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A Replication of "The Macroeconomic Impact of Europe's Carbon Taxes" by Metcalf and Stock (2023)

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A Replication of "The Macroeconomic Impact of Europe's Carbon Taxes" by Metcalf and Stock (2023)*

Thomas Ash, Giorgi Nikolaishvili†

September 10, 2024

Abstract

Metcalf and Stock (2023) find that an increase in carbon tax has a weakly positive effect on output and employment, along with a negative effect on C02 emissions over a 6-year horizon. The paper identifies a carbon tax shock and uses it to quantify the effect of a permanent unexpected increase in the carbon tax rate. The effect of this increase is obtained using a policy counterfactual exercise based on dynamic effects estimated using panel local projections. We use the authors' own Stata replication package to reproduce the main results of the paper and carry out additional robustness tests. We also conduct these empirical analyses using popular open-source econometric libraries in R. We compare the original permanent carbon tax increase policy counterfactual impulse responses to standard one-time carbon tax shock impulse responses. The justification for this robustness test is that carbon tax rate changes are persistent, so that a transitory shock effectively mimics a permanent shock. We find that (1) the authors' replication package successfully reproduces the results of the paper; (2) alternative local projection specifications and policy counterfactuals largely exhibit the same qualitative properties as the main results of the paper.

KEYWORDS: carbon tax, policy counterfactual, panel local projection

JEL CODES: E23, E24, H23, Q54, Q58

*Ash: UCLA Anderson School of Management. E-mail: thomas.ash@anderson.ucla.edu. Nikolaishvili: Wake Forest University. E-mail: nikolag@wfu.edu. Our R code is publicly available via the following GitHub repository: https://github.com/gionikola/replication_macro-impact-euro-carbon-tax. The authors declare they have no conflicts of interest.

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1 Introduction

Metcalf and Stock (2023) find that an increase in carbon tax has a weakly positive (negative) effect on output (unemployment), as well as a negative effect on emissions. On pages 265-266, the authors state that "The paper estimates that carbon taxes have no adverse effects on GDP growth or employment. In fact, it finds that carbon taxes may have a zero to modestly positive effect on both indicators." On page 266, they also state that "A $40/ton CO2 tax covering 30% of emissions leads to a cumulative emissions reduction of 4 to 6%. The reductions are likely to be higher in a broad-based US carbon tax scenario." In this replication report, we attempt to reproduce these results using the paper's original empirical strategy, and test their robustness under varying model specification and methodological deviations.

Metcalf and Stock gather data on carbon taxation and macroeconomic variables in 31 European countries covering the years 1990 through 2018. Included countries are part of the EU-wide emissions trading system (EU-ETS), with 15 of them also imposing additional carbon taxes. The dataset contains information on real GDP (adjusted for inflation and exchange rates); employment (including total emplyment and manufacturing employment), CO2 emissions from fuel combustion in key sectors like transportation, commercial buildings, and households; and carbon tax rate variations over time and across countries, reflecting differences in tax levels and coverage. Sources for the above data include the World Bank, EU Eurostat database, and other country-specific statistical agencies.

The paper identifies a carbon tax shock for each country as the component of country-level carbon tax series that is unpredicted by past carbon tax rates and macroeconomic conditions. In other words, the carbon tax shock series for each country is the residual from projecting carbon tax series onto lags of itself and a standard set of country-specific macroeconomic series. The shock is used in panel local projections models to estimate the dynamic response of

output, unemployment, and CO2 emissions to a permanent unexpected increase in carbon tax. The permanent increase in carbon tax is simulated using the policy counterfactual approach developed by Sims and Zha (2006), in which a sequence of carbon tax shocks is simulated to keep the carbon tax constant after the occurrence of the initial exogenous change.

In this report prepared for the Institute for Replication (Brodeur et al. 2024), we have been successful in reproducing the main results of the paper using the authors' Stata replication package. However, we note that there are *minor* quantitative differences in both point estimates and confidence intervals between those in our reproduction and those in the paper, across the board. We have not been able to diagnose the cause of these deviations, but would like to stress that they are negligible. We also attempt to reproduce the main point estimates of the paper using custom R routines built on open-source econometric and statistical libraries (Adämmer 2019, Croissant and Millo 2008, 2018). We find that some of the counterfactual policy impulse response function (IRF) point estimates do not match those of the paper. In certain cases, there are slight numerical deviations in point estimates, whereas some cases exhibit inverted signs and incomparable magnitudes. Given that we use the same data in our R routines as the authors do in their Stata replication package, the differences in results must stem from the coding of panel local projection estimation procedures by Metcalf and Stock versus Adämmer. We do not pinpoint precise deviations between these two codebases. However, we note that the qualitative conclusions of Metcalf and Stock continue to hold, even if the precise estimates differ. The above-mentioned reproduction results and a brief description of the Sims-Zha policy counterfactual methodology is presented in Section 2 of this report.

In addition to a direct reproduction of the paper's main results, we carry out the following robustness tests using both the authors' replication package and our own R routines:

1. Modification: Add C02 emissions controls to the baseline panel local

projection (LP) specification. Software: Stata. Finding: A permanent increase in carbon tax is estimated to have a consistently negative impact on output, although none of the point estimates are individually statistically significant. Jointly however, a test of whether the IRF for GDP of the carbon tax change is different from 0 can no longer be rejected. This may be because there is some correlation between emissions, the carbon tax and GDP that masks some small negative impact of carbon taxes on GDP. More testing might be useful here, though the negative effect is small and insignificant, and so does not strongly contradict the authors' conclusions;

2. Modification: Remove time fixed effects from the baseline panel LP specification. Software: Stata. Finding: No consistent/notable deviation from the original results;

3. Modification: Estimate the effects of a 2-year carbon tax increase instead of a permanent one. Software: Stata. Finding: No consistent/notable deviation from the original results;

4. Modification: Estimate the effects of a 1-year carbon tax increase instead of a permanent one. Software: R. Finding: No consistent/notable deviation from the original results.

The results for the above-mentioned robustness tests can be found in Section 3 of this report.

2 Reproduction

We start this section with a brief overview of the Sims and Zha (2006) policy counterfactual methodology that Metcalf and Stock (2023) use to estimate the dynamic effect of a permanent exogenous carbon tax increase. We then present some of the main results of the paper obtained by running routines provided in the authors' own Stata replication package. Finally, we reproduce the main analysis of the paper in R with custom routines using the same data as the authors'.

2.1 Policy Counterfactual Methodology

The paper estimates the following lag-augmented panel LP with year- and country-fixed effects:

$$100 * \Delta \log(GDP_{it+h}) = \alpha_{1,i} + \theta_{1,h}\tau_{it} + \beta_1(L)\tau_{it-1} + \delta_1(L)\Delta X_{1,it-1} + \gamma_{1,t} + u_{1,it}\,, \tag{1}$$

where τ_{it} is the carbon tax for country i at time t, L is the lag operator, $X_{m,it-1}$ is a vector of controls, h is the impact horizon, and $\gamma_{m,t}$ and $\alpha_{m,i}$ are time- and country-fixed effects. The coefficient of interest is $\theta_{1,h}$, which represents the h-period ahead effect on GDP of an "unexpected" change in tax policy. The model is estimated using least squares. Standard errors are heteroskedasticity-consistent (HC), since according to Montiel Olea and Plagborg-Møller (2021) heteroskedasticity- and autocorrelation-consistent (HAC) standard errors are unnecessary in the case of lag-augmented local projections specification in a wide variety of cases. Other specifications of this LP use employment and C02 emissions as the response variable.

For the purposes of the policy counterfactual, the paper also estimates the following panel LP:

$$\tau_{it+h} = \alpha_{2,i} + \theta_{2,h}\tau_{it} + \beta_2(L)\tau_{it-1} + \Psi_h(100 * \Delta \log(GDP_{it-1})) + \delta_2(L)\Delta X_{2,it-1} + \gamma_{2,t} + u_{2,it}\,. \tag{2}$$

This estimation deals with the issue of simultaneity between GDP and τ since $\theta_{1,h}, \theta_{2,h}$ are formally equivalent to reduced-form coefficients in a VAR system (Jordà (2023)) i.e.:

$$\begin{pmatrix} GDP_{i,t} \\ \tau_{i,t} \\ ... \end{pmatrix} = A \begin{pmatrix} GDP_{i,t-1} \\ \tau_{i,t-1} \\ ... \end{pmatrix} + \epsilon_{\mathbf{i,t}} \tag{3}$$

Further the Local Projection method allows for the addition of a range of extra controls $X_{m,it-1}$ to assist with identification, without having to estimate a large VAR model.

The treatment coefficients, $\theta_{2,h}$, represent the effect of carbon tax ($\tau_{i,t}$) on the future carbon tax. The portion of the effect that can be predicted by past values of other macroeconomic variable such as GDP, employment and manufacturing employment (included in the control vector) is partialed out. This LP is also estimated using least squares with HC standard errors.

Finally, the paper carries out a counterfactual exercise in the spirit of Sims and Zha (2006). The authors use the parameter estimates obtained using the LPs in Eqs. (1) and (2) to construct a sequence of carbon tax shocks that would equate to a permanent \$40 carbon tax increase for the entire impulse horizon (6 years) applied to 30% of a given country's emissions. Algebraically, this involves solving for a shock vector Γ, so that that:

$$\Theta_2 \Gamma = \begin{pmatrix} 40 * 0.3 \\ ... \\ 40 * 0.3 \end{pmatrix} \quad \Leftrightarrow \quad \Gamma = \Theta_2^{-1} \begin{pmatrix} 40 * 0.3 \\ ... \\ 40 * 0.3 \end{pmatrix}, \tag{4}$$

where

$$\Theta_2 \equiv \begin{pmatrix} \theta_{2,1} & 0 & ... & 0 \\ \theta_{2,2} & \theta_{2,1} & ... & 0 \\ ... & ... & ... & ... \\ \theta_{2,h} & \theta_{2,h-1} & ... & \theta_{2,1} \end{pmatrix}. \tag{5}$$

Γ is a $h \times 1$ vector containing the sequence of shocks for a policy counterfactual of imposing a 40 carbon tax applied to 30% of emissions. The $h \times h$ matrix Θ_2 is arranged such that one period after the initial policy shock, $\theta_{2,1}\Gamma_1 = 40(0.3)$, two periods after the initial shock $\theta_{2,2}\Gamma_1 + \theta_{2,1}\Gamma_2 = 40(0.3)$ and so on. This ensures that in each period the carbon tax remains at \$40 applied to 30% of emissions. The following yields the policy counterfactual IRFs of GDP:

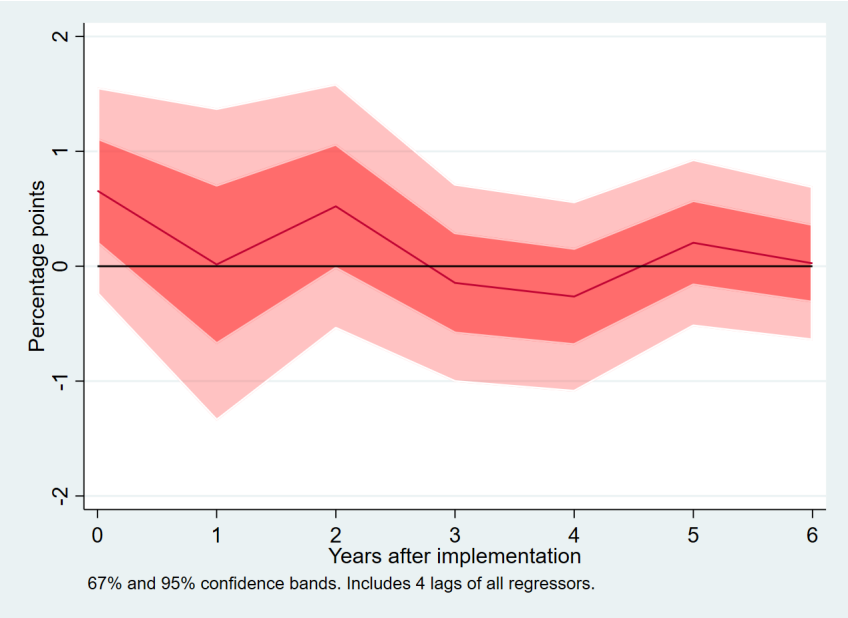
$$IR(h) = \Gamma^h \theta_1 \,, \tag{6}$$

where θ_1 is the vector of coefficients $\theta_{1,h}$. The paper uses the same approach to determine the impact of a permanent increase in carbon tax on employment and emissions.

2.2 Reproduction Using Authors' Stata Replication Package

We run the Stata routines provided by the authors in their replication package to reproduce the main results of the paper. The replication package is complete – it includes all relevant raw data, routines used to import and clean the data, as well as routines that carry out the empirical analyses presented in the paper and generate the corresponding figures. The qualitative takeaways from these reproductions match those of the paper, but there are quantitative discrepancies. Figure 1 below shows the effect of a permanent carbon tax increase on GDP – a reproduction of Figure 3A from the original paper using the authors' own replication package. Notice that, for example, the one-period-ahead response point estimate in the below figure is positive, whereas the same point estimate in Metcalf and Stock (2023) is clearly negative. Both of these point estimates are insignificant, however, and the shape of the full IRF generally matches that of the paper – therefore, the scientific takeaways are unchanged.

Figure 1: A direct reproduction of Figure 3 Panel A



Notes: Quantitatively different results from Figure 3 Panel A in the paper, but qualitative takeaways are the same

2.3 Reproduction Using R

As an indirect check on the authors' application of the paper's methodology, we replicate the study using R. We use popular open source R packages to estimate panel local projections with HC standard errors. Specifically, we use the R package **lpirfs** (Adämmer 2019) to estimate panel LPs, which is based on the panel linear model infrastructure provided by the **plm** package (Croissant and Millo 2008, 2018).

We present the following reproductions:

1. **Figure A.1:** Effect of a one-time change in the carbon tax rate on the future path of the carbon tax rate (a reproduction of Panels A and B of Figure A4 in the paper, respectively);

2. **Figures A.2 and A.3:** Effect of a permanent exogenous increase in carbon tax on GDP (a reproduction of Panels A and B of Figure 3 in the paper, respectively);

3. **Figures A.4 and A.5:** Effect of a permanent exogenous increase in carbon tax on total employment (a reproduction of Panels A and B of Figure 6 in the

paper, respectively);

4. **Figure A.6 and A.7:** Effect of a permanent exogenous increase in carbon tax on manufacturing employment (a reproduction of Panels A and B of Figure 8 in the paper, respectively);

5. **Figure A.8 and A.9:** Effect of a permanent exogenous increase in carbon tax on covered sector emissions (a reproduction of Panels A and B of Figure 10 in the paper, respectively).

All estimates are obtained using the same data provided in the replication package of the original paper, and using the same LP specifications. Yet, many of the above counterfactual policy IRF point estimates do not match those of the paper quantitatively. In virtually all of these cases, the differences are minor (slight numerical deviations). The qualitative takeaways, signs, and magnitudes are generally matching and/or comparable.

3 Robustness Tests

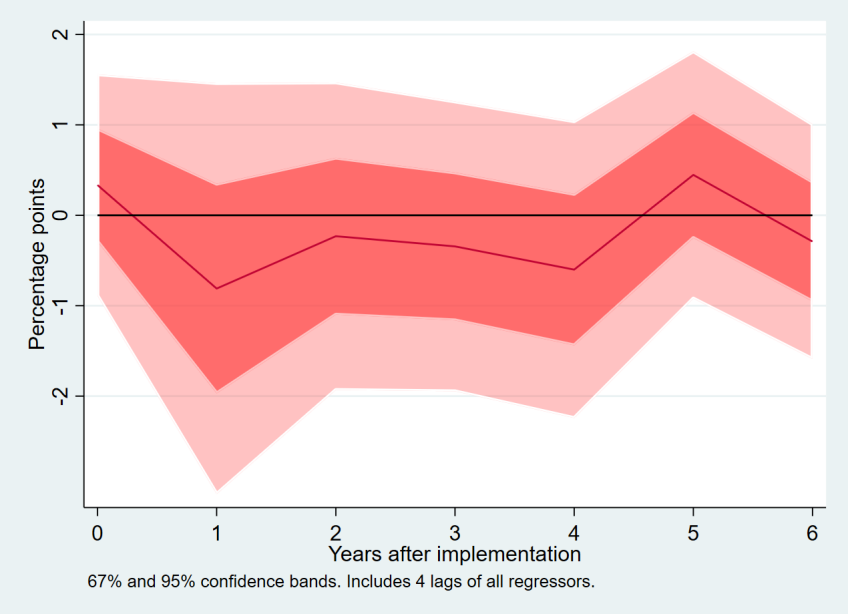
In this section, we conduct a series of robustness tests to the authors' results. In general we do not find large issues with the authors' main results from these tests. The only exception is with the addition of emissions to the set of control variables, which appears to show a consistent, negative impact of carbon taxes on GDP when this is accounted for. This may suggest that some correlation between the carbon tax and lagged emissions may be offsetting the true negative impact of the carbon tax – emissions and GDP are known to be positively correlated since more emissions are created in the production of economic output. However, we note that the authors cite some evidence that emissions do not drive carbon tax policy.

3.1 Emissions controls

In the authors' main specification, emissions controls are not included (for example in their Figure 3, panel A). We test the sensitivity of results to this assumption

in Figure 2 below. The Figure shows a fairly consistent negative impact of the carbon tax on GDP, despite no single point estimate being statistically significant. These results suggest that when emissions are not included in the LP, the carbon tax effect is biased upward towards 0. A possible reason for this is that higher emissions have induced countries to introduce or raise carbon taxes, and emissions themselves are positively related to GDP. This could result in the described upward bias, however more work would need to be done to determine if this is indeed true. In particular since the authors cite evidence that emissions outcomes do not typically affect carbon tax policy – of course this could be a short-term conclusion, with results here suggesting there is some medium-term relationship.

Figure 2: Use of emissions as control variable



Notes: Fig3, panel A of main paper but with lagged emissions included in set of controls.

Below we also include the authors' test of whether the IRF is equal to 0 for their main results versus for the robustness. Notice that the null hypothesis is no longer rejected when emissions are included in the LP specification as controls.

	Main result	Emissions control
test stat	31.7624	12.99346
chi-val	3.529156	1.443718
p-value	.0002189	.1629023

3.2 Removing time fixed effects

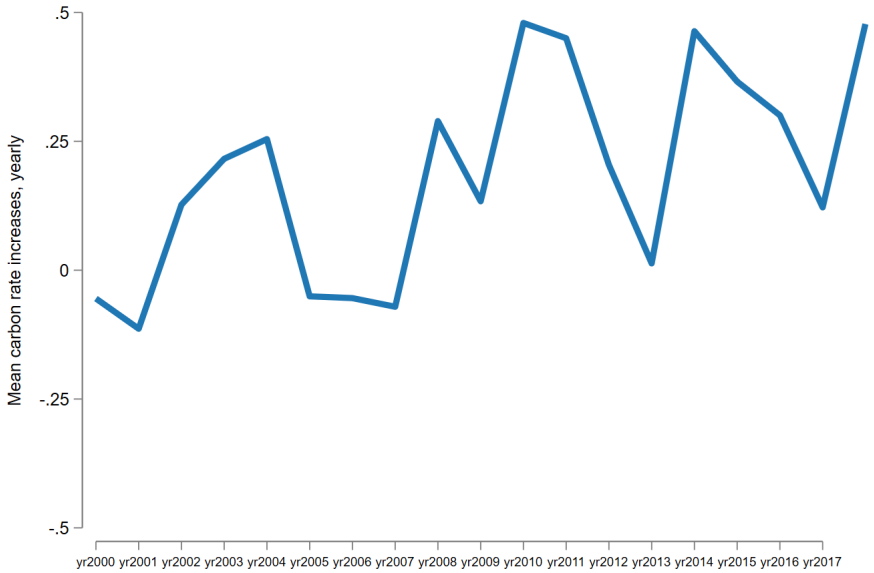
The authors include time fixed effects in their main specification and justify this on the basis that all panel countries are European and so may share common political trends, as well as the impact of common economic events such as the Great Recession in 2008/09. It is also possible that including time fixed effects over-parameterizes the model and absorbs some of the variation that is truly related to the carbon tax – this could particularly be true if many countries adopt carbon taxes in the same year since time fixed effects are common across countries. Indeed, Figure 3 below shows that there are some years with much higher than typical carbon tax increases suggesting there is some clustering across countries on dates that carbon taxes increase:

Figure 4 below shows the results when removing time fixed effects. We conclude that the authors' conclusions are robust to removing time-fixed effects.

3.3 2-year tax shock counterfactual

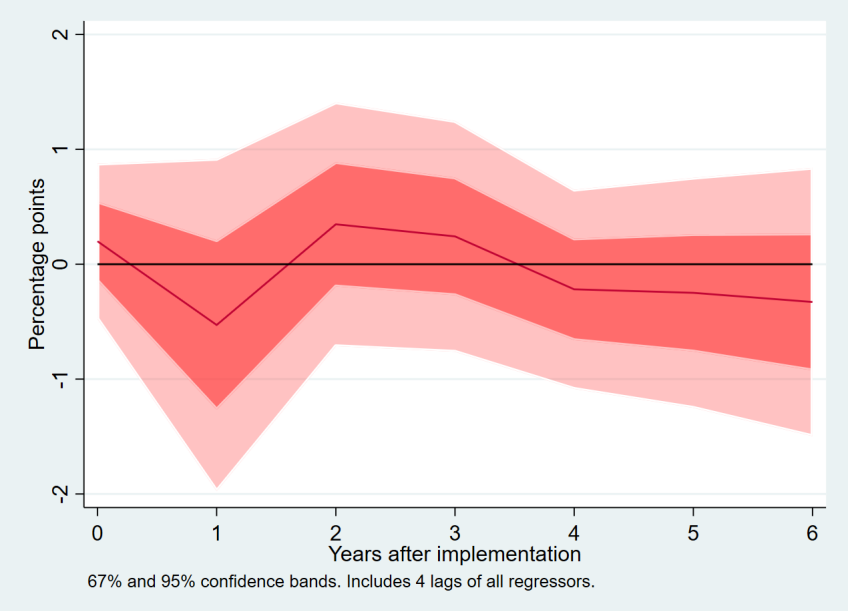
The paper's main policy counterfactual simulates an increase in the carbon tax for the whole horizon of $40 applied to 30% of a country's emissions. We use the authors' methodology but instead for a 2-year carbon tax increase, which is then removed (i.e. a 0 carbon tax thereafter). Figure 5 below shows the result of this alternative policy counterfactual simulation. Generally, the test does not show a strong contradiction of the authors' methodology. Based on the paper's results, we would expect the imposition of the carbon tax to have no effect on GDP, and similarly the withdrawal of the tax would have no effect. Indeed this is mostly true in the Figure. We note that year 4 shows a statistically significant negative impact

Figure 3: Mean tax increases by year



Notes: For share-weighted carbon tax increases averaged across all countries, plot yearly first differences. Chart shows several years exhibit by far the largest increases suggesting that many countries increased their carbon taxes in those years specifically.

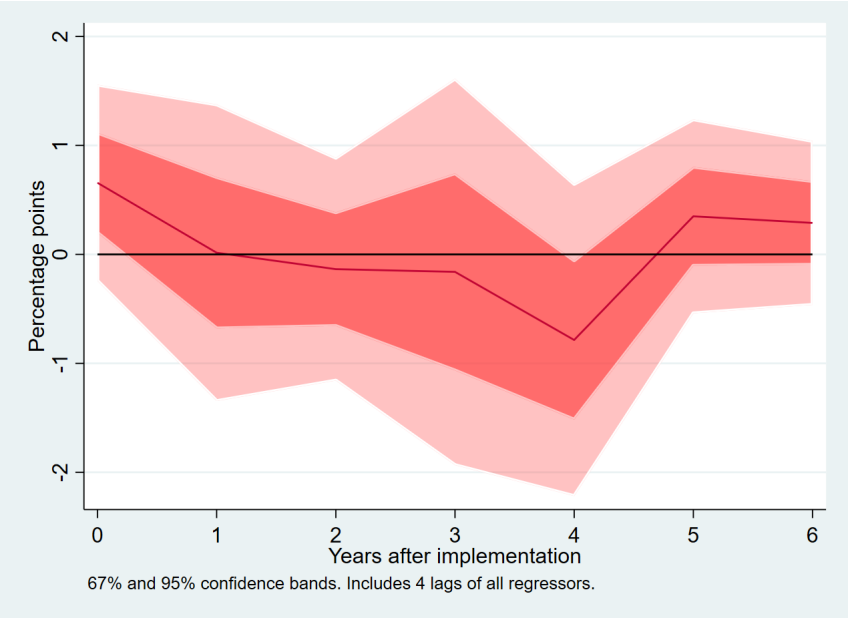
Figure 4: Removing time fixed effects



Notes: Fig3, panel A of main paper but without time fixed effects included in the model.

on GDP, which is unintuitive.

Figure 5: IRF of two-year carbon tax increase



Notes: Fig3, panel A of main paper but with two year $40 carbon tax counterfactual instead of permanent $40.

3.4 Transitory shock

A look at Figure A4 in the original paper and our reproduction in Figure A.1 shows that a one-time unit increase in the carbon tax is essentially permanent. This is intuitive, since the data shows that increases in the carbon tax are rarely reversed in the sample. Therefore, it is unclear whether a policy counterfactual exercise that precisely enforces a permanent increase in the carbon tax is even necessary. Given that the impulse response of the carbon tax after a one-time unit increase hovers around zero with a small magnitude, it is possible that these point estimates are noise-driven. With this motivation, we check the robustness of the paper's main results by estimating standard impulse responses that track the dynamic effects of a one-time unit increase in the carbon tax.

We present the following replications:

1. **Figures B.2 and B.1:** Effect of a one-time exogenous increase in carbon tax on GDP (an alternative replication of Panels A and B of Figure 3 in the paper, respectively);

2. **Figures B.4 and B.3:** Effect of a one-time exogenous increase in carbon tax on total employment (an alternative replication of Panels A and B of Figure 6 in the paper, respectively);

3. **Figure B.6 and B.5:** Effect of a one-time exogenous increase in carbon tax on manufacturing employment (an alternative replication of Panels A and B of Figure 8 in the paper, respectively);

4. **Figure B.8 and B.7:** Effect of a one-time exogenous increase in carbon tax on covered sector emissions (an alternative replication of Panels A and B of Figure 10 in the paper, respectively).

Although the standard IRFs deviate slightly from their corresponding policy counterfactual IRFs across the board, they exhibit all of the same qualitative properties. Therefore, we conclude that the authors' results are robust to this alternative methodology.

4 Conclusion

In this replication report, we find that Metcalf and Stock (2023) is reproducible using the authors' own replication package, as well as using custom-written routines following the paper's methodology, with only minor quantitative discrepancies in the estimates across both reproductions. Furthermore, we find that the main results of the paper are robust to (1) controlling for lagged emissions in the baseline local projections, (2) removing time-fixed effects from the LP specifications, and (3) alternative policy counterfactuals with transitive increases in carbon tax.

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Appendix

A Permanent Shock IRF Point Estimates

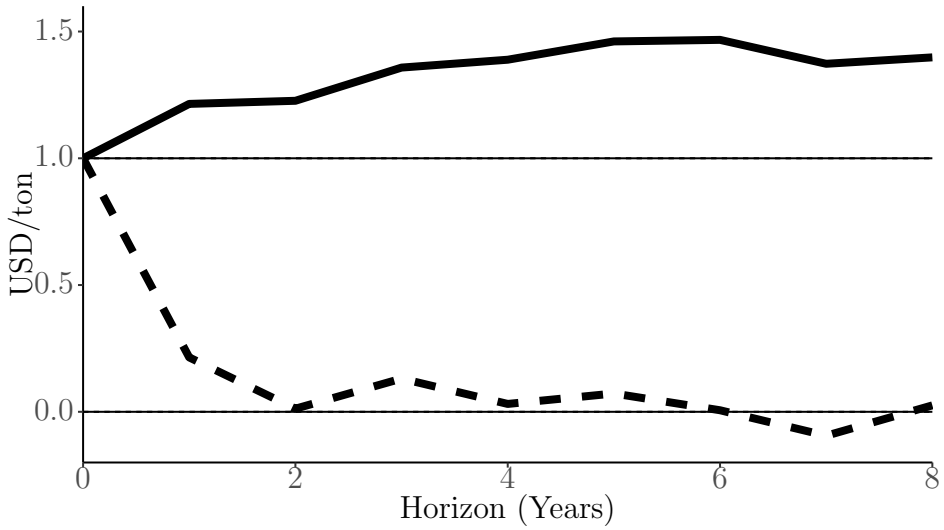

Figure A.1: The cumulative (solid line) and non-cumulative (dashed line) response of the carbon tax rate to a one-time unit shock to the carbon tax rate.

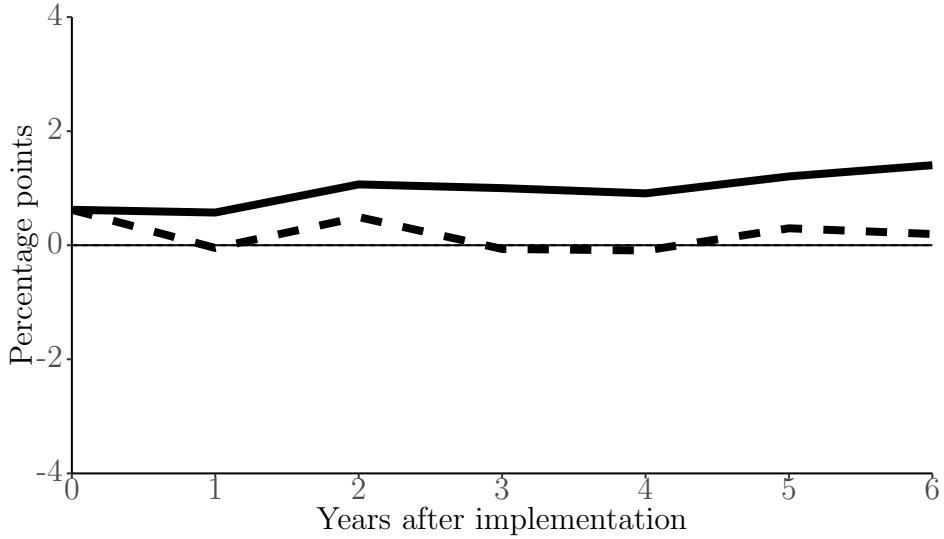

Figure A.2: Point estimates of the cumulative (solid line) and non-cumulative (dashed line) response of GDP growth to a permanent increase in the carbon tax rate based on the *unrestricted* linear local projections model.

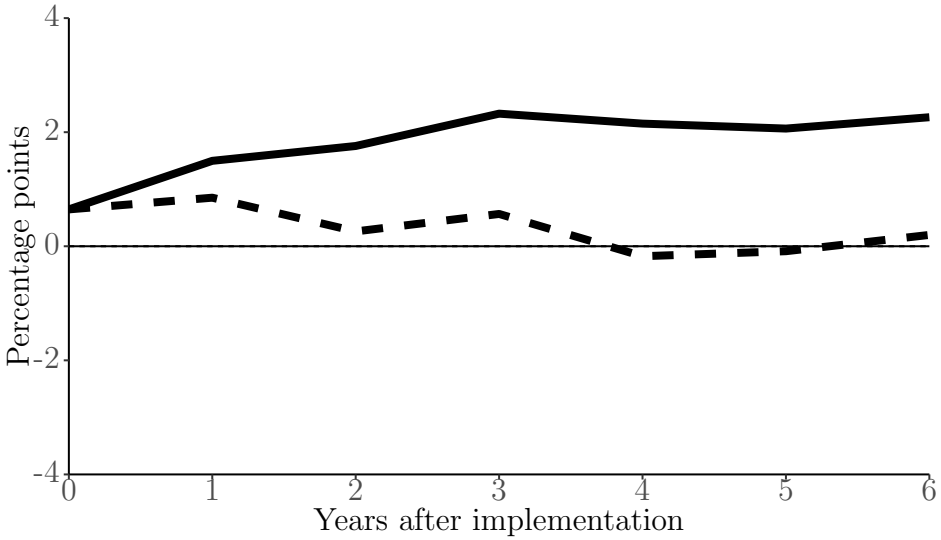

Figure A.3: Point estimates of the cumulative (solid line) and non-cumulative (dashed line) response of GDP growth to a permanent increase in the carbon tax rate based on the *restricted* linear local projections model.

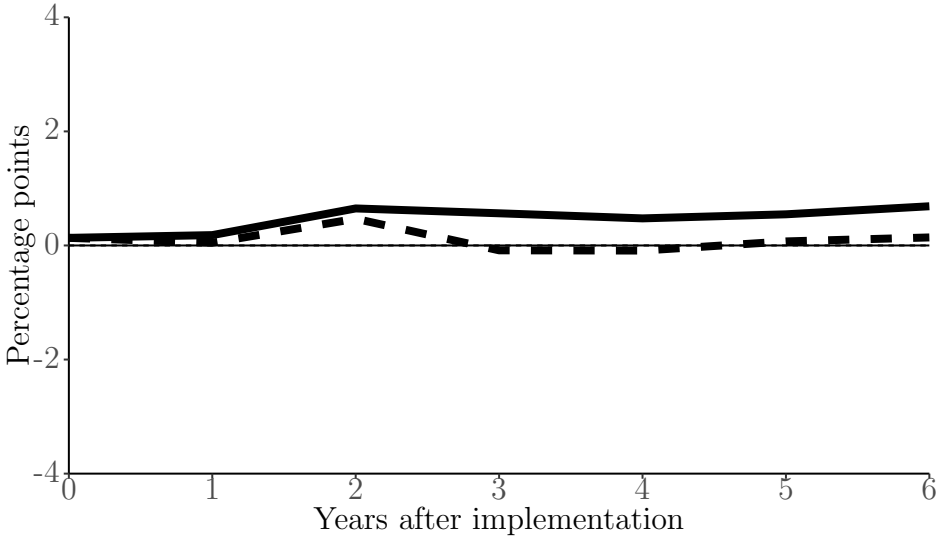

Figure A.4: Point estimates of the cumulative (solid line) and non-cumulative (dashed line) response of total employment growth to a permanent increase in the carbon tax rate based on the *unrestricted* linear local projections model.

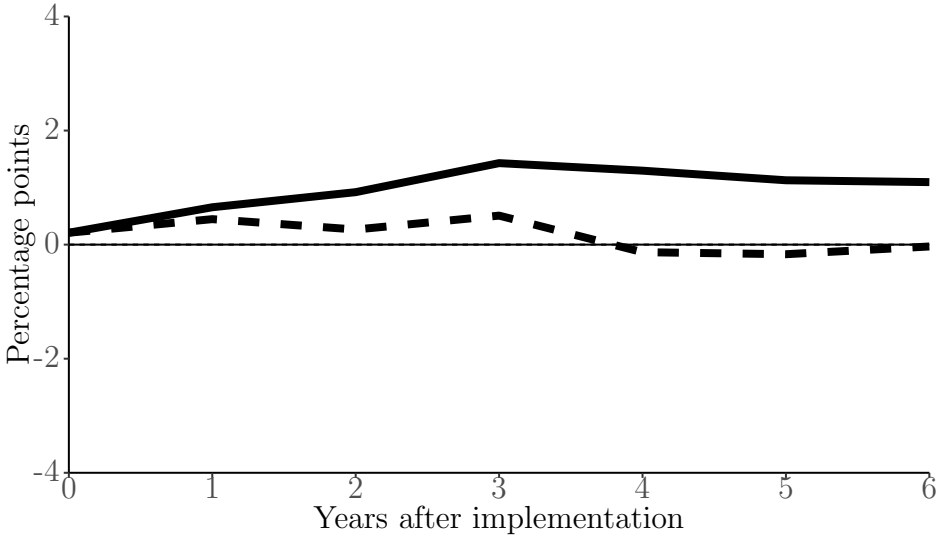

Figure A.5: Point estimates of the cumulative (solid line) and non-cumulative (dashed line) response of total employment growth to a permanent increase in the carbon tax rate based on the *restricted* linear local projections model.

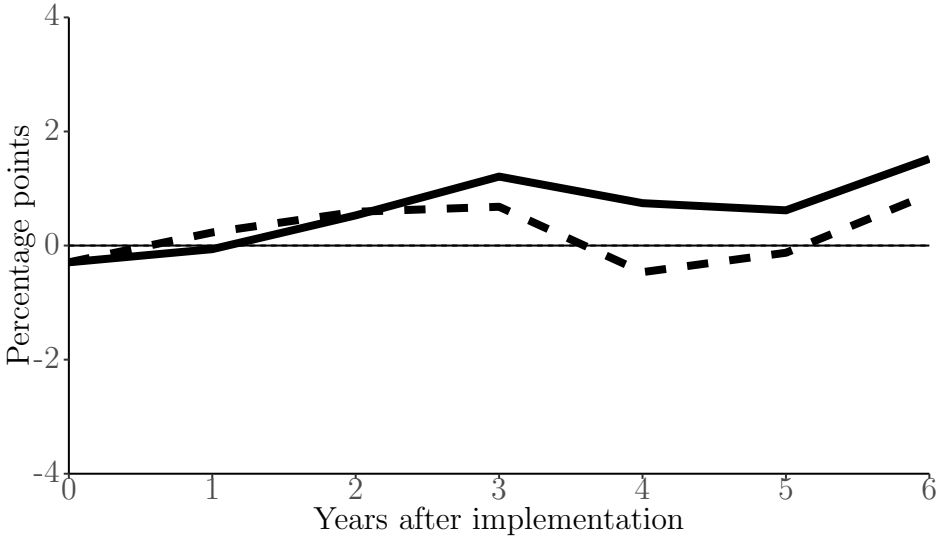

Figure A.6: Point estimates of the cumulative (solid line) and non-cumulative (dashed line) response of manufacturing employment growth to a permanent increase in the carbon tax rate based on the *unrestricted* linear local projections model.

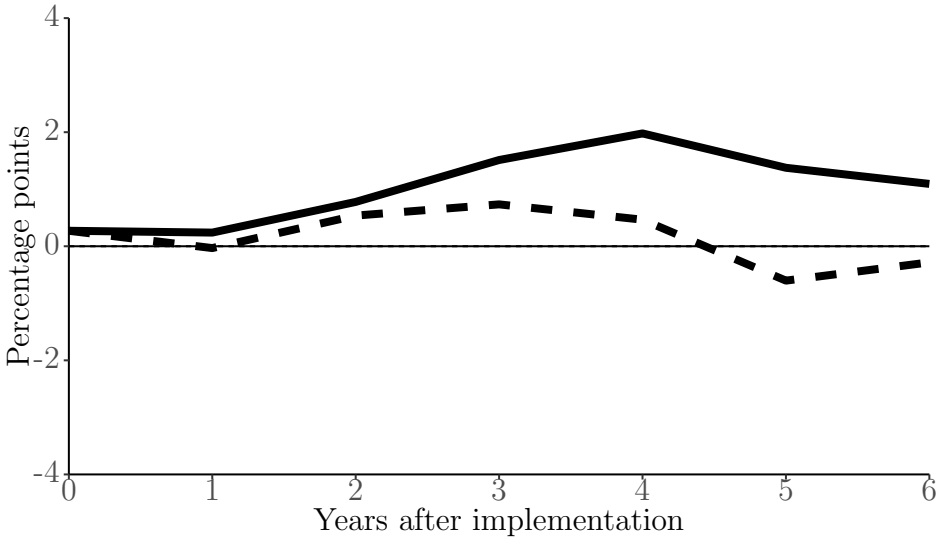

Figure A.7: Point estimates of the cumulative (solid line) and non-cumulative (dashed line) response of manufacturing employment growth to a permanent increase in the carbon tax rate based on the *restricted* linear local projections model.

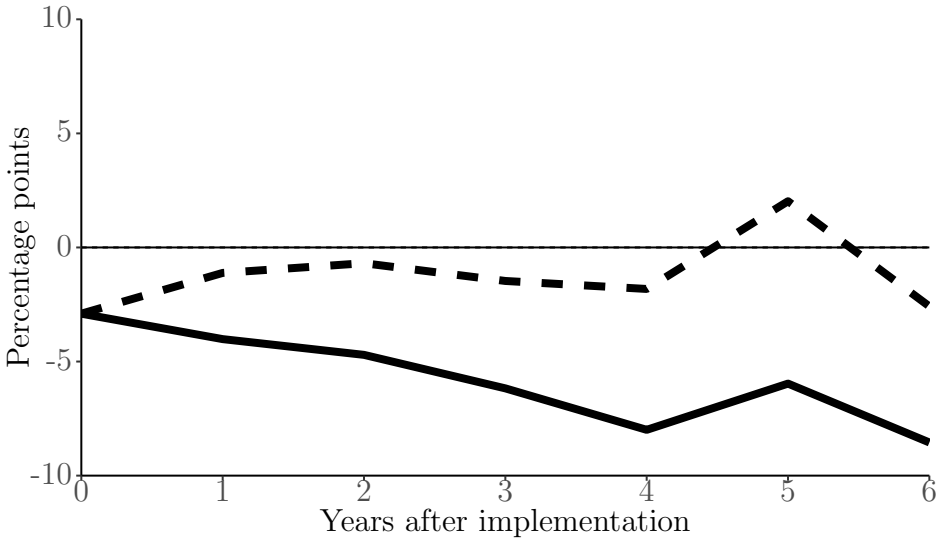

Figure A.8: Point estimates of the cumulative (solid line) and non-cumulative (dashed line) response of covered sector emissions growth to a permanent increase in the carbon tax rate based on the *unrestricted* linear local projections model.

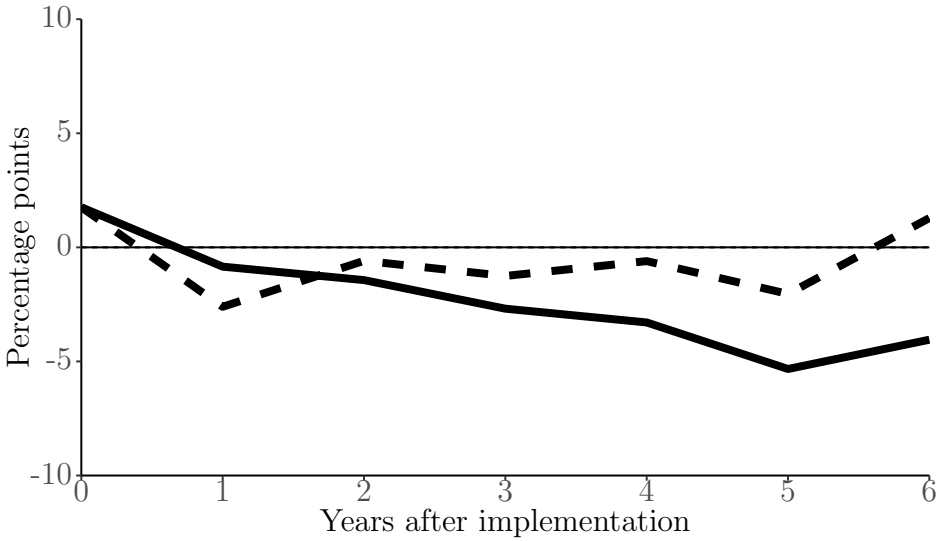

Figure A.9: Point estimates of the cumulative (solid line) and non-cumulative (dashed line) response of covered sector emissions growth to a permanent increase in the carbon tax rate based on the *restricted* linear local projections model.

B Temporary Shock IRF Estimates

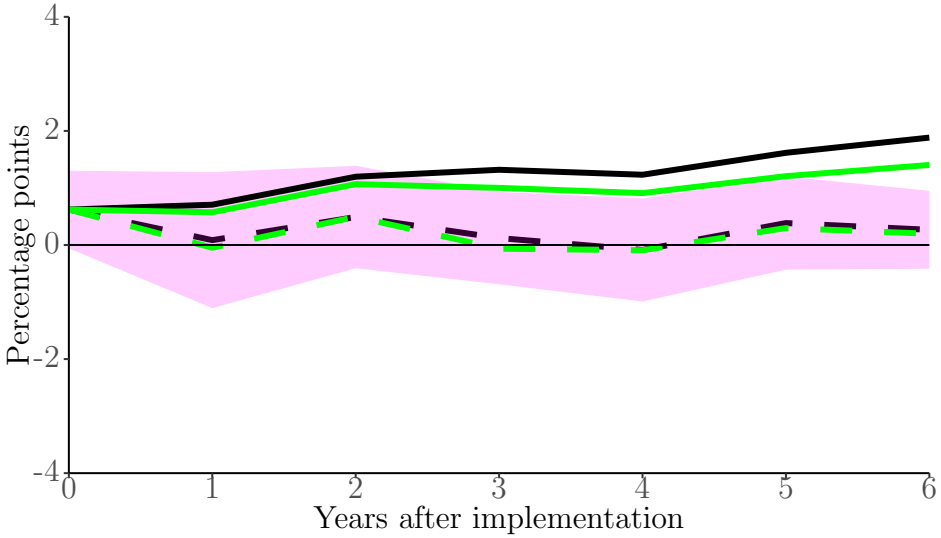

Figure B.1: Dashed black line and magenta bands: Point estimates for the response of GDP growth to a one-time carbon tax shock, along with their corresponding 95% HC confidence intervals. Solid black line: Implied cumulative response of GDP to a one-time carbon tax shock. Dashed green line: Point estimates for the response of GDP growth to a permanent increase in carbon tax. Solid green line: Implied cumulative response of GDP to a permanent carbon tax shock. Estimates are generated using the "unrestricted" specification.

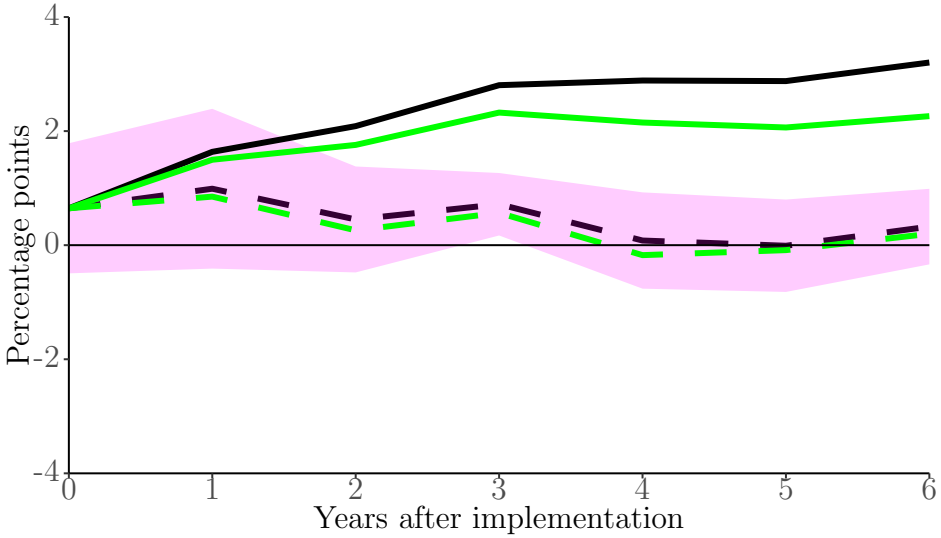

Figure B.2: Dashed black line and magenta bands: Point estimates for the response of GDP growth to a one-time carbon tax shock, along with their corresponding 95% HC confidence intervals. Solid black line: Implied cumulative response of GDP to a one-time carbon tax shock. Dashed green line: Point estimates for the response of GDP growth to a permanent increase in carbon tax. Solid green line: Implied cumulative response of GDP to a permanent carbon tax shock. Estimates are generated using the "restricted" specification.

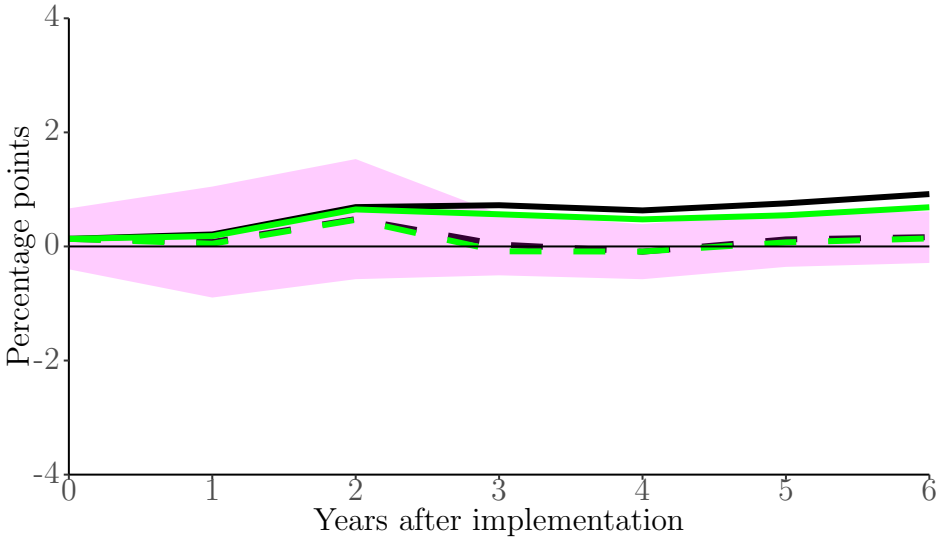

Figure B.3: Dashed black line and magenta bands: Point estimates for the response of total employment growth to a one-time carbon tax shock, along with their corresponding 95% HC confidence intervals. Solid black line: Implied cumulative response of total employment to a one-time carbon tax shock. Dashed green line: Point estimates for the response of total employment growth to a permanent increase in carbon tax. Solid green line: Implied cumulative response of total employment to a permanent carbon tax shock. Estimates are generated using the "unrestricted" specification.

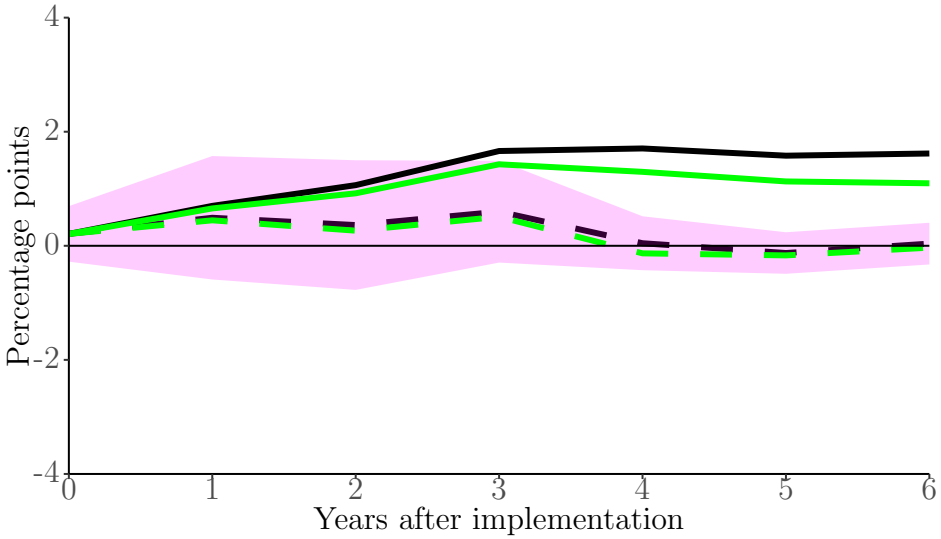

Figure B.4: Dashed black line and magenta bands: Point estimates for the response of total employment growth to a one-time carbon tax shock, along with their corresponding 95% HC confidence intervals. Solid black line: Implied cumulative response of total employment to a one-time carbon tax shock. Dashed green line: Point estimates for the response of total employment growth to a permanent increase in carbon tax. Solid green line: Implied cumulative response of total employment to a permanent carbon tax shock. Estimates are generated using the "unrestricted" specification.

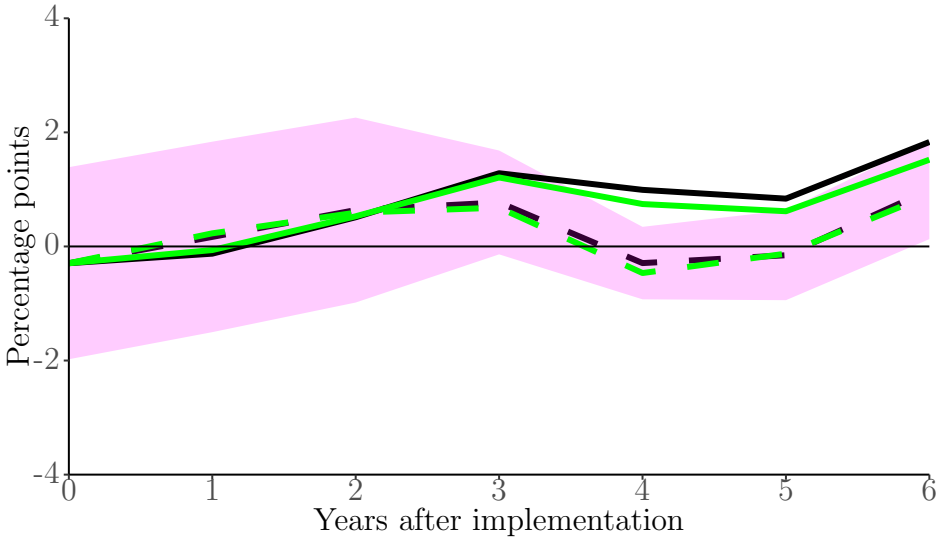

Figure B.5: Dashed black line and magenta bands: Point estimates for the response of manufacturing employment growth to a one-time carbon tax shock, along with their corresponding 95% HC confidence intervals. Solid black line: Implied cumulative response of manufacturing employment to a one-time carbon tax shock. Dashed green line: Point estimates for the response of manufacturing employment growth to a permanent increase in carbon tax. Solid green line: Implied cumulative response of manufacturing employment to a permanent carbon tax shock. Estimates are generated using the "unrestricted" specification.

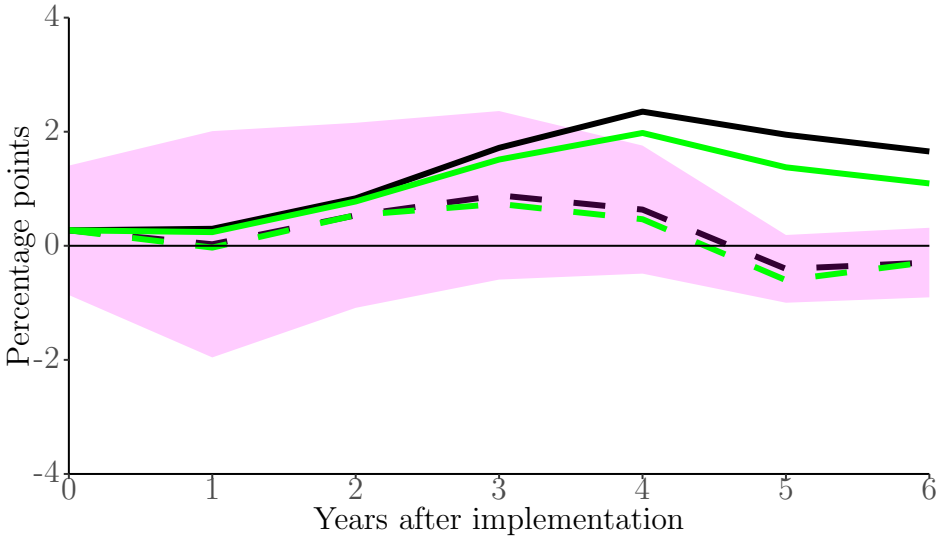

Figure B.6: Dashed black line and magenta bands: Point estimates for the response of manufacturing employment growth to a one-time carbon tax shock, along with their corresponding 95% HC confidence intervals. Solid black line: Implied cumulative response of manufacturing employment to a one-time carbon tax shock. Dashed green line: Point estimates for the response of manufacturing employment growth to a permanent increase in carbon tax. Solid green line: Implied cumulative response of manufacturing employment to a permanent carbon tax shock. Estimates are generated using the "restricted" specification.

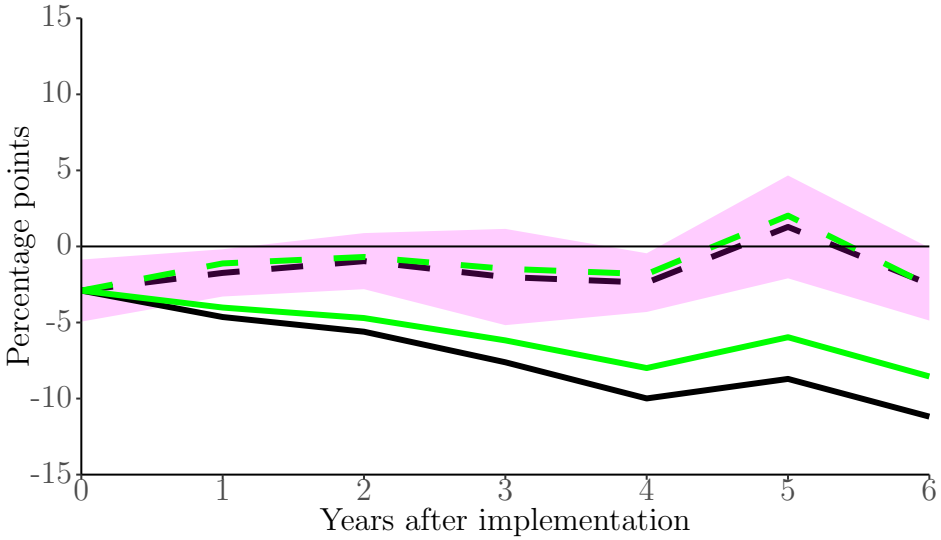

Figure B.7: Dashed black line and magenta bands: Point estimates for the response of covered sector emission growth to a one-time carbon tax shock, along with their corresponding 95% HC confidence intervals. Solid black line: Implied cumulative response of covered sector emissions to a one-time carbon tax shock. Dashed green line: Point estimates for the response of covered sector emission growth to a permanent increase in carbon tax. Solid green line: Implied cumulative response of covered sector emissions to a permanent carbon tax shock. Estimates are generated using the "unrestricted" specification.

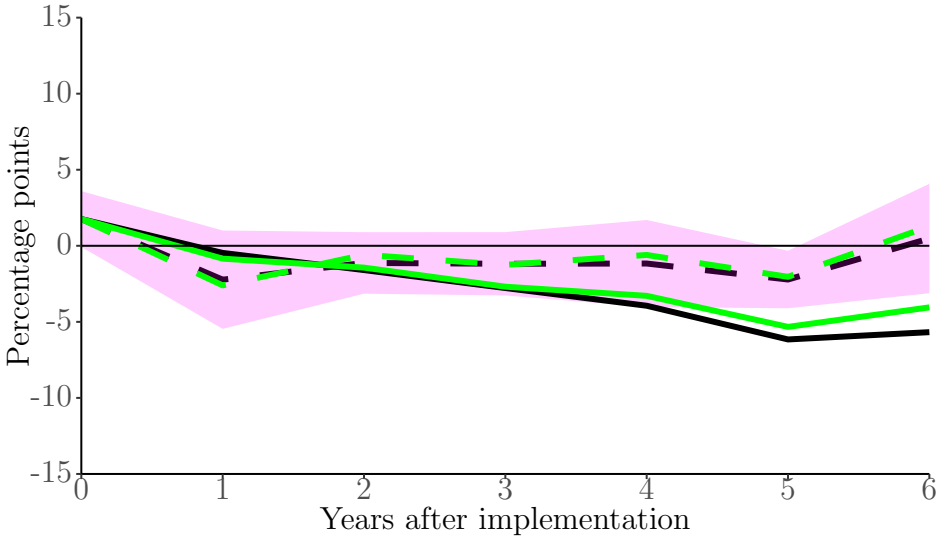

Figure B.8: Dashed black line and magenta bands: Point estimates for the response of covered sector emission growth to a one-time carbon tax shock, along with their corresponding 95% HC confidence intervals. Solid black line: Implied cumulative response of covered sector emissions to a one-time carbon tax shock. Dashed green line: Point estimates for the response of covered sector emission growth to a permanent increase in carbon tax. Solid green line: Implied cumulative response of covered sector emissions to a permanent carbon tax shock. Estimates are generated using the "restricted" specification.