emissions cap constraint.

Table 3: Comparison of electric sector metrics in IRA scenario and carbon tax scenario that matches the IRA CO_2 emissions time path. Historical electricity generation shares come from the U.S. Energy Information Administration's "Electric Power Monthly" (available here). Historical emissions come from U.S. Environmental Protection Agency's "Inventory of U.S. Greenhouse Gas Emissions and Sinks" (available here).

		IRA Scenario		**Carbon Tax**		**Difference (p.p.)**	
Metric (units)	2021	2030	2035	2030	2035	2030	2035
Generation Share (%)							
Coal	22%	11%	8%	7%	4%	-4%	-5%
Coal CCS	0%	3%	3%	0%	0%	-3%	-3%
Gas	39%	20%	18%	35%	34%	15%	17%
Gas CCS	0%	0%	0%	0%	0%	0%	0%
Other	2%	9%	11%	7%	8%	-2%	-3%
Nuclear	19%	17%	14%	17%	16%	0%	2%
Hydro	6%	6%	6%	6%	6%	0%	0%
Wind and Solar	13%	33%	41%	28%	32%	-6%	-9%
CO_2 (% Drop from 2005)	35%	64%	68%	64%	68%	0%	0%
Generation Price ($/MWh)	$64	$56	$52	$65	$62	16%	20%
Abatement Cost ($/t-$CO_2$)	N/A	$45-61	$45-61	$10	$10	-85%	-82%

of carbon of approximately \$200/ton (EPA, 2022). Similarly, Stock and Stuart (2021) compare a suite of electric sector policies to the social cost of carbon and find that extensions of the PTC, ITC and subsidies for CCS (but not all of the credits eventually included in IRA) have an average abatement cost of about \$35/ton, well below the social cost of carbon. Cole et al. (Forthcoming) estimate that the EV tax credits, combined with the subsidies for EV charging stations included in the Infrastructure Investment and Jobs Act, would reduce emissions at a cost of \$95/ton.

As shown in Table 3, our estimates in US-REGEN indicate that IRA tax credits reduce CO_2 emissions at an average abatement cost of \$45-61 per metric ton for the power sector (discussed in Section 3.4). There may be an efficiency gap between IRA incentives and carbon pricing with equivalent CO_2 (with average abatement costs of about \$10/t-CO_2), but these incentives nevertheless pass the benefit-cost test for most of the updated ranges for the social cost of CO_2 (Rennert et al., 2022), even before accounting for air pollution and other potential co-benefits.

6.6 Political Economy Considerations and Alternative Policy Instruments

The approach embodied in IRA is motivated in part by political economy constraints on feasible policy instruments in the 117th U.S. Congress, including legislative dynamics that led to climate policy via budget reconciliation, which is a procedure to pass budgetary legislation that can override filibuster rules in the Senate, and hence can pass by a simple majority rather than a 60-vote supermajority.

Although carbon pricing approaches can be efficient, effective, and equitable, their strengths can create political liabilities by raising costs of energy. Many Americans support government action to address climate change, but willingness-to-pay may be low (Jenkins, 2014).[59] In contrast, tax credits can lower energy prices and hide policy costs, which may be one reason why subsidies tend to poll better in the U.S. relative to carbon pricing (Krosnick and MacInnis, 2020; Bergquist, Mildenberger and Stokes, 2020).

In addition to tax credits and carbon pricing, there are several additional policy instruments that have been used and proposed to reduce emissions and encourage adoption of clean energy technologies, including rate-based performance standards (e.g., the Clean Power Plan proposed by the U.S. Environmental Protection Agency in June 2014), portfolio standards (e.g., for renewables or broader clean energy), mandates (e.g., for offshore wind and energy storage in various U.S. states), feed-in tariffs (e.g., for renewables in several European countries), and others. Each instrument has policy design elements such as their stringency, timing, trading provisions, and eligible technologies that affect economic and environmental outcomes and that emphasize different abatement margins. The literature suggests that the relative performance of tax credits versus other policy instruments

[59] For instance, a poll by the AP-NORC Center and EPIC in 2019 indicated that 43% of adults are unwilling to pay an additional \$1 on their monthly utility bill (available here).

depends on several factors about the setting, including the regional energy system, level of decarbonization, renewable resource quality, and demand effects (Borenstein and Kellogg, 2022; Abrell, Rausch and Streitberger, 2019; Young and Bistline, 2018; Paul, Palmer and Woerman, 2015; Fell and Linn, 2013).

6.7 Industrial Policy Components

As discussed in Section 2.2, some of the tax credits include bonuses for using domestic content or are only available for domestically produced goods with stringent sourcing requirements, as is the case for the electric vehicle credits for purchases (not leases). There are also significant bonuses for certain labor practices. While the political economy benefits of the bonuses are clear, the economic implications depend on underlying conditions. One central question is how much the bonuses will lead to adjustments. For example, if most electricity plant construction workers and operators already receive prevailing wages and use apprentices, the bonuses serve as a political statement but will not meaningfully change practices or the economic costs. If the bonuses lead to behavioral adjustments, they may be solving market failures. For example, the literature on industrial policy suggests governments can use temporary protection to help local industries achieve economies of scale (Juhasz, 2018). Also, supply chain vulnerabilities may create externalities if individual buyers do not fully account for the broader economic harm created by disruptions in foreign supply. In the absence of market failures, the bonuses could raise costs more than is socially beneficial, undermining the climate benefits of the tax credits. Future work quantifying these possible externalities will be valuable.

Domestic-content provisions also have implications for trade partners, as evidenced by the reaction to IRA from European leaders. Some of the United State's most important trade partners have sizable carbon prices (e.g., the EU and Canada), and those countries may feel pressure from industry to reduce those costs, lest they lose production to the U.S. Such a scenario would undermine the climate benefits of IRA.[60] Clausing and Wolfram (2023) discuss the possible dynamics when countries adopt asymmetric approaches to carbon mitigation.

7 Quantifying IRA's Macroeconomic Impacts

7.1 Recent Trends in Electric Power Investment

As shown in Section 3 (Figure 4), IRA has significant impacts on the level of investment in clean electricity generation, with 34-116 gigawatts of nameplate capacity added annually on average relative to 18 GW/yr on average in the previous decade and 36 GW/yr in 2021. Table 4 below

[60]If EU or other countries respond by introducing clean energy subsidies rather than reducing carbon taxes, global climate benefits could be strengthened.

	Nominal, 2018-2022 averages			Growth, annualized rate, 2012-2022		REGEN IRA impact, 10-year avg
	$ bn	% of BFI	% of GDP	Real output	Price level	$ bn (2022)
Gross domestic product	22350			2.2	2.5	
Nonresidential fixed investment	2974		13.3	3.3	1.5	
Structures	633	21.3	2.8	-0.8	4.2	
Electric power structures (BEA estimate)	79	2.7	0.4	-3.1	4.2	21
Equipment	1199	40.3	5.4	2.5	0.6	
Electrical transmission, distribution, and industrial apparatus	52	1.8	0.2	3.8	2.4	7
Electrical equipment, n.e.c	9	0.3	0.0	1.2	2.1	

Table 4: Investment in power generation structures and equipment

shows data from the Bureau of Economic Analysis for investment in power generation and electricity distribution. Over the last five years, nominal investment in electric power structures averaged $79 billion, and nominal investment in electrical transmission and distribution average $52 billion. Investment in electric power structures accounts for one-eighth of overall structures investment, but nonresidential structures investment is quite modest as a share of GDP. Likewise, electrical transmission and distribution accounts for just 4% of nonresidential investment in equipment. Total investment in electrical power generation, distribution, and transmission is 5% of nonresidential fixed investment and less than 1% of GDP.

The US-REGEN model sees a boost (relative to 2022 levels) of approximately $21 billion per year over 10 years in electric power generation and approximately $7 billion per year in transmission and distribution. These magnitudes are sizable relative to the current level of investment, but comparatively small as both a share of overall investment and overall economic activity. Even substantially larger increases in investment in power generation, transmission, and distribution (a doubling or more) would carry relatively modest macroeconomic impacts given the low share of power and electricity investment relative to overall investment. An apt comparison for the magnitude of the IRA impacts on electric power generation could be the shale revolution in the prior decade. Nominal investment in mining and wells rose from $98 billion between 2006-2010 to $152 billion between 2011-2015 – an increase of more than 50% in a short period of time. Investment in mining and oilfield machinery nearly doubled from $18 billion to $33 billion. The macroeconomic impacts from this investment boom appeared comparatively modest however, with relatively limited macroeconomic impacts from the sharp slowdown in shale investment after 2015.[61]

The BEA data also suggests relatively high price growth over the past decade for investment in electricity generation. As Table 4 shows, prices rose 4.2% (annualized rate) for investment in electric power generation structures, and real investment fell 3.1% (annualized) over the same period. Price increases were more in line with overall inflation for transmission and distribution, rising 2.5%

[61] US GDP growth did decelerate in 2015, and nonresidential structures investment turned sharply negative (falling nearly 10% year-over-year), but the unemployment rate continued to fall and core inflation appeared largely unchanged.

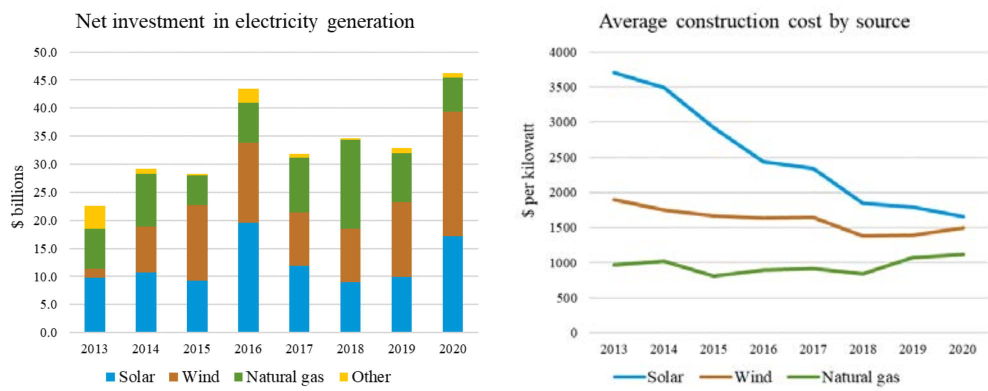


Figure 16: Net investment in electricity generation (left panel) and average construction costs (right panel) over time.

at an annualized rate. In contrast to electric power structures, real investment in transmission and distribution rose over the past decade. Price increases for investment in structures has been particularly sharp over the last two years; the price index for electric power structures rose 12.3% year-over-year as of 2022Q4. Negative real investment in electric power generation over this period is largely a function of flat nominal investment and surging price indices. Real investment in power structures grew at 2.0% annualized rate between 2012-2022.

The BEA investment data is mirrored by data collected by the U.S. Energy Information Administration (EIA) on net additions to electricity generation and data on construction cost of new electric generation facilities. Figure 16 shows total construction expenditures for solar, wind, and natural gas electricity generation from 2013-2020. Total investment in power generation rose from $22 billion to $46 billion, with wind and solar rising from $10 billion and $2 billion to $17 billion and $22 billion, respectively, over this period. Nameplate capacity installed rose from 12 GW to 31 GW during this time – much faster than the level of real investment inferred from BEA data. Figure 16 also shows substantial drops in the average construction cost of solar power over this period along with substantial declines for wind generation. The construction cost for natural gas remained largely stable over this period.

How do we reconcile the BEA and EIA data? The BEA reports gross investment in structures and equipment. The BEA's annual data on net investment from its fixed asset tables is quite close to EIA's value for net investment in electricity power generation. In 2020, the BEA recorded gross investment of $83 billion in electric power structures and $41 billion in depreciation; EIA's value for net investment in 2020 was $46 billion. The EIA however does suggest materially different trends in both real investment and the price index for investment in electric power generation due to sharp fall in construction costs for utility scale solar and wind.[62]

[62] The difference in price trends in BEA and EIA data may reflect that the BEA price index is weighted on a capital stock basis (i.e. disproportionately weighted toward coal and gas). The BEA uses indices from Handy-Whitman and

The US-REGEN model shows substantial and growing impacts on electricity prices relative to the non-IRA scenario (Figure 11 in Section 4). To a first approximation, the inflation impact of declining retail electricity prices is simply its weight in household prices multiplier by the change in electricity prices (post IRA). The US-REGEN model finds that retail electricity prices are 1.2% higher in 2025 (relative to baseline) but fall 2.2% by 2030 and 12.8% by 2050. Electricity has a weight of 2.5% in the consumer price index and 1.3% in price index for personal consumption expenditures. Therefore, electricity prices would add 1.5-3 basis points to inflation in 2025, but subtract 3-6 basis points in 2030 and 15-30 basis points in 2050. Overall, these are small direct effects on inflation. For reference, the impacts on the price of electricity in 2025 and 2030 are an order of magnitude lower than the increase in retail electricity prices experienced over the pandemic.[63]

7.2 FRBUS Simulation

To quantify the macroeconomic impacts of the climate provisions of IRA, we rely primarily on the Federal Reserve's U.S. model (FRBUS). This general equilibrium model is regularly estimated and used by Federal Reserve staff in formulating forecasts and assessing the macroeconomic outlook. Ideally, one would be able to model economic and energy market impacts within a single general equilibrium model, where changes in subsidies or a carbon tax would jointly impact both industry equilibrium and incorporate feedbacks to the broader economy. The current FRBUS model has only limited modeling of energy market impact on the broader economy (primarily through the price of oil). To simulate the macroeconomic impact of IRA's climate provisions, we take the principal economic outputs of the US-REGEN model and incorporate those impacts into the current baseline FRBUS model.

Specifically, the tax credits received by households for electric vehicles and for residential improvements (heat pumps, etc.) are modeled as an increase in transfer income to households (akin to cash stimulus) and the increased investment in wind, solar, and other clean power generation is modeled as an increase in the growth rate of business fixed investment.[64] Additionally, we also include a shift in the consumer price index for energy to reflect the impact of lower retail electricity prices from increased electricity production. The outputs from the US-REGEN model are at five-year time steps, so we convert these values to quarterly shocks for the FRBUS model. The

the Bureau of Reclamation to construct their price index for electric power structures. It is not clear that those price indices have sufficient weight in solar and wind, which account for a sizable share of electric power investment in the recent data. EIA documents an average 3.1% increase in construction costs for natural gas powerplants, which is close to the 2.6% increase in the BEA's price index.

[63] From 2020-2022, the CPI price index for electricity services has risen 22.6%.

[64] To the extent that household rebates are captured by manufacturers through higher prices, the transfer raises corporate profits and equity valuations. The marginal propensity to consume out of the transfer would likely be lower.

impulse responses below show the relative impact of IRA on Fed funds rate, the unemployment rate, 10-year Treasury rates, and the inflation rate.

The FRBUS simulation largely confirms what might be expected given the small share of investment accounted for by power generation and the relatively modest size of the household transfers. As Figure 17 shows, the Fed funds rate rises initially due to stronger nonresidential investment and increased household consumption from clean vehicle and residential improvement tax credits. The Fed funds rate and 10-year Treasury rate peak by 2026 and then return back to their baseline levels. The funds rate falls slightly below baseline after 2030 as the fiscal impetus from increased nonresidential investment and increasing transfer turns to a drag after 2030. The unemployment rate initially falls before rising above baseline slightly after 2030. Quantitatively, all effects are small. At its peak, the Fed funds rate increases 6 basis points and the Treasury rate increases 2 basis points. The maximum fall in the unemployment rate is just 4 basis points. Impacts on core inflation are an order of magnitude smaller in the simulation and, with core inflation rising relative to baseline over the first decade before falling after 2030. However, headline inflation falls because of the direct effect of lower electricity prices on consumer prices, which the FRBUS model does not include. Including these direct effects on electricity, headline CPI inflation falls about 3-6 basis points by 2030 and up to 30 basis points by 2050.[65]

The FRBUS model may understate the impacts from higher nonresidential investment in power generation in two ways: 1) The model may not fully capture the upstream impacts on manufacturing and materials demand from an increased level of structures and equipment investment; 2) The model is unlikely to capture fluctuations in energy commodity prices (electricity, natural gas, crude oil, and gasoline) that will have material impacts on producer and consumer prices. Using data from BEA input-output tables, the upstream impacts of investment in power structures does not appear significantly larger than demand for any other commodity. The 2012 total requirements table shows that a $1 increase in final demand for investment in power structures implies a $1.64 increase in gross output across all commodities.[66] Upstream impacts for electrical transmission and distribution equipment are somewhat higher: $2.46 for each $1 increase in final demand. By comparison, the ratio of gross output to GDP is approximately 1.8.

As we noted earlier, the scale of the increase in fixed investment under IRA is comparable to the shale oil boom in the early 2010s. The direct contribution of shale oil investment in mining structures and equipment may not have been large (relative to aggregate investment or GDP), but clearly had significant effects on energy prices that kept overall inflation low and supported a

[65] Del Negro, di Giovanni and Dogra (2023) examine how differential price stickiness and subsidies approach may lead a green energy transition to be disinflationary.

[66] Business fixed investment in FRBUS is not modeled at the industry level, so upstream impacts to manufacturing are only captured indirectly through lagged terms and accelerator effects. Any impact of lower electricity prices on manufacturing is also not captured.

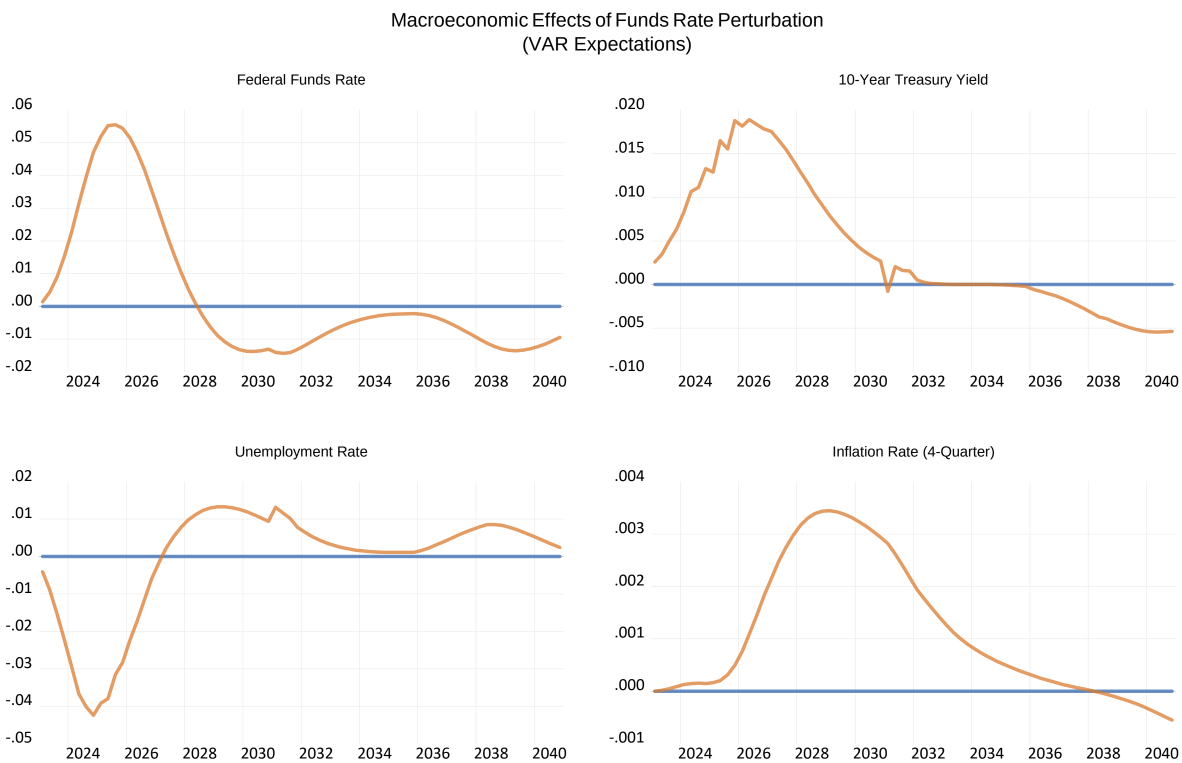


Figure 17: Interest rate, unemployment, and inflation rate response to IRA. Source: Authors' calculations using FRBUS.

recovery in manufacturing after the financial crisis. Moreover, the sharp drop in global oil prices and slowdown in shale investment after 2014 and resulting weakness in U.S. manufacturing stalled the exit from the zero lower bound until 2016.

The macroeconomic impact of the clean energy provisions of IRA should also be considered in concert with the other major recent legislation that increases demand in domestic manufacturing and construction. Both the Infrastructure Investment and Jobs Act and the CHIPS and Science Act have provisions that are intended to increase structures and equipment investment, with expenditures ramping up on a similar timeline to the clean energy investments due to IRA. The combined impact of this increased investment demand, along with upstream impacts on manufacturing, construction, and raw materials, may carry a more meaningful quantitative impact on the U.S. macroeconomic aggregates. One data point that points to a larger macroeconomic impact is announcements for battery manufacturing since the passage of IRA; a tabulation finds 29 companies announcing $46 billion in domestic battery manufacturing as of March 2023. These investments in battery production that may be eligible for IRA manufacturing tax credits have not been incorporated in our quantitative estimates.

It's important to note that any negative macroeconomic effects on fossil fuel extraction, refining, and utilities are not modeled here, along with any broader macroeconomic effects for the revenue components of IRA. Just as power investment in structures and equipment is small relative to overall economic activity, the same holds for fossil fuel extraction and refining. Moreover, oil and natural gas are partly global commodities whose outlook will be strongly influenced by global events (e.g., European demand for liquified natural gas), with demand for natural gas in the US likely to remain steady in any case. Employment in these industries is small and investment in fossil fuel power generation (particularly coal) was already waning well before IRA.

8 Impacts of the Macroeconomic Environment on IRA

To test the sensitivity of IRA impacts to the assumed macroeconomic environment, the US-REGEN electric sector outputs from earlier sections are compared to a scenario with higher supply-side costs and interest rates. In this illustrative scenario, the discount rate for power sector investments is increased from 7% in the reference run to 11% (Dunkle Werner and Jarvis, 2022; EPA, 2018). In addition, this higher cost scenario assumes that upward pressure on labor and materials costs lead to increases in the capital costs of generation and energy storage technologies. Elevated costs in 2022 are assumed to persist through 2030 instead of following the declining cost trajectories used in earlier sections (Figure 18), as discussed in Bistline et al. (2023).

This stylized scenario with a more pessimistic macroeconomic outlook and higher costs leads to higher emissions and lower clean electricity generation relative to the scenario with reference costs presented earlier (Figure 19). Higher interest rates increase the costs of new investments,

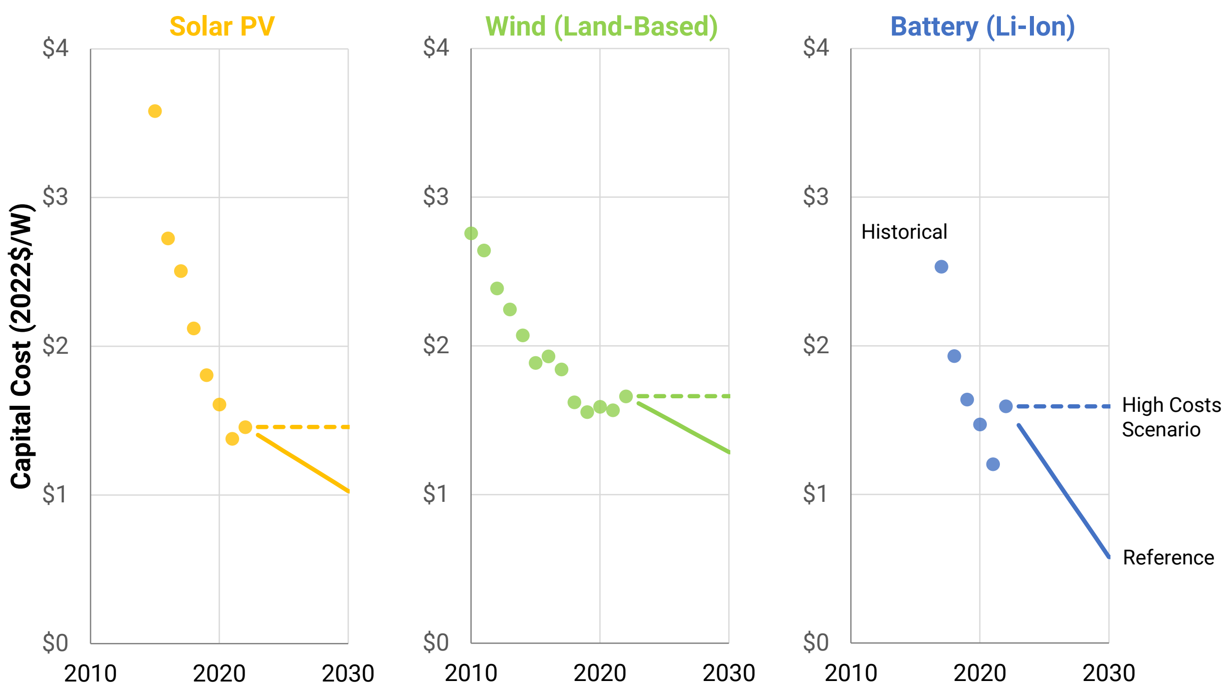


Figure 18: Capital cost assumptions for utility-scale solar PV, land-based wind, and lithium-ion battery storage with four-hour duration. Costs are expressed in 2022 dollar terms before accounting for IRA subsidies. Historical costs (dots) come from LBNL (wind and solar) and BloombergNEF (batteries). 2022 values are based on EPRI cost estimates (EPRI, 2022).

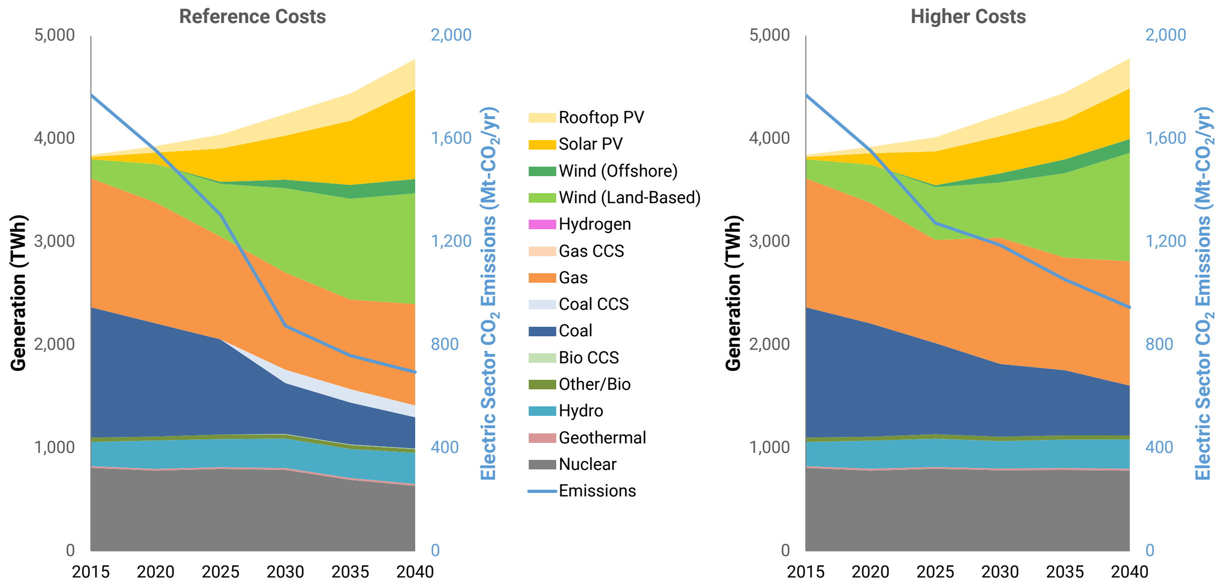


Figure 19: Generation by technology over time for a scenario with reference cost assumptions (left panel) and one with higher costs (right panel) from the US-REGEN model. Electric sector CO_2 emissions are shown in blue on the secondary axes.

especially for capital-intensive technologies such as many IRA-subsidized zero-emitting resources (as the LCOE examples in Section 4 illustrate). This dynamic lowers the deployment of wind, solar, and CCS-equipped capacity and increases generation from existing assets, especially coal- and gas-fired capacity.[67] These changes lead to increases in CO_2 emissions in the higher cost scenario, which are 1,190 Mt-CO_2/yr in 2030 (compared with 870 Mt-CO_2/yr with reference costs).

Table 2 in Section 3 compares emissions and fiscal costs associated with this scenario relative to the central IRA case. Economy-wide emissions reductions are similar to reference levels with higher costs, and cumulative tax credit expenditures through 2031 are $240B (i.e., similar to the CBO/JCT score) instead of $780B in the central case.

These comparisons illustrate how macroeconomic conditions may have larger impacts on IRA investments than IRA investments have on macroeconomic conditions, at least for the magnitudes investigated here. There is considerable uncertainty about the persistence of these shocks and their magnitudes, which depend not only on domestic conditions but also global factors. For instance, prices of materials – including specialty metals and bulk commodities – depend on global material production and demand, which are driven by the pace of decarbonization-related deployment and non-energy demand (International Energy Agency, 2023; Wang et al., 2023).[68]

[67] The ratio of wind to solar generation increases with higher costs in 2030, given the relative magnitudes of their capital cost increases (Figure 18).

[68] Another global driver is increasing liquified natural gas exports from the U.S. that connect domestic gas markets with global ones. This fuel market integration could lead to a prolonged period of higher U.S. natural gas prices. The

9 Conclusions

IRA incentives are expected to significantly alter the economics of decarbonization, encouraging deployment of clean energy technologies and lowering emissions. Economic tools will play important roles in the years to come in understanding potential macroeconomic and microeconomic implications of IRA incentives. This paper offers several initial perspectives on what IRA's climate-related provisions could imply for energy transitions and key macroeconomic indicators using stylized examples, data analysis, detailed energy systems modeling, and general equilibrium modeling of the U.S. economy.

This analysis using EPRI's US-REGEN model suggests that IRA, along with other policies and market trends, shift baseline expectations of firms, households, and policymakers for the pace and extent of future decarbonization:

- Clean electricity investments span 34-116 gigawatts of nameplate capacity added annually under IRA through 2035 compared with 18 GW/yr on average in the previous decade and 36 GW/yr in 2021 (Figure 4 in Section 3). Average annual additions of low-emitting capacity in US-REGEN is 51 GW/yr with IRA through 2035, which nearly doubles the 27 GW/yr in the counterfactual without IRA.

- Electric vehicle sales increase from over 6% of new light-duty vehicle sales in 2022 to nearly half of new sales by 2030 (Figure 3 in Section 3). IRA increases the electric vehicle share of new vehicle sales by 12 percentage points in 2030 from 32% in the reference without IRA to 44% with IRA credits.

The projected pace and extent of these changes depend on assumptions about future policies, technologies, and markets. The uncertainty associated with these projections reflects IRA implementation details and unknown responses to siting and permitting challenges, workforce changes, global supply chain shifts, and non-cost barriers to deployment. IRA continues to drive emissions reductions in this modeling beyond 2030, as key power sector tax credits may last until electricity CO_2 emissions reach 25% of their 2022 levels, potentially providing support throughout the 2030s.

The acceleration in the deployment of clean supply- and demand-side technologies in this modeling leads to greater uptake of IRA incentives than initial estimates indicated. These projections indicate that fiscal costs of IRA tax credits for clean electricity, carbon capture, and electric vehicles may be $780B by 2031 in our central case – nearly three times the CBO/JCT score for comparable credits. This finding that budgetary effects of IRA may be larger than initial CBO is reflected in other studies, which indicate that US-REGEN estimates in this paper could be conservative for

scenarios above do not include higher natural gas price sensitivities, which could increase short-run coal generation (and associated emissions) but decrease fossil fuel consumption in the long-run (and emissions) (Stock and Stuart, 2021; Bistline and Young, 2022).

several uncapped tax credits. Notably, the CBO/JCT fiscal score does not reference the implied carbon reductions. Models that indicate emissions reductions in the range of 40% imply larger fiscal costs than CBO/JCT. US-REGEN estimates also suggest that the increasing economic competitiveness of transport electrification and renewables in the power sector mean that non-trivial shares of these tax credits would be inframarginal transfers.

This analysis points to limited macroeconomic effects of IRA, though the macroeconomic environment is shown to influence IRA-incentivized investments. The conceptual framework in Section 5 provides intuition for fiscal and macroeconomic impacts of IRA, including the dependence on supply elasticities for labor and key materials, price elasticity of demand for fuels, market and non-market bottlenecks, stock dynamics for emissions-intensive assets, and potential for endogenous technical change for low-carbon energy technologies (e.g., learning-by-doing effects). Although changes in investment from IRA are large in absolute terms (i.e., tens of billions of dollars per year), even substantial investment increases for power generation, transmission, and distribution carry relatively modest macroeconomic impacts given their low shares relative to overall investment. Magnitudes of change in fixed investment under IRA are comparable to the shale revolution in the 2010s.[69] Likewise, household transfers through tax credits for electric vehicles, heat pumps, etc. are relatively modest in size.

Numerical simulations in Section 7 using the Federal Reserve's FRBUS model with inputs from US-REGEN show the relative impact of IRA on the Fed funds rate, 10-year Treasury rates, and inflation, which rise initially from increases in nonresidential investment and household consumption before returning to their baseline levels. Quantitative effects are small in all cases. Comparisons in Section 8 using US-REGEN illustrate how increases in the cost of capital and supply-side costs for electricity generation and storage technologies lead to lower IRA-induced investments in low-emitting capacity and higher emissions over time.

Our survey of potential IRA impacts points to several areas for additional research. Ex-ante and ex-post analysis of individual IRA provisions will be important for updating baselines for future policies and for understanding the effectiveness of IRA incentives. Assessing interactions between IRA incentives and changes in federal regulations, state policies, and company targets will also be important. Future work should also quantify aggregate macroeconomic impacts of IRA, Infrastructure Investment and Jobs Act, and CHIPS and Science Act, as all three are expected to increase investments across a similar timeframe and have impacts on manufacturing, construction, and raw materials. Finally, understanding the economic incidence of subsidies and distributional implications of IRA will be valuable to policymakers and other stakeholders, especially since many IRA provisions target energy equity, environmental justice, and disadvantaged communities.

[69] Although the direct contribution of shale investment may not have been large (relative to aggregate investment or GDP), it clearly had significant effects on energy prices that kept overall inflation low and supported a recovery in manufacturing after the financial crisis.

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A Macroeconomic Framework

In this section, we lay out the macroeconomic framework used in Section 5 to analyze the qualitative macroeconomic impacts of the clean energy tax credits. A neoclassical growth model is augmented with electricity generation and clean energy capital.

A.1 Households

A representative household chooses a path for consumption and investment in clean energy power generation. The capital stock is owned by the household and used to generate electricity that is sold at price p_t^e in each period. Electricity is consumed by both households and firms. Electricity generation is captured by a generation function $G(\cdot)$ that is increasing in the clean power capital stock. The representative household inelastically supplies a fixed level of labor $\bar{N}$ that is paid wage W_t by the representative firm. The household can purchase new clean energy capital at relative price p_t^c in each period, and invests in one-period government debt that pays interest rate r_{t-1}. There is no aggregate or idiosyncratic risk.

The household pays lump sum taxes T_t to the government in each period and receives both a production and investment tax credit. The production tax credit is proportional to electricity generated while the investment tax credit reduces the effective price of clean energy investment. The household's dynamic optimization problem is given below:

$$V(K_0) = \max_{C_t, E_t^h, B_{t+1}^g, K_{t+1}^c} \sum_{t=0}^{\infty} \beta^t u\left(C_t, E_t^h\right)$$

$$\text{subject to} \quad C_t + \left(1 - \tau_t^{inv}\right) p_t^c I_t^c + p_t^e E_t^h + B_{t+1}^g = \left(p_t^e + \tau_t^p\right) E_t + \left(1 + r_{t-1}\right) B_t^g - T_t + W_t \bar{N} \tag{A1}$$

$$K_{t+1}^c = I_t^c + \left(1 - \delta_c\right) K_t^c \tag{A2}$$

$$E_t = G\left(K_t^c\right) \tag{A3}$$

The optimal path for investment satisfies a dynamic condition where the marginal cost of investing an additional unit of clean power equals the marginal benefit from additional power generation. Household electricity demand is given by a static condition equating marginal utility for electricity consumption and marginal cost.[70]

$$p_t^c \left(1 - \tau_t^{inv}\right) u_c\left(C_t, E_t^h\right) = \beta u_c\left(C_{t+1}, E_{t+1}^h\right) \left[G_c\left(K_{t+1}^c\right)\left(p_{t+1}^e + \tau_{t+1}^p\right) + p_{t+1}^c\left(1 - \tau_{t+1}^{inv}\right)\left(1 - \delta_c\right)\right] \tag{A4}$$

$$u_c\left(C_t, E_t^h\right) = \beta u_c\left(C_{t+1}, E_{t+1}^h\right)\left(1 + r_t\right) \tag{A5}$$

$$u_e\left(C_t, E_t^h\right) = p_t^e \tag{A6}$$

[70] Retail electricity prices for households typically also include charges for funds that pay for energy efficiency, clean energy, and transmission/distribution. The modeling here ignores those considerations, and is probably closer to price-setting in the wholesale market.

A.2 Firms

Firms hire labor and purchase electricity to produce a consumption good and can transform consumption goods to investment goods at $1/p_t^c$ in each period. The production function is increasing in both factors of production, features decreasing returns to each individual factor but has constant returns to scale:

$$\max \quad \Pi_t = Y_t - W_t N_t - p_t^e E_t^f$$
$$Y_t = F\left(E_t^f, N_t\right) \tag{A7}$$

The firm's optimal choice of electricity and labor imply standard factor demands:

$$F_e\left(E_t^f, N_t\right) = p_t^e \tag{A8}$$
$$F_n\left(E_t^f, N_t\right) = W_t \tag{A9}$$

A.3 Government and Market Clearing

The government collects taxes from households to finance the investment and production tax credit for power generation. For simplicity, we assume no government spending. The government can also finance expenditures via debt issuance. The government's flow budget constraint is given by:

$$\tau_t^p E_t + \tau_t^{inv} p_t^c I_t^c + (1 + r_{t-1}) B_t^g = T_t + B_{t+1}^g \tag{A10}$$

Market clearing requires the price of electricity and the wage to clear each factor market:

$$E_t^f + E_t^h = E_t \tag{A11}$$
$$N_t = \bar{N} \tag{A12}$$

An equilibrium is given by quantities $\{N_t, Y_t, C_t, E_t, E_t^f, E_t^h, K_{t+1}^c, I_t^c, T_t\}_{t=0}^{\infty}$ and prices $\{r_t, p_t^e, W_t\}_{t=0}^{\infty}$ that jointly satisfy equations A1-A12 given exogenous processes for clean energy tax credits $\tau_t^p, \tau_t^{inv}, B_{t+1}^g$ and the relative price of clean energy investment p_t^c.

A.4 Extension with Fossil Fuel Electricity

To consider the impact of carbon taxes, we modify the household's problem by adding fossil fuel capital as an additional source of electricity production. Fossil fuel capital K_t^f generates electricity via an increasing generation function $G^f(\cdot)$ and electricity generated from fossil fuels is a perfect substitute for electricity generated by clean energy. A carbon tax τ_t^f is levied on electricity produced by fossil fuels with κ representing a technological constant for carbon emissions generated from a given stock of fossil fuel capital.

With fossil fuel capital, the representative household's budget constraint, laws of motion for capital, and electricity production are given below:

$$C_t + \left(1 - \tau_t^{inv}\right) p_t^c I_t^c + p_t^f I_t^f + B_{t+1}^g = p_t^e E_t + \tau_t^p E_t^c - \tau_t^f \kappa E_t^f + \left(1 + r_{t-1}\right) B_t^g - T_t + W_t \bar{N} \quad \text{(A13)}$$

$$K_{t+1}^c = I_t^c + \left(1 - \delta_c\right) K_t^c \quad \text{(A14)}$$

$$K_{t+1}^f = I_t^f + \left(1 - \delta_f\right) K_t^f \quad \text{(A15)}$$

$$E_t^f = G^f \left(K_t^f\right) \quad \text{(A16)}$$

$$E_t^c = G^c \left(K_t^c\right) \quad \text{(A17)}$$

where δ_f is the depreciation rate for fossil fuel capital which may differ from the depreciation for clean energy capital δ_c.

The optimal choice of fossil fuel capital by the representative household is given the following Euler equation:

$$p_t^f \lambda_t = \beta \lambda_{t+1} \left[G_1^f \left(K_{t+1}^f\right) \left(p_{t+1}^e - \tau_{t+1}^f \kappa\right) + p_{t+1}^f \left(1 - \delta_f\right)\right] \quad \text{(A18)}$$

$$\text{(A19)}$$

where $\lambda_t = u_c \left(C_t, E_t^h\right)$ is the marginal utility of consumption.

In this extension of the model, an equilibrium consists of the quantities and prices in the baseline model along with allocations for $K_{t+1}^f,\ I_t^f,\ E_t^f$ and exogenous sequences for the carbon tax τ_t^f and the relative price of fossil fuel capital p_t^f.

A.5 Externalities and the Planner's Problem

To consider optimal fiscal policy, we make two changes to the baseline model extended with carbon taxes and fossil fuel capital. We modify the representative household's utility function to include both damages from cumulative carbon emissions and a law of motion for cumulative emissions. The planner's problem is given below:

$$V\left(K_0, Q_0\right) = \max_{C_t, K_{t+1}^c, K_{t+1}^f} \sum_{t=0}^{\infty} \beta^t u\left(C_t\right) - D\left(Q_t\right)$$

$$C_t + p_t^c I_t^c + p_t^f I_t^f = F\left(E_t, \bar{N}\right) \quad \text{(A20)}$$

$$K_{t+1}^c = I_t^c + \left(1 - \delta_c\right) K_t^c \quad \text{(A21)}$$

$$K_{t+1}^f = I_t^f + \left(1 - \delta_f\right) K_t^f \quad \text{(A22)}$$

$$E_t = E_t^f + E_t^c = G^c\left(K_t^c\right) + G^f\left(K_t^f\right) \quad \text{(A23)}$$

$$Q_{t+1} = Q_t + \kappa E_t^f \quad \text{(A24)}$$

where Q_t is the cumulative level of emissions and $D\left(\cdot\right)$ is a damages function that is increasing in cumulative emissions and enters the planner's utility function. The planner chooses clean energy and fossil fuel investment subject to laws of motion for emissions and the respective capital stocks.

The planner's Euler equations under optimal policy are given below:

$$p_t^c = \frac{1}{1+r_t}\left[p_{t+1}^e G_c'\left(K_{t+1}^c\right) + p_{t+1}^c\left(1-\delta_c\right)\right]$$
$$p_t^f = \frac{1}{1+r_t}\left[p_{t+1}^e G_f'\left(K_{t+1}^f\right) + p_{t+1}^f\left(1-\delta_f\right)\right] - \underbrace{\mu_{t+1}\kappa G_f'\left(K_{t+1}^f\right)}_{\text{time-varying carbon tax}}$$

where μ_{t+1} is the multiplier that implicitly prices, in real dollar terms, the damages from cumulative carbon emissions Q_t. Relative to the competitive equilibrium, the planner's choice for clean energy capital is undistorted (i.e. no subsidy is required) but the optimal choice of fossil fuel capital requires a time-varying carbon tax. Thus, optimal policy only requires a carbon tax.

A learning-by-doing externality is present if the relative price of clean energy capital is now a decreasing function of the stock of installed capital: $p_t^c = p\left(K_t^c\right)$. The planner's resource constraint becomes:

$$C_t + p\left(K_t^c\right)I_t^c + p_t^f I_t^f = F\left(E_t, \bar{N}\right) \tag{A25}$$

The Euler equation for investment from the planner now differs from the private optimality condition with an extra term that reflect the additional future benefit from lower cost of future investment:

$$p\left(K_t^c\right)u_c\left(C_t\right) = \beta u_c\left(C_{t+1}\right)\left[p_{t+1}^e G_c\left(K_{t+1}^c\right) + p\left(K_{t+1}^c\right)\left(1-\delta_c\right) - p_c\left(K_{t+1}\right)I_{t+1}^c\right] \tag{A26}$$

This higher level of investment can be achieved by an appropriately chosen time-varying subsidy.

B Event Study

To assess the impact on firm profits of the Inflation Reduction Act, we look at the response of equity prices around key announcement dates. Table 5 shows the daily excess return for selected clean energy equities. Specifically, we take the daily return (from open to close) relative to the S&P 500.[71] The clean energy ETF return is an equal-weighted average of the following ETFs: ICLN, TAN, PBW, FAN, and LIT. The fossil fuel ETF is an equal weighted average of PXE and IEO. Selected clean energy stocks are an equal-weighted basket of TSLA, RIVN, FSLR, ALB, and NEE. Selected fossil fuel stocks are CVX, DVN, BTU, and ARCH. In related work, Bauer, Offner and Rudebusch (2023) examine the response of returns in fossil fuel and clean energy equities around the Manchin/Schumer announcement dates in July of 2022 and investigate the implications for pricing climate risk in financial markets.

The event study shows results that are broadly consistent with increased profits and higher valuations as a result of the Inflation Reduction Act. Clean energy ETFs and stocks fell sharply

[71] For announcement days that fall on the weekend, the daily return is difference between the opening price and previous close.

Event date	Event	Excess daily return (relative to S&P 500) Clean energy ETFs	Fossil fuel ETFs	Selected clean energy stocks	Selected fossil fuel stocks	S&P 500 return	10-year Treasury (bp change)
19-Nov-21	House passage of Build Back Better	2.1	-1.7	2.2	-0.7	-0.2	-5
19-Dec-21	Manchin announces decision to vote against Build Back Better	-3.1	-3.0	-2.6	-2.6	-0.7	2
14-Jul-22	Annoucement of end of Manchin-Schumer negotiation	0.5	1.0	1.3	0.3	0.7	5
27-Jul-22	Annoucement of agreement on Inflation Reduction Act	0.6	0.9	-0.1	1.2	1.8	-3
03-Aug-22	CBO/JCT score of Inflation Reduction Act	-1.9	-4.9	-1.5	-4.5	1.1	-2
07-Aug-22	Senate passage of Inflation Reduction Act	1.6	-0.1	2.7	-0.2	0.3	-6
12-Aug-22	House passage of Inflation Reduction Act	0.6	0.2	0.7	1.8	1.3	-3

Table 5: Equity price response around key announcement dates.

after Senator Manchin's announcement that he would not support the Build Back Better Act passed by the House in November of 2011. Fossil fuel stocks also fell on his announcement, but this may reflect that Manchin's announcement occurred over the weekend and Omicron cases were impacting oil markets. Clean energy stocks did not respond strongly to the announcement of an agreement between Manchin and Schumer on July 27, 2022, perhaps reflecting continued uncertainty about the likelihood of Senate passage. However, on Senate passage of IRA, clean energy ETFs rose 1.6% while fossil fuel ETFs and stocks fell slightly. On Senate passage, First Solar (FSLR) had a 6.9% excess return relative to the overall market. The muted response of fossil fuel stocks suggests that IRA had little in the way of negative impacts for oil and gas producers.

Overall, the event study suggests that the major stock responses were around Manchin's BBB announcement and Senate passage of IRA. These responses suggest that some increase in stock valuation may reflect the prospect of increased profits from as a result of IRA.