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Emissions Reduction, Fiscal Costs, and Macro Effects: A Model-based Assessment of IRA Climate Measures and Complementary Policies

Simon Voigts and Anne-Charlotte Paret

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Prepared by Simon Voigts and Anne-Charlotte Paret

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ABSTRACT: The IMF's Macroeconomic Model for the Energy Transition (GMMET) is applied to assess the climate-related measures in the U.S. 2022 Inflation Reduction Act (IRA). Explicitly accounting for corporate income tax funding and assuming no permitting delays for energy-related investment, the measures are expected to cut annual greenhouse gas emissions by 710 MMT by 2030, predominantly driven by more electricity generation from renewables combined with a rising share of electric vehicles. Aggregate output and inflation are not impacted significantly, while the fiscal costs amount to about \$700 billion through 2030 (another \$120 billion of fixed grants and loans are not modelled). In the presence of investment delays from permitting, emission cuts would be reduced by about a third. We also show that the IRA leaves room for sizable additional emission abatement at very low costs; by targeting electricity generation from coal and methane emissions from oil and gas industries.

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WORKING PAPERS

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I. Introduction

For most countries there is a wide gap between announced greenhouse gas mitigation pledges and actual policy implementation (*UN Environment Program, 2023*). The *Inflation Reduction Act* (IRA), signed into law by President Biden on August 16, 2022, aims to significantly narrow that implementation gap, in addition to pursuing other objectives such as reducing the fiscal deficit over the next decade, fighting inflation, and investing in domestic energy production and manufacturing. This paper applies the Fund's new Global Macroeconomic Model for the Energy Transition model (GMMET, see Carton et al., 2023) to assess the impact of those IRA measures that are related to Climate and Energy Security, focusing on both greenhouse gas (GHG) emissions and the macroeconomy up to 2030. We pay special attention to the role of permitting delays for energy infrastructure investment in dampening the impact of the IRA. We also discuss additional regulatory measures that could help further reduce the implementation gap without imposing significant macroeconomic costs.

The impact of the IRA climate measures on emissions and the macroeconomy has been assessed in a variety of studies (see Section II.B. below). However, the use of GMMET sets this paper apart in that it provides a unified assessment of emissions reduction, macro effects, and fiscal costs. GMMET combines a rich set of features from quantitative New-Keynesian models used for macro policy analysis with a granular modelling of GHG-emitting sectors. These sectors include electricity generation, transportation, and fossil fuel extraction. The sectoral granularity helps capture the effects of key IRA measures, with their uptake, and resulting fiscal costs, determined endogenously. The model can explicitly capture permitting delays in the deployment of energy infrastructure (associated with the National Environmental Policy Act of 1970, see Section III.B for details) and features corporate income taxes used to fund these measures.

Our simulations suggest that when permitting delays in energy infrastructure investment are eliminated in 2023, IRA subsidies for renewables spark a surge in investment that crowds out fossil fuels in the electricity mix and boosts the overall volume of electricity generation. The resulting decline in the electricity price lifts the economy's productive capacity and causes output to increase somewhat by the end of the decade, despite the rise in corporate income taxes as a counterbalancing fiscal instrument. Regarding road transport, IRA subsidies trigger a virtuous circle boosting electric vehicle (EV) adoption: a higher share of EVs incentivizes the deployment of chargers, while a denser charging network density incentivizes the purchase of EVs. The climate-related measures' fiscal costs as a share of GDP are about 0.25 percent per year on average and peak towards the end of the decade, adding up to total undiscounted costs of about \$700 billion by 2030 (another \$120 billion of fixed grants and loans are part of IRA climate measures but not modelled). This is significantly higher than the initial CBO/JCT estimate of about \$350 billion over this period (CBO, 2022), but only moderately above the \$590 billion resulting from the 2023 update of JCT scores (CRFB, 2023, over 2022-30). Annual GHG emissions are estimated to decline by about 710 million metric tons of CO₂ equivalent (MMT CO₂e) by the end of the decade.

To assess the importance of the reduction in GHG emissions achieved by the IRA climate measures, it is useful to start with the U.S. goal, which is to reduce emissions by 50-52 percent between 2005 and 2030. Several papers (Mahajan et al., 2022, Jenkins et al., 2022 and Larsen et al., 2022) estimate that, in the absence of the IRA, emissions would decline by around 27 percent during this period.¹ This leaves a gap of

¹ For reference, Energy Innovation (Mahajan et al., 2022) estimates emissions to have declined by around 19% in 2022, compared to 2005 levels.

around 23 percent. The IRA's 710 MMT reduction by 2030 corresponds to about 11 percent of 2005 emissions, covering roughly half of the implementation gap. As the simulations make clear however, such progress hinges on reforms that eliminate permitting delays. Lack of reform in this area would constrain the effectiveness of the IRA in cutting emissions: If delays persisted until 2030, the IRA-induced emission decline would be smaller by about a third. Permitting reform is therefore crucial to unlock the IRA's full potential.

As GMMET lacks a description of warming damages, it is not suitable for a cost-benefit analysis of the IRA's climate measures. However, their cumulative fiscal cost per ton of abated GHG emissions (referred to as "fiscal abatement costs"), obtained from the simulations in this paper, can be compared to estimates of the social cost of carbon (SCC) to give a sense of the policy's desirability. We find that fiscal abatement costs start at a high level but then decline rapidly to reach the SCC estimate of \$185/tCO₂e (Rennert et al., 2022) by 2029, suggesting that benefits would start outweighing the costs before the end of the decade. After 2029, fiscal abatement costs continue to decline towards \$50 and durably stay at that level, coinciding with a prolonged period of substantial reductions in annual emissions. These dynamics arise because IRA subsidies boost renewable energy investment and electric vehicle (EV) adoption, both of which lead to longer-term emission reductions over the lifetime of the capital equipment/EV fleet. As a result, emission reductions accumulate and persist even after the IRA spending has faded out. The policy is thus desirable in the sense that \$1 of fiscal spending generates a gain, measured by the SCC, greater than \$1. This is true during the first decade, and substantially more so at longer horizons.

Finally, we also discuss additional measures that could complement the IRA to bridge the remaining emission gap. This last step generally requires a stronger policy effort, as marginal abatement costs tend to rise as decarbonization advances. However, this paper discusses two areas with potential for low-cost abatement that are left mainly unexploited by the IRA. The first and most prominent area is curbing electricity production from coal, which is the most polluting fuel. Coal extraction only employs about 0.02 percent of the workforce and can be readily replaced with existing technologies in electricity generation. While the clean investment surge triggered by IRA subsidies crowds out electricity generation from coal, the fuel retains a significant share of the post-IRA electricity mix by 2030. We therefore assess a regulatory measure that would gradually dampen generation from coal, without adding extra fiscal cost. The second area is abating methane emission for oil and gas extraction operations. According to recent research by the International Energy Agency, emissions of about 300MMT of CO₂e—roughly 40 percent of our projected emission decline from the IRA—can be abated at negligible costs (IEA, 2023). This abatement remains largely untapped by the IRA, despite measures included in the IRA (Mahajan et al., 2022). We therefore analyze a regulation that leads oil and gas industries to realize their full abatement potential, again without adding additional fiscal costs. Our analysis suggests that neither measure significantly alters the macroeconomic adjustment relative to the IRA, while at the same time jointly yielding additional emission cuts of 560 MMT by 2030 (which would cover roughly two-thirds of the post-IRA gap to the target).

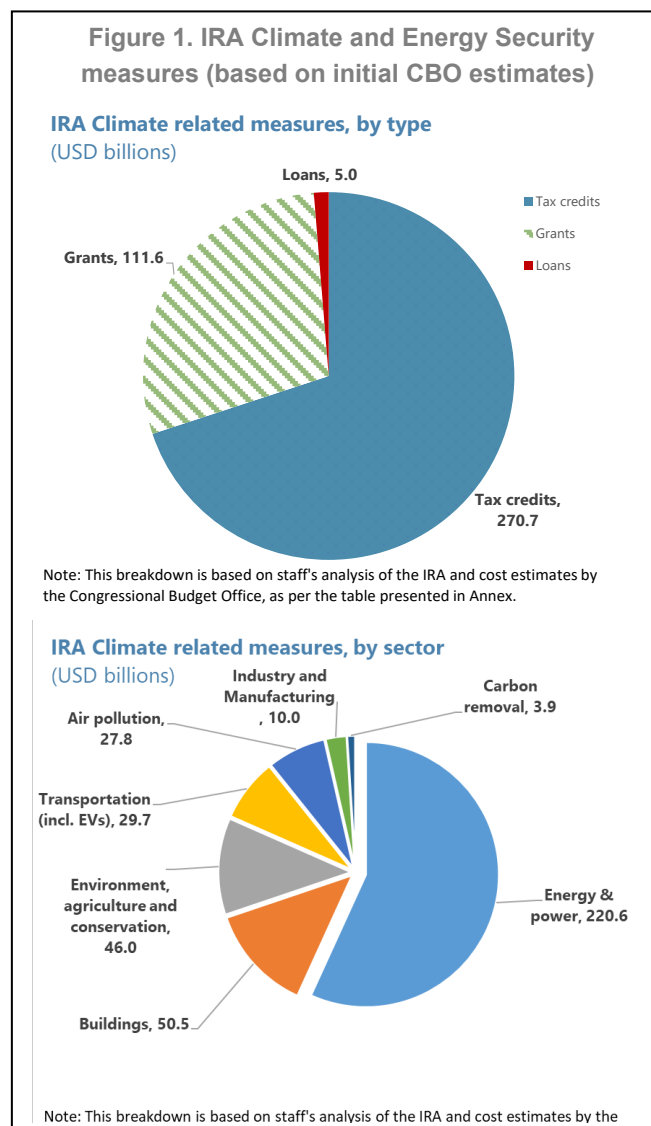
The remainder of the paper proceeds as follows. Section 2 is a stocktaking exercise, presenting the IRA's different Climate and Energy-related measures. Section 3 presents the main simulation results and highlights the role of permitting delays for energy infrastructure, as well as the funding from higher corporate income taxes. Section 4 assesses the impact of potential additional measures, beyond the IRA, that could help to bridge the gap to the announced target of a 50-52% reduction in emissions by 2030. The last section concludes.

II. Stocktaking: What are the Climate-related provisions in the IRA?

A. Climate-related IRA measures

According to the initial estimates by the Congressional Budget Office (CBO) and the Joint Committee on Taxation (JCT), published in 2022, the IRA directs almost US\$400 billion in federal funding to Energy Security and Climate Change measures through 2031.² More recently, the JCT updated its scores, leading to a significantly higher cost estimate of \$660 billion (CRFB, 2023, over 2022-31, or about \$590bn over 2022-30), with upward revisions driven by a combination of higher inflation, greater demand for subsidized activities, and looser than expected regulations, among others. The IRA's climate-related measures are mainly composed of tax credits, and to a lesser extent of grants or loans (Figure 1). More specifically, based on initial CBO cost estimates (see CBO, 2022) over 2022-31:

- Most of the funding (57 percent of estimated fiscal cost, or \$221bn) is expected to be directed to the *energy and power sector*, to support an expansion and retainment of the domestic production capacity of clean energy, and the retirement or retrofit of nuclear production. This includes tax credits for the production of electricity from renewable sources and for the investment in clean electricity, tax credits for the production of clean hydrogen and nuclear power, disincentives for oil and gas production (including higher royalty rates), incentives for offshore wind and to enable methane emission reduction activities, and different types of financing, grants and loans to repurpose energy infrastructure, improve energy efficiency, and support renewable energies and clean energy.
- Another 13 percent of measures aims at promoting *energy efficient buildings and home production of green energies*, including through tax credits and rebates for residential production of clean energy and energy efficient home improvements, as well as grants for investment in low-carbon materials and buildings.



² This section focuses on the initial estimates by the CBO, since this is how the Inflation Reduction Act was initially presented to the public.

- A similar amount is devoted to measures related to the *agriculture sector and conservation of the environment* more generally. This includes assistance for rural energy and electricity and support of undeserved farmers, as well as programs for environmental quality, conservation, resilience and mitigation, partly offset by revenues generated by the Methane emissions reduction program. While the latter includes penalty charges for facilities with annual methane emission rates that exceed various thresholds, several features of the legislation, including reporting requirements, raise substantial doubt on the effectiveness of the program (Mahajan et al., 2022).
- 8 percent of measures are devoted to *greener transportation and a wider production and use of electric vehicles (EVs)*, including tax credits for the purchase of clean vehicles, the placement into services of EV chargers, and financing for clean heavy-duty vehicles.
- A similar amount aims to support the reduction of air pollution, including through the Greenhouse Gas Reduction Fund. The rest of the measures are linked to the industry sector, to support innovation or infrastructure, as well as carbon removal.

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Some of the IRA's green tax credits are wholly or partially tied to domestic content requirements. The most visible "Made in America" provision is the Clean Vehicle Credit which offers a US\$7,500 credit to consumers for the purchase of a qualified EV, plug-in hybrids, or hydrogen fuel cell vehicle, which requires final assembly to occur in North America and has domestic content requirements for critical minerals and battery components that increase over time, although some of them have been relaxed in the meantime (with more countries now meeting the "free trade agreement" criterion, for example) . In addition, the four major electricity production and investment tax credits are available to tax-paying companies and boosted by an additional 10 percent (bonus) if project inputs meet specific domestic content requirements. Additionally, some of the IRA tax credits are also wholly or partially tied to wage and apprenticeship, and energy communities' requirements, which means either full credit or an additional bonus tax credit would be granted if some thresholds are met on these aspects. In practice, it is difficult to anticipate the extent to which such requirements will be complied with. We therefore assume in our baseline that tax credits are granted in full, without any additional bonuses.

B. A Brief Review of the literature

We briefly review twelve papers which have assessed the macro, fiscal, or emissions impact of the IRA. An overview of their findings is shown in Table 1 and summarized below.

Macroeconomic impact

By and large, the literature expects the IRA to have a marginal impact on GDP and inflation over 10 years, but to significantly reduce emissions by shifting the electricity mix towards more renewables and boosting the sales of EVs. Available studies assessing the macroeconomic impact of the IRA measures often present a range of estimates, based on different assumptions on the cost of dirty vs. clean technologies, on economic growth, or on the take up or eligibility for the available tax credits or subsidies, for example. We focus on the median or intermediary scenario presented in each study:

- Studies generally find real GDP to increase by around 0.1 percent over 10 years due to the IRA (relative to pre-IRA baseline), although estimates differ in that some studies focus on the Climate measures without incorporating their financing, while others assess the effect of the whole IRA package (including non-climate measures), which embeds more revenue generation than spending to trim the deficit.
- When it comes to inflation, despite its name, the Inflation Reduction Act is expected to have a very marginal impact on the CPI index by 2030 (see Table 2).

- On fiscal cost, several studies (Credit Suisse, 2022, Goldman Sachs, 2023, and Bistline et al., 2023) have challenged the initial CBO/JCT estimate. Credit Suisse and Bistline et al. both report that tax credits are likely to cost more than 3 times as much as estimated by the CBO over the next ten years, while Goldman Sachs estimates the IRA Energy and Climate provisions could cost up to USD 1.2 trillion through 2032, i.e. three times more than the initial CBO estimates (over a slightly longer time period). Bistline et al. find differentials in cost estimates to be driven mostly by measures in the transportation sector, CCUS tax credits, and the investment tax credit. Authors have argued that most of the tax credits are uncapped, so that total fiscal costs are a function of the uptake of the respective measures (which are subject to important uncertainty, especially when it comes to eligibility of cars for the EV subsidies, given associated requirements). In addition, public spending is expected to leverage further private sector spending, which would increase production and investment, and therefore the amount of tax credits that are based on these bases. Finally, the different loan programs and the Green House Reduction Fund that is created to channel private funding are both expected to catalyze more investments as well, which would further increase the multiplier and explain a higher-than-expected cost of the measures. More recently, based on updated JCT scores, the CBO/JCT estimate rose to \$659 billion, with upward revisions said to be driven mainly by higher inflation, greater demand for subsidies, and looser than expected regulations.
- Finally, studies generally find the IRA to increase the share of electricity generation from non-fossil fuels by around 21 percentage points, to around 75 percent of the total.

Table 1. Estimated macroeconomic impact of IRA measures

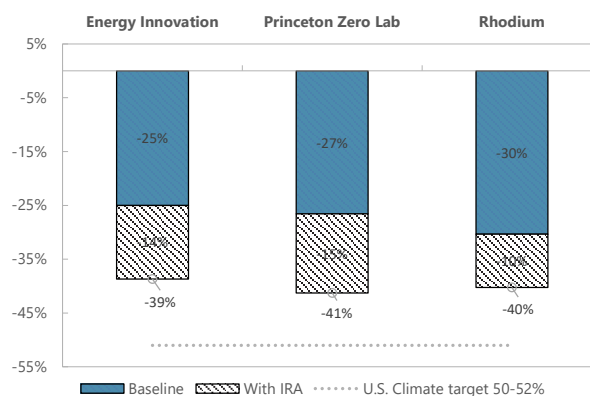
Macro variables	References	Macro impact of the IRA (additional, relative to baseline)
Real GDP	<i>Energy Innovation</i>	Real GDP in 2030 +0.65-0.77 percent
	<i>Moody's</i>	Real GDP in 2030 +0.1 percent
	<i>Penn University</i>	No GDP impact by 2030
	<i>Baker Institute</i>	Real GDP by 2030 -0.1 percent
Inflation	<i>Moody's</i>	CPI index 0.33 percent lower by 2030
	<i>Penn University</i>	Non statistically significant
Fiscal cost	<i>CBO/JCT 2022</i>	US\$369bn over 2022-2031
	<i>CBO/JCT with updated scores 2023</i>	US\$659bn over 2022-2031, or \$590bn over 2022-30
	<i>Credit Suisse</i>	US\$576bn over 2022-2031, tax credits only
	<i>Bistline et al.</i>	US\$900bn through 2031.
	<i>Goldman Sachs</i>	US\$1.2trn over 2023- <u>2032</u> (different time span)
Electricity mix (share of electricity generation from non-fossil fuels)	<i>Energy Innovation</i>	From 49 to 75 percent with IRA (i.e. +26pp)
	<i>Rhodium</i>	From 58 to 76 percent with IRA (i.e. +18pp)
	<i>Annual Energy Outlook</i>	From 51 to 69 percent with IRA (i.e. +18pp)

impact on GHG emissions

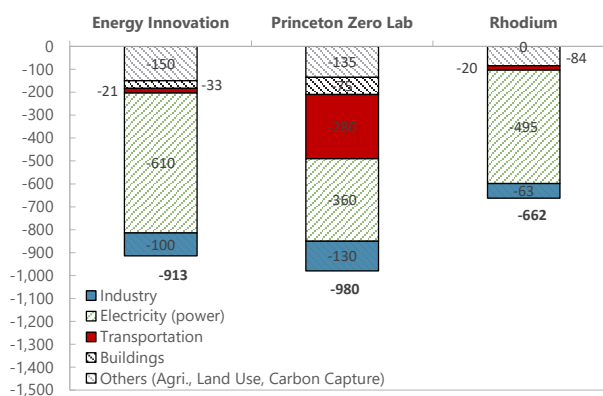
Available studies³ estimate that by 2030, the IRA will have caused emissions to decline by 10 to 15 percent of their 2005 level. This would leave a gap of around 12 percent of 2005 emissions to the U.S. Climate goal of an 50-52% emission reduction between 2005 and 2030. In the mentioned estimates, the emission reduction is found to be largely driven by measures in the electricity power sector (including clean energy tax credits), followed by measures in the industry and transportation sectors, with agriculture-related measures and carbon capture also contributing significantly. While the Zero Lab study finds transportation measures to contribute significantly to the overall reduction, this is not the case of the two other studies, which might be because the latter incorporate the effect of high electricity use from EV usage as coming from the transportation sector (as opposed to the electricity sector).

Figure 2. Emission reduction enabled by IRA measures, external estimates

U.S. Emissions Reductions in 2030 under the IRA (compared to 2005 levels)



Emission reductions under the IRA (relative to 2030 baseline, mmt CO2e)



³ Energy Innovation (Mahajan et al., 2022), Princeton Zero Lab (Jenkins et al., 2022), and Rhodium (2022).

III. Modelling IRA climate measures in GMMET

A. Model details

GMMET is a global model designed for the analysis of the macroeconomic implications of reducing GHG emissions. A detailed description is provided in Carton et al., 2023. The focus is on the potential costs of different mitigation policies, including the impact on output, employment and inflation. GMMET builds on the IMF's workhorse Global Integrated Monetary and Fiscal model (GIMF), which is a large-scale, non-linear, structural, New-Keynesian dynamic general equilibrium model.⁴ As in GIMF, households and firms are forward-looking and choose consumption, labor supply, asset holdings, and investment optimally. The model also features a rich set of nominal and real frictions, while its global dimension allows for a careful treatment of international trade and external adjustment.

Relative to GIMF, GMMET features several novel sectors to capture various aspects of energy generation, transmission, and consumption, and their implications for GHG emissions. These include:

- *Fossil fuel sectors.* The supply elasticity of fossil fuels is a key determinant for the effectiveness of mitigation policies in reducing emissions. The model therefore features fuel-specific extraction sectors for coal, gas, and oil that allow to replicate empirical estimates of the respective fuel's supply elasticity. The model also features a global market for coal and oil, as well as bilateral trade in gas.
- *Electricity generation sectors.* The model features electricity generation from five technologies: coal, gas, renewables, as well as nuclear and hydropower. Each technology has its own representative electricity utility with a specific capital stock, investment rigidity, cost structure and emission intensity. For electricity from renewables, the model captures a key real-world obstacle to increasing their share in the electricity mix: their generation is intermittent, i.e., subject to uncontrollable weather-related fluctuations. In the absence of grid-scale electricity storage and sufficient flexibility on the part of other electricity suppliers, intermittency gives rise to an upper bound of renewables in the electricity mix, above which meeting demand is not always guaranteed. GMMET captures intermittence by modelling renewable generation from so-called renewable-plus-backup utilities, which pairs renewable generation with a flexible fossil fuel-based backup in a cost-efficient fashion (considering variable and fixed costs of both technologies as well as the distribution of weather regimes).
- *Transportation sector.* The model's transportation sector distinguishes between combustion engine cars and EVs, fueled by gasoline (modelled as oil) respectively electricity. The fleet of each type is modeled similarly to a capital stock and adjusts gradually in response to shifts in the share of newly purchased cars. The choice of car type depends on the relative price, current and expected prices of the respective fuels, and on the charging/fueling station density. The role of the latter is captured by modelling network externalities between EV adoption and the deployment of charging stations, in the spirit of Li and others (2017). This allows for a virtuous feedback loop that can bring about a substantial EV market share in the absence of extreme relative price changes.

⁴ For more details on GIMF, see Kumhof et al. (2010) for the theoretical structure, and Anderson et al. (2013) for standard model properties.

- *Tracking and abatement of non-CO₂ GHG emissions.* The model also accounts for non-CO₂ GHG. Policies can lead firms to abate these emissions optimally. Firms are equipped with a reduced-form abatement technology in which marginal abatement costs are informed by the estimates in EPA, 2022. Optimal abatement by firms equalizes marginal abatement costs with the monetary incentive for marginally cutting emissions, for example stemming from the avoided tax burden on a marginal unit of carbon emissions. This mechanism does not play a role in the assessment of the IRA but are listed for completeness.
- *Home heating.* Households consume a bundle of natural gas and electricity that represents fuel for home heating.
- *Energy use by manufacturing.* As additional input, the tradable goods sector consumes a bundle of fossil fuels and electricity.

B. Implementation of selected IRA climate measures

Mapping IRA measures into policy changes in GMMET is at the core of this exercise. The legislation of 274 pages covers a myriad of policy measures, many of which are unrelated to climate change mitigation. Among the climate-related measures, some do not have a representation in GMMET, and others are expected to be too narrow to have implications on a macroeconomic scale.

We therefore model a subset of measures which the literature generally considers the most relevant for the aggregate economy as well as for emissions. Most of the modelled measures are uncapped tax credits, so that we cover about 90 percent of total tax credits according to the initial CBO/JCT estimates.⁵ Tax credits are implemented as subsidies, which implicitly assumes that their tradability makes them as valuable as the credit amount in cash. For electricity and transportation sector measures (except the nuclear power credit), the subsidized object or activity is represented in the model, so the measures are directly implemented, and their impact unfolds endogenously. Three further measures (related to carbon capture and storage, residential energy efficiency and various agriculture measures) have a comparably minor impact on spending and emissions, and their calibration is based on other studies. The phase-out of the different measures is in line with the legislation and occurs soon after 2030. Agents thus do not expect a continuation of the measures, which would increase their effectiveness due to forward-looking nature of investment decisions.

Regarding the funding side, a 15 percent minimum tax on profits made by large corporations and a 1 percent excise tax on stock buybacks and exemptions are key measures in the IRA to generate revenues. Thus, for a plausible representation of the policy package, the measures are assumed to be fully funded by an increase in corporate income taxes. The latter are not approximated as a tax on the return of capital, but instead, following Carton et al. (2017), as a tax on the profit from the ownership of firms.

We also assess the implications of investment delays for the IRA's effectiveness in cutting emissions. These delays stem from the permitting process. The National Environmental Policy Act of 1970 requires federal permit for infrastructure projects, including for energy, and this permitting process takes around 4.5 years on average

⁵ Modelling the lion's share of uncapped tax credits is crucial for the computation of the total fiscal cost of IRA climate measures. As the remaining measures then mostly consist of fixed grants and loans, their volume does not depend on an uncertain uptake, so that they can be readily added to the simulated costs of the modelled measures (as done below).

(see, for example, J.P. Morgan, 2023 or American Clean Power Association 2023). The Fiscal Responsibility Act signed into law on June 3, 2023, contains important steps toward speeding up the permitting process, but delays remain a prominent obstacle to energy investment. We assess the role of permitting delays by varying the calibration of the real investment rigidity in the electricity sector. Real investment rigidities in the model capture the speed with which investment responds to shocks and changes in policy. We consider two calibrations of real investment rigidity in the electricity sector: one where it takes 4.5 years on average for investment projects to come on board, which we refer to as the version with permitting delays, and one where it takes only 1.5 years, in line with other sectors, which we refer to as the version without investment delays.⁶ The following list details the implemented measures.

Electricity sector measures

- *Clean Electricity Production Tax Credit (PTC, combining the extension of the existing credit and its replacement by the new credit, Sections 45 and 45Y):* Abstracting from various bonuses and requirements, the PTC amounts to $\phi 1.5/\text{kWh}$. To convert the credit into a proportional subsidy on the renewable utility's total production cost, we must assume generation costs for both technologies. While there is a variety of estimates, we use $\phi 3.5/\text{kWh}$ for wind and $\phi 5/\text{kWh}$ for solar, and weight them by 1/3 and 2/3 respectively (accounting for an expected rise in the share of solar). This yields a proportional subsidy of 33 percent of production costs.
- *Clean Electricity Investment Tax Credit (ITC, combining the extension of the existing credit and its replacement by new credit, Sections 48 and 48E):* Taxpayers are required to choose between this incentive and the PTC. Following Credit Suisse (2022), we assume that renewable utilities mostly opt for the PTC, allowing us to neglect the ITC in our modelling.
- *The New Advanced Manufacturing Production Tax Credit (Section 45X)* subsidizes domestically produced clean electricity components, for example solar panels, wind turbines, battery components, and critical materials. This corresponds to the investment good employed by the renewable electricity utility, and the quantification of the credit is guided by Credit Suisse (2022) and Goldman Sachs (2022). For solar equipment, the latter assesses the credit to make up about 40 percent of the costs, whereas it is 60 to 80 percent in the former study. For wind, Credit Suisse (2023) estimates subsidized costs to be 50 percent below the non-subsidized. Taking a mid-point between both studies, averaging between both technologies, and proxying for a partial fulfillment of the domestic content requirements leads us to assume a subsidy of 40 percent of the price of the investment good when the incentive is fully passed on.
- *The Nuclear Power Production Tax Credit (Section 45U)* provides a production tax credit of up to $\phi 1.5/\text{kW}$. This measure has no direct counterpart in the model as nuclear power investment is treated as exogenous, reflecting that investment decisions are of political nature in most countries. Hence, the measure is implemented in an ad-hoc fashion, using CBO estimates for fiscal costs, and Rhodium Group (2022) to calibrate the impact of the measure, according to which it will prevent 10-20 GW of

⁶ In technical terms, real investment rigidity of electricity utilities is adjusted such that the average delay after a one-period investment incentive amounts to either 4.5 years, or, in the case of no permitting delays, to 1.5 years as in other sectors. As permitting delays only constrain the upward (but not downward) adjustment of investment, the rigidity parameter is always 1.5 years for utilities whose investment exclusively drops in response to the IRA.

nuclear power capacity from retiring through 2030 (roughly 15 percent of today's capacity). Exogenous investment is increased such that capacity in the model rises accordingly, and the fiscal costs are introduced as government spending.

Transportation sector measures

- *The Clean Vehicle Credit (Section 13401)* maintains, with modifications, an existing consumer tax credit for qualifying EVs. A maximum credit of US\$7,500 can be granted if the vehicle fulfills domestic content requirements (for its battery components and assembly), costs less than a certain cap, and if the buyer's income is below a certain threshold. It is modelled as a gradually rising EV subsidy starting at 7.5 percent of the EV retail price and reaching 15 percent by 2030. This pattern reflects an assumed increasing share of manufacturers fulfilling the domestic content requirements, and an average EV price of roughly US\$50,000. Explicit modelling of EVs and conventional cars in the household consumption bundle allows to directly implement the subsidy on the EVs' purchase price.
- *The Alternative Fuel Refueling Property Credit (Section 13404)* extends, up to 2032, a tax credit on the installation of qualifying EV charging property in the amount of 30 percent of its costs. The credit is capped at US\$1,000 for residences and at US\$30,000 for businesses, and only charging equipment installed in low-income or rural areas qualifies. For businesses, the subsidy rate is reduced to 6 percent if certain wage and apprenticeship requirements are not fulfilled. The various requirements and caps are captured, in a rule-of-thumb fashion, by modelling a 20 percent instead of a 30 percent subsidy rate. To model this measure, we follow Cole et al. (2023), assuming an elasticity of charging station supply with respect to its costs of 0.67. This translates into a subsidy-induced expansion of the charging network by 13.4 percent, which is introduced as an exogenous scaling of the endogenous charging station density.

Other measures:

- *The Carbon Capture and Sequestration Tax Credit (45Q)* amounts to \$50 to \$85 per ton of captured emission by industrial facilities and power plants. Its impact is calibrated based on existing estimates by the Rhodium Group (2022) and by Energy Innovation (2022). Taking a mid-point between both studies, we assume that the induced expansion of CCUS reduces industrial emissions by 15 MMT CO₂e annually by 2030. The fiscal costs of the measures are expected to be minor over the considered time horizon, compared to the other measures. We use the cost estimates by CBO (2022) as a starting point and gradually scale them up to be 40 percent higher by 2030, which corresponds to the Rhodium Group's expected additional deployment due to the IRA by end of the decade. This yields a cumulative fiscal cost of around 0.015 percent of GDP.
- *Measures aimed at improving residential energy efficiency (including Sections 25C and 25D as well as HOMES)* are modelled as a positive productivity shock on the bundle of natural gas and oil used by household for home heating. This allows to capture general equilibrium effects from reduced fuel demand. It is calibrated such that emissions from home heating decline by 33MMT by the end of the decade, in line with building-related emission reductions in Mahajan et al. (2022). The fiscal costs—again minor compared to other measures—are modelled as government consumption and amount to roughly 0.02% of GDP annually, which is informed by initial CBO estimates.
- *Measures related to agriculture and waste (Sections 21001, 21002, 22001, 22002, 22004, 23001, 23002, 23003)* are introduced in a stylized fashion because GMMET lacks a detailed representation of these sectors (emissions are associated with tradable goods production). The induced decline in

emissions—113 MMT by 2030—follows the projection by Mahajan et al. (2022), and costs are assumed to be in line with initial CBO estimates. Since the bulk of the measures are capped grants, there is less uncertainty surrounding fiscal cost than for uncapped measures whose costs depend on the uptake.

C. Simulation results

Simulation results are presented in three steps to illustrate the role of a permitting reform and funding measures. The first step shows the impact of the package when it is funded by lump-sum taxes on households and there are no permitting delays affecting the power sector from 2023 onwards. Step two illustrates how the effect of the package is impacted by the presence of permitting delays (in line with the observed 4.5 years required on average to receive authorization for power infrastructure investment). Step three investigates the implications of funding these measures by raising corporate income taxes, which corresponds to the actual financing of IRA climate-related measures.⁷

⁷ An assessment of the IRA's spillover to other countries is beyond the scope of this paper. Fournier et. al. (2023) provides an analysis of spillovers within North America.

Exercise 1: No permitting delays, lump-sum funding

Figure 3 (split into two sub-figures) shows the impact of the IRA climate measures when they are funded by lump-sum taxes and when energy-specific permitting delays are fully eliminated in 2023—that is, when the permitting reform is effective one year after the IRA is adopted. The two key electricity sector measures, the Clean Electricity Production Tax Credit and The New Advanced Manufacturing Production Tax Credit, lower the renewable utility’s overall generation costs and, respectively, the price of capital. This triggers a surge in renewable investment and reduces investment in coal utilities via crowding out (Figure 2/2, Panel C). Gas investment ticks up slightly due to its role as a back-up for renewables, and investment in nuclear power rises mildly from the Nuclear Power Production Tax Credit. These investment dynamics result in a gradual shift in the electricity mix (2/2, Panel D). The share of renewables increases by around 19 percentage points by 2030, at the expense of gas and coal.⁸ The subsidies boost the total volume of electricity generation and thereby reduce the electricity price (1/2, Panel F).

At the macro level, the package triggers an increase in aggregate investment (Figure 1/2, Panel B), reflecting higher investment in the electricity and manufacturing sectors. The latter is driven by lower electricity prices as energy and capital are assumed to be complements. This complementarity, combined with the non-distortionary source of funding, provide the key explanation for the mild increase in output, of close to 0.25 percent by the end of the decade (1/2, Panel A). The remaining macro aggregates exhibit a milder response. The trade balance decreases slightly to accommodate the surge in investment, and consumption remains roughly constant as higher taxes are offset by higher income. The impact on inflation and the policy rate is negligible, in line with the mild macro effects and the fact that the electricity sector (where the IRA has the largest effect) is small.

Turning to transportation, the share of EVs in newly purchased cars increases by slightly less than 5 percentage points upon introduction of the Clean Vehicle Credit and thereafter rises gradually to reach 19 percent by 2030 (1/2, Panel G)—the policy-induced increase is roughly in line with the results from the US-REGEN model presented in Bistline et al. (2023). The transmission to the EV share in the overall transport fleet is delayed, owing to an assumed average lifetime of cars of 8 years. The EV charging station density exhibits a similar dynamic, with an initial increase when the Alternative Fuel Refueling Property Credit is adopted, followed by a gradual rise that more than doubles the density by 2030 (1/2, Panel H). EV adoption and charger deployment reinforce another in a virtuous circle set in motion by network externalities, where a denser charging network incentivize EV adoption, while a rising EV share makes it more attractive to deploy additional chargers.⁹

Total fiscal costs of the modelled measures amount to about 0.1 percent of GDP in 2022 (1/2, Panel E). As subsidy take-up increases over time, fiscal costs gradually climb and peak at about 0.4 percent GDP towards the end of the decade. Applying these cost shares to nominal GDP projections from the October 2023 World Economic Outlook, and cumulating through 2030, yields undiscounted total costs of about \$700 billion. Together with IRA climate-measures that are not modeled and whose emission impact is therefore not

⁸ The uptick in natural gas investment is compatible with a declining electricity share as some of the additional capacity is used as backup for renewables (with a lower utilization rate), and because the overall volume of electricity increases.

⁹ The model does not capture the loss in motor fuel tax revenues resulting from the declining share of conventional cars. To approximate its size, U.S. motor tax revenues can be scaled down in line with the simulated reduction in the conventional car share in the total fleet. This yields a loss in the order of magnitude of 0.01 percent of GDP by 2030, which we neglect.

captured (mostly fixed grants and loans in the amount of about \$120 billion per CBO, 2022 and in line with CFRB, 2023), total costs stand at \$820 billion. This is well above the initial CBO/JCT estimate of about \$350 billion over this period (CBO, 2022), but only moderately above the \$590 billion estimate resulting from the 2023 update of JCT scores (CFRB, 2023, over the 2022-30 period). Costs stem mainly from three subsidies (2/2, Panel A): The New Advanced Manufacturing Production Tax Credit (rising in volume as the surge in renewable investment gathers pace), the renewable electricity generation subsidy (increasing as generation capacity builds up from higher investment), and the EV subsidy (becoming more costly as network externalities boost EV adoption), roughly in line with the updated CBO/JCT estimates.

The subset of IRA climate-related measures considered in this paper is estimated to reduce total annual GHG emissions by about 710 MMT of CO₂e by the end of the decade (1/2, Panel D), which corresponds to a cumulative decline of roughly 3,300 MMT. The bulk of the reduction stem from electricity generation, followed by the transport sector and agricultural measures (2/2, Panel B). Without the IRA, the baseline emission reduction between 2005 and 2030 is assumed to be 27 percent (Mahajan et al., 2022, Jenkins et al., 2022, Rhodium Group, 2022), while the mitigation target is a 50-52 percent reduction over this period. This leaves a gap of annual excess emissions of about 1600 MMT (roughly 24 percent of 2005 emissions) by 2030. In our simulation, the IRA-induced emission reduction closes slightly less than half of this gap, which means that another 800 MMT reduction would be needed to reach the emission reduction objectives, on top of the IRA measures. Emissions in the rest of the world increase mildly, by about 100 MMT (2/2, Panel E). This reflects an uptick in the use of fossil fuels resulting from a decline in their prices on global markets, which, in turn, is driven by weaker demand from the U.S (see Fournier et. al., 2024, for a more detailed analysis of spillovers).

As GMMET does not feature warming damages, it does not address the question of whether IRA climate measures are desirable from a cost-benefit-perspective. To get an approximative answer, we compare the fiscal costs per ton of GHG reduction from our simulation with a plausible estimate of the social costs of carbon (SCC), \$185 per ton, taken from Rennert et al. (2022). The ratio of cumulative fiscal costs over cumulative emission reductions—a metric for average fiscal abatement costs—stands at about \$400/tCO₂ in 2022, but then declines swiftly to reach the SCC of \$185/tCO₂ in 2029 and settle at \$50/tCO₂ in the long run.¹⁰ This suggests that by the end of the decade, the social value of IRA emission reductions greatly outweighs their fiscal cost, making the measures highly desirable from a cost-benefit viewpoint. Furthermore, since GMMET (in its current version) abstracts from technological progress via learning by doing, our results should be interpreted as a lower bound, in the sense that IRA-induced deployment of low-carbon technologies is likely to drive down costs and make the transition more favorable.

¹⁰ The decline in fiscal abatement costs results from the IRA's focus on subsidizing investments that yield long-lived emission reductions, as for example renewable electricity capacity and EVs. As the stock of emission-reducing capital gradually accumulates during the period of IRA spending, the associated emission cuts rise and push down fiscal abatement costs. Furthermore, the accumulated capital continues to yield emission reduction benefits after the phaseout of IRA subsidies.

Figure 3 (1/2): Exercise 1, No Permitting Delays and Lump-sum Funding

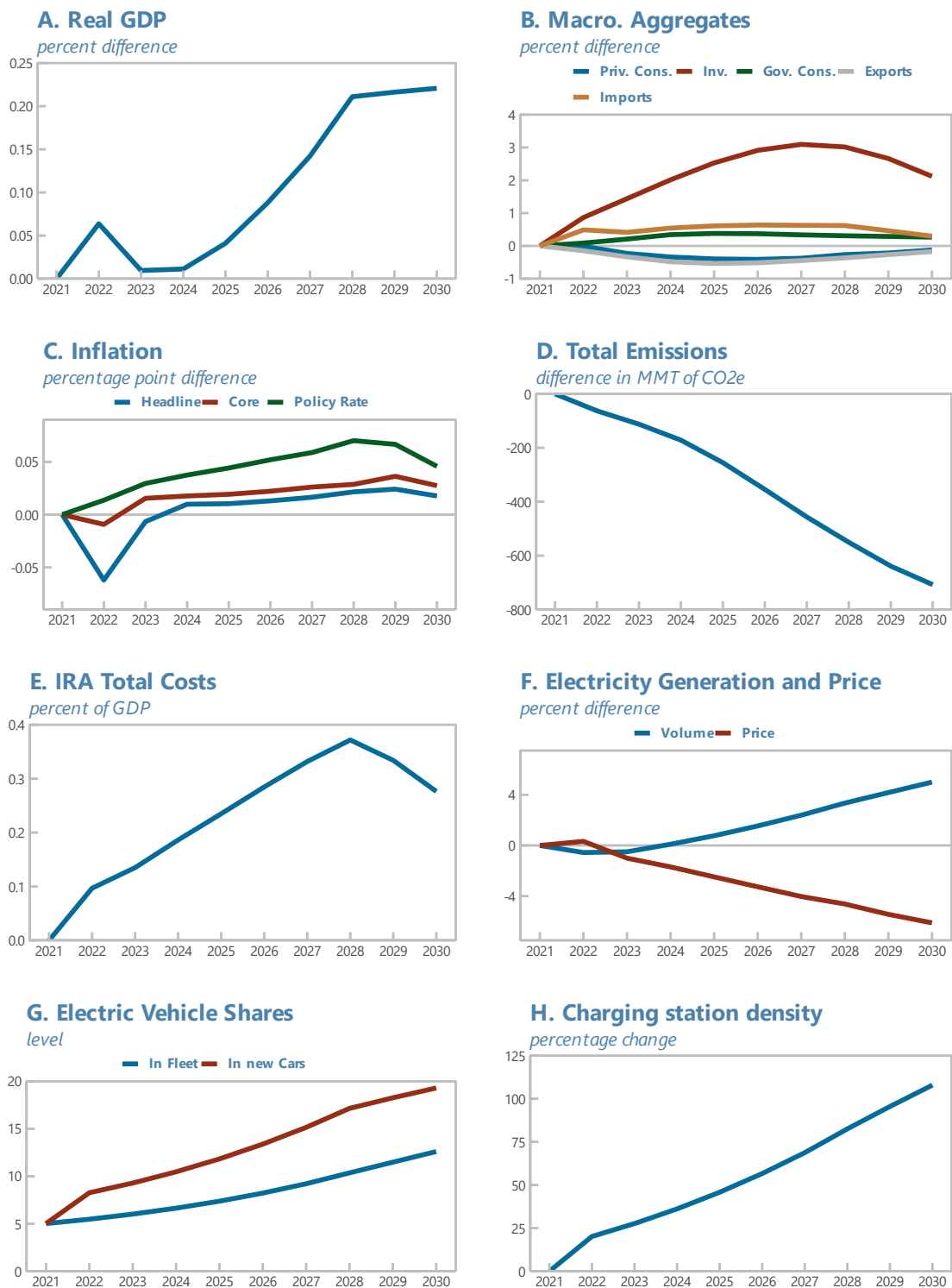


Figure 3 (2/2): Exercise 1, No Permitting Delays and Lump-sum Funding

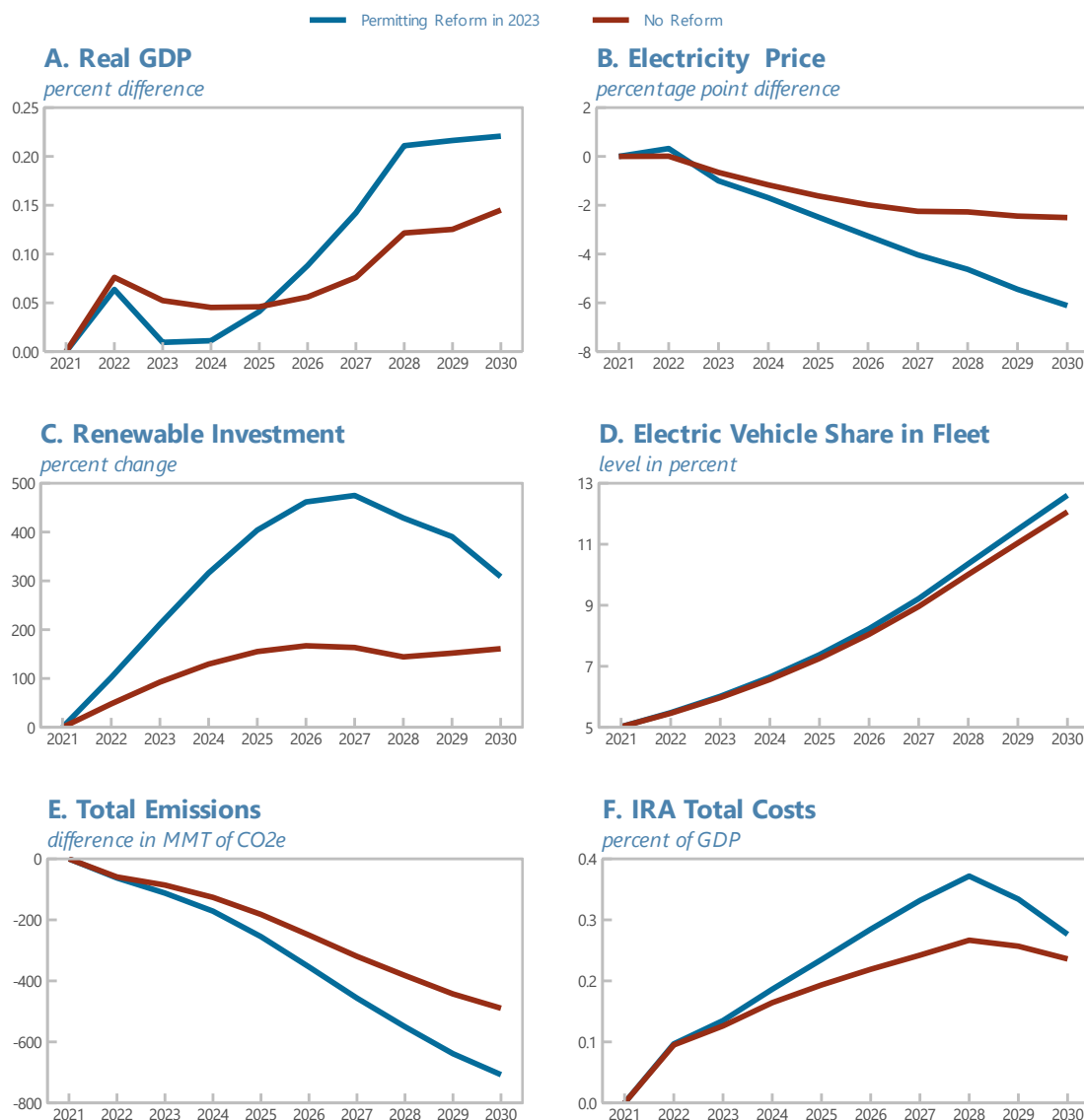


Exercise 2: Permitting delays, lump-sum funding

In contrast to Exercise 1, we now assume that delays in electricity investment (4.5 years on average) stay in place after 2023, i.e., there is no permitting reform. Red lines in Figure 4 depict the case when permitting delays remain in place, while blue lines duplicate, for comparison, Exercise 1, where they are assumed to be eliminated in 2023. With permitting delays, the investment surge in renewable generation is weaker and more gradual (Panel C). The addition of new generation capacity and the decline in the electricity price is muted (Panel B). This, in turn, results in a milder increase in output by 2030 (Panel A). EV pickup is less pronounced due to the smaller decline in electricity prices, but the effect is negligible since fuel costs only makes up a small share of an EV's lifetime user cost. More importantly, the delayed decarbonization of electricity generation dampens the emission reduction generated by the rising EV share. The fiscal costs (Panel F) are smaller as permitting delays constrain the take-up of uncapped power sector measures—not only for the investment

subsidy, but also, via the slowdown in the buildup of capacity, for the production tax credit. The overall reduction in 2030 annual emissions amounts to slightly over 500 MMT, which is roughly 2/3 of the IRA’s mitigation impact when a permitting reform takes place in 2023 (Panel E). This result emphasizes that overcoming real-world challenges such as delays in permitting projects is crucial to unlock the full potential of the IRA measures.

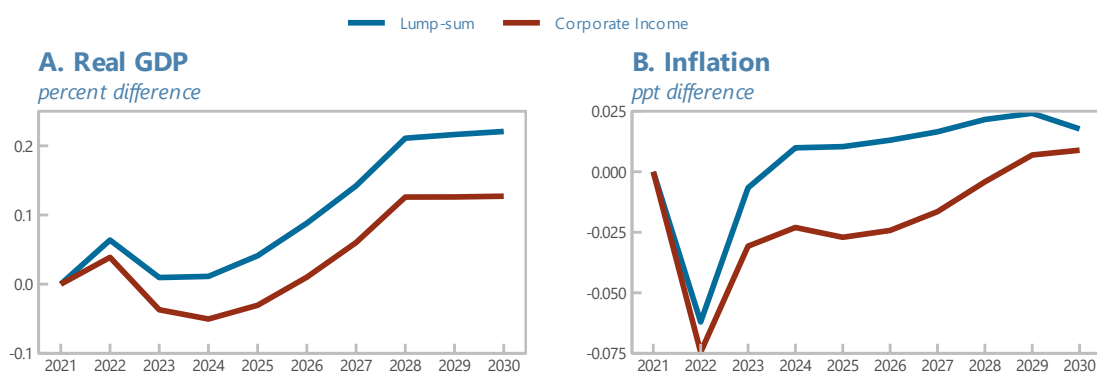
Figure 4. Exercise 2: Permitting delays and Lump-sum Funding



Exercise 3: No permitting delays, corporate income tax funding

In this exercise, energy-related permitting delays are eliminated in 2023 (as in Exercise 1), but the measures are funded by higher corporate income taxes instead of lump-sum taxes. As the funding assumption has negligible implications for the effectiveness of IRA measures itself, the focus is on the adjustment of GDP and inflation. Figure 5 shows that additional distortions induced by higher corporate income taxes (levied on firm profits) offset some of the increase in output from more abundant electricity (Panel A). However, the impact of the funding assumption remains modest in absolute terms, which carries over to a navigable difference in inflation adjustment between both scenarios (Panel B). The results suggest that, even when the funding side is modelled appropriately, climate-related IRA measures have a vanishingly small impact on output and inflation. In the remainder of this paper, our baseline corresponds to Exercise 3, which more closely proxies how IRA measures are financed.

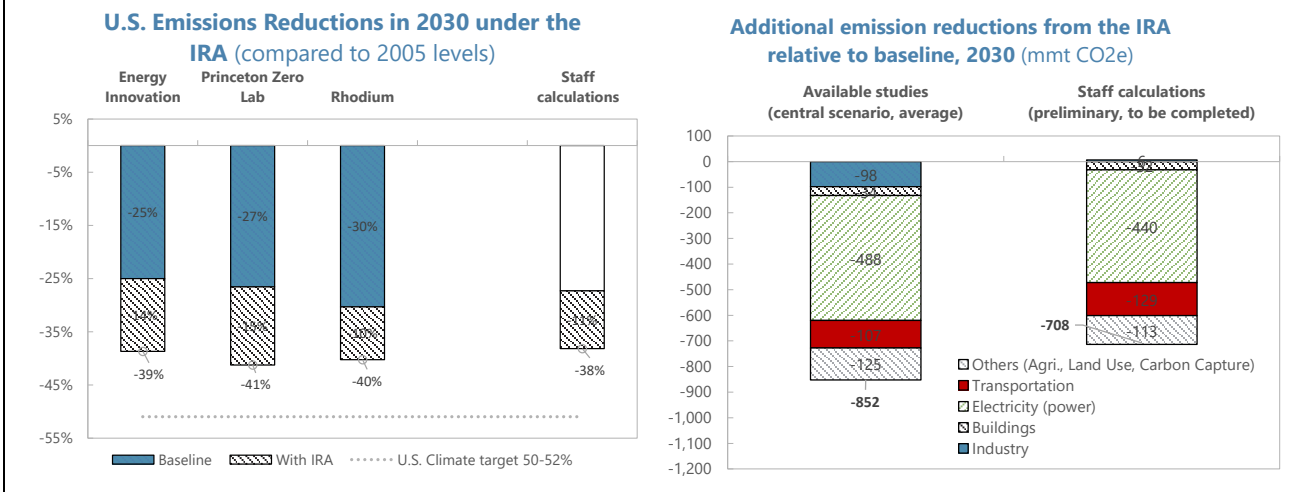
Figure 5. Exercise 3: The Role of Corporate Income Tax Financing



Box 2. IRA related emission cuts - Comparison with other studies

In the GMMET simulations, energy security and climate-related measures in the IRA cut emissions by an additional 11 percent of 2005 emissions by the end of the decade. When these IRA-induced cuts are added to other studies' estimates of the no-policy baseline, it would lead to a decline of around 38 percent of 2005 emissions by 2030. This is close to other estimates in the literature, documenting that the IRA would help emissions to decline by around 40 percent between 2005 and 2030.

Figure 6. Emission impact of the IRA Energy and Climate measures



IV. Beyond the IRA

This section discusses two measures that would allow the U.S. to get substantially closer to its goal of halving GHG emissions between 2005 and 2030. The purpose of this section is not to provide a conclusive list of measures to bridge the remaining post-IRA emission gap, but to highlight two areas of low-cost emission abatement that are not addressed by the IRA to a significant extent. The two measures detailed in the following are of regulatory nature and therefore do not add to the fiscal costs of the climate-related IRA measures. Both are aligned with the call from the U.S. and China, made ahead of the COP28 summit, to support accelerating “*the substitution for coal, oil and gas generation, and thereby anticipate post-peaking meaningful absolute power sector emission reduction, in this critical decade of the 2020s*”, and to make methane targets part of national climate plans (U.S. Department of State, 2023). More generally, the summit concluded with an agreement that calls on countries to transition away from fossil fuels in line with global climate goals, and to substantially reduce methane emissions by 2030 (although falling short of specifying an amount for these reductions, see MSCI, 2023).

- *Regulation to curb electricity generation from coal*

Coal is the most polluting fuel used for electricity generation, with emissions per generated kilowatt-hour more than twice as high as for gas. While the surge in renewable capacity induced by IRA subsidies leads to a crowding-out of coal generation, its share in the 2030 electricity mix is still estimated to be significant, at about 15 percent. One reason is that the IRA measures do not directly target the use of coal. This leaves ample scope for further emission reductions with limited macroeconomic costs due to the availability of cost-competitive alternatives to generate electricity. To study the impact of a coal-curbing regulation, we introduce a feebate-like tax on electricity from coal. Revenues from the tax are used to subsidize electricity generation from other technologies, shifting relative prices of the various technologies to the disadvantage of coal. When added to the IRA, the measure leads to a gradual decline in the electricity share of coal by about one percentage point per year.

- *Regulation to curb methane emissions from the oil and gas sector*

Production of oil and gas are themselves a highly significant emission source for methane, a highly potent GHG. In 2022, emissions from this source amounted to nearly 400 MMT of CO₂e (IEA, 2023).¹¹ According to the International Energy Agency, roughly three quarters of these emissions can be abated with currently available technologies at minimal costs—for about US\$7 and US\$5 per tCO₂e for gas and oil respectively (IEA, 2023).¹² It is instructive to express the costs of this feasible abatement as a share of the market value of total oil and gas annual output (using average prices from 2017 to 2021). For gas production, the IEA assesses that 180 MMT of CO₂e (about 73 percent of the sector’s total emission) can be abated for about 1.2 percent of the sector’s output value. For oil production, abating 121 MMT of CO₂e (about 76% of total emissions) is deemed feasible and would cost around 0.2% of output value. Despite low abatement costs and various pledges by the industry, actual reductions in methane emissions have been negligible relative to their potential. IRA includes provisions aimed at curbing emissions (the Methane Emissions Reduction Program, MERP), including an emissions charge that has the potential to make abatement economical for a wide set of producers. However, the likely effectiveness of the charge has been substantially weakened in the final draft of the legislation, as the scope of covered emissions is restricted by details in the legislation.

¹¹ There is a growing consensus that emissions were underestimated in previous studies (see, for example, Barkley et. al., 2021)

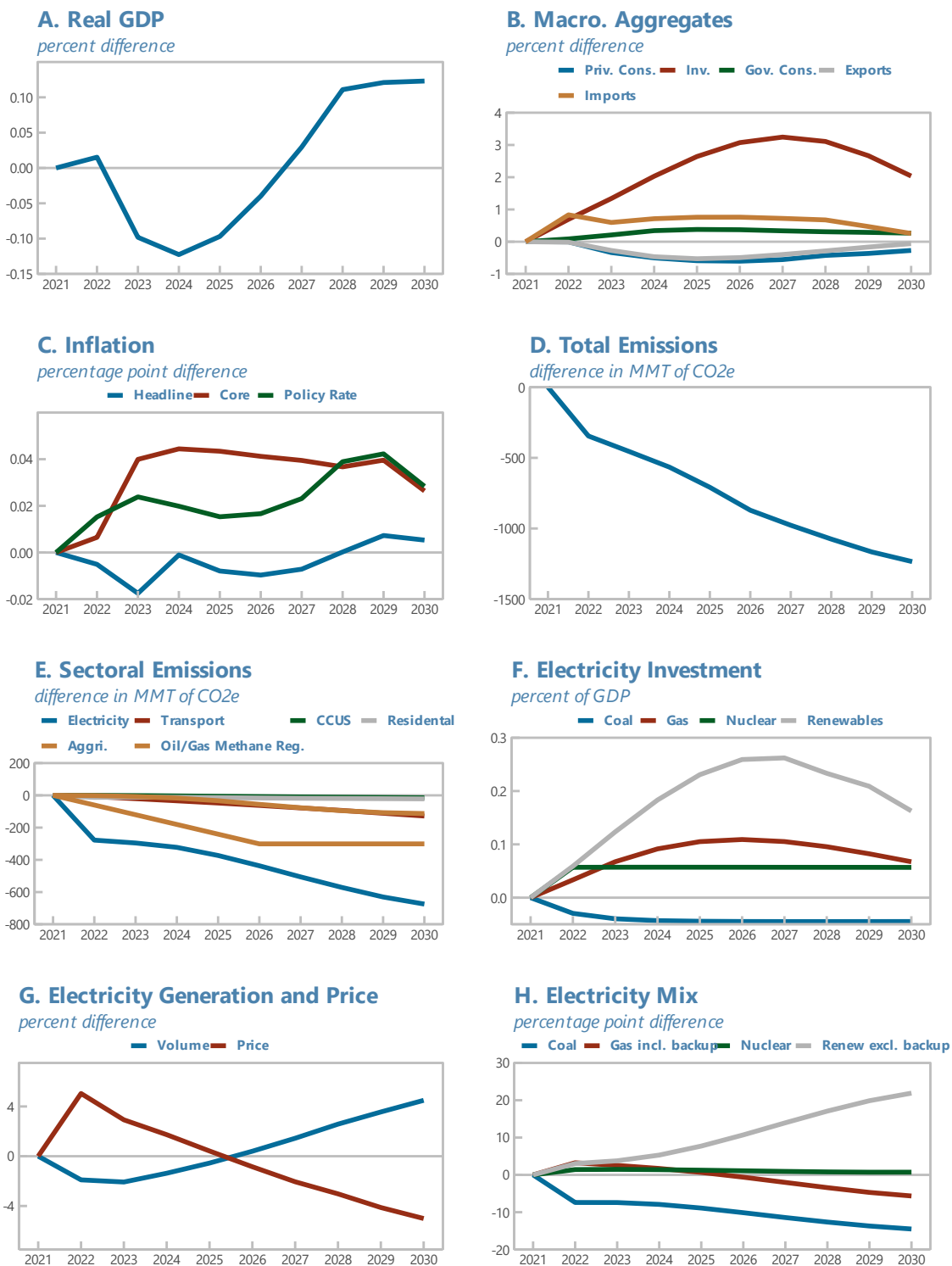
¹² Emissions can be abated, for example, by detecting and repairing leaks, by installing emission control devices, or replacing components that emit methane in their normal operations.

These details include high reporting thresholds (facilities with emissions below the threshold are not required to report them and are not charged), high emission thresholds (reporting facilities are exempt if emissions as a share of sales are below the threshold), and rules governing the aggregation of emissions across companies' various sites. While the measures' effectiveness is uncertain, we use the estimate by Energy Innovation (2022), who expect that the MERP will lead to an emission reduction by the end of the decade of 29 MMT CO₂e—just below 10 percent of the decline that the IEA deems possible with existing technologies at minimal costs.

We investigate a regulatory measure that leads oil and gas industries to abate the maximum that is deemed feasible with existing technologies, about $\frac{3}{4}$ of total emissions. The presence of oil and gas mining sectors in GMMET allows us to assess the impact of the adoption of abatement technologies by those industries. In particular, abatement costs from the IEA's 2023 Methane Tracker, expressed as a share of the respective sector's output value, are introduced as productivity decline of the specific sector. The purpose of this exercise is again to analyze macroeconomic implications rather than providing specifics on a potential regulation (see Parry et. al., 2022, for a discussion of policy options).

Figure 7 shows the impact of the IRA when it is complemented by the two regulatory measures mentioned above. It is assumed that energy-specific permitting delays are eliminated after 2023 and that IRA measures are funded by corporate income taxes (as in Exercise 3 above). As the productivity decline of oil and gas extraction from the methane regulation is negligible, there is no significant impact beyond the emission reduction itself (the measure is assumed to be fully phased-in by 2026, see Panel E). Relative to the standalone-IRA, the coal regulation further dampens investment in coal power plants and strengthens the rise in renewables and gas investment (Panel F). This is reflected in the electricity mix, with the share of coal declining by about 14 percentage points by 2030 (Panel H), as opposed to roughly 7 percentage points under the standalone-IRA. Regarding the volume of electricity generation and its price, the disinvestment from coal triggered by the regulation works in the opposite direction from IRA subsidies boosting renewable generation capacity. In the initial phase of the adjustment, the decline in coal generation dominates and causes the electricity generation volume to decline (respectively the price to go up), while the IRA-induced surge in capacity dominates from 2026 onwards, leading to a rise in the volume (and a decline in the price) by the end of the decade (Panel G). In the short term, this reduces output and pushes up inflation slightly but the impact on the macroeconomy is virtually unchanged (Panels A and C respectively). This is not surprising given that methane abatement comes at minimal cost and that the coal regulation lowers its electricity share very gradually. However, the additional regulatory measures matter greatly for total emissions, which would then be reduced by close to 1300 MMT in total, shrinking the post-IRA gap to the mitigation target to about 300 MMT (Panel D).

Figure 7: IRA with complementary regulatory measures



V. Conclusion

When implemented in GMMET, the climate-related IRA measures are effective at curbing GHG emissions, while their macroeconomic implications are of negligible magnitude, despite being funded by higher corporate income taxes. That is, output and inflation remain virtually unchanged, while emissions decline by about 720 MMT, mostly driven by an almost 20 percentage point rise in the share of renewables, combined with an increase in the electric vehicle sales share by close to 15 percentage points. The impact on output is minor because distortions from higher taxes are more than offset by the increase in the economy's productive capacity, resulting from the IRA-induced surge in electricity generation. The measures' total fiscal costs through 2030 are estimated at \$700 billion (another \$120 billion of direct spending is not modelled), which is only moderately above the recently updated CBO/JCT projection. While GMMET does not speak to the policy's welfare implications, a back-of-the-envelope calculation suggests that the fiscal costs per ton of mitigated GHG emission will decline below the social cost of carbon in nearly five years, suggesting that the climate-related measures are welfare-improving. The simulations also highlight the importance of cutting energy-related permitting delays. Permitting delays mitigate the surge in renewables generation capacity brought about by IRA subsidies. If these persisted until 2030, IRA-induced emission reduction would be roughly a third smaller.

While the IRA is an important step to close the U.S. implementation gap between GHG mitigation targets and tangible action, GMMET simulation suggest it will cover only roughly half of this gap by 2030. We have also used GMMET to assess two complementary regulatory measures. The first measure would force a gradual reduction in the use of coal in electricity generation by roughly 1 percent of the electricity mix per year. The second measure foresees the mitigation of the bulk of methane emissions from oil and gas production, which is estimated to be feasible with current technologies at minimal costs. These complementary regulatory measures could lead to sizable emission reductions—coming close to bridging the gap to the U.S. objective of halving GHG emissions between 2005 and 2030—at very low macroeconomic costs.

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