The Macroeconomic Impact of Europe's Carbon Taxes
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Online Appendix

Appendix A – European Carbon Tax Systems

Countries with carbon taxes are as follows (listed in chronological order of enactment):[1]

Finland (1990): The first wave of carbon taxes in Europe began with Finland's enactment of a tax in 1990. As was also the case in subsequent Nordic carbon tax implementations, Finland's carbon tax was enacted during a time of income tax reform to lower high marginal income tax rates (Carl and Fedor, 2016). Between 1990 and 1994, Finland taxed all fossil fuels including gasoline, diesel, fuel oil, coal, natural gas with some fuels (e.g. natural gas) taxed at a lower rate per ton carbon dioxide.[2] Between 1994 and 1997, Finland switched to a combined carbon and energy tax before switching back to a carbon tax in 1997. The tax base since 1997 was predominantly motor and heating fuels. Tax revenues are not specifically earmarked for particular uses but coincides with reductions in income tax rates both initially and over time (OECD, 2019). It raised a little under $1.5 billion in 2018, according to the World Bank Carbon Pricing Dashboard.

Poland (1990): According to the World Bank's *States and Trends of Carbon Pricing*, Poland has the lowest carbon tax rate among those countries with a carbon tax. It also covers a small share of emissions (less than five percent). Revenues are on the order of $1 million annually and are earmarked for environmental spending (OECD, 2019).

Norway (1991): Norway was also one of the early Nordic carbon tax adopters, with the tax adopted as part of broader income tax reform (see also Brannlund and Gren (1999) who document the green tax reforms in Denmark, Norway, and Sweden). Like other Nordic countries, the taxes go into general revenue and are not earmarked though it is understood that they, in part, make up for lost income tax revenue from lowering income tax rates. The tax

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[1] This section draws on material from Sumner et al. (2011), Carl and Fedor (2016), Marten and Dender (2019), and World Bank Group (2019).

[2] https://sustainabledevelopment.un.org/index.php?page=view&type=99&nr=183&menu=1449, accessed March 29, 2020.

covers oil, gasoline, and natural gas in the transportation and industrial sectors (primarily) with modest contributions from agriculture as well as the residential and commercial sectors (OECD, 2018).[3]

Sweden (1991): Sweden's carbon tax applies primarily to transport and heating fuels (Hammar and Akerfeldt, 2011). Initially enacted with lower rates for trade intensive sectors of the economy, the gap between the standard and reduced rates has gradually been reduced until it was eliminated in 2018. As Andersson (2019) notes, roughly 90 percent of the tax revenue comes from the transport sector. As with other Nordic countries, Sweden's carbon tax was enacted as part of a broader tax reform that saw reductions in income tax rates as well as an expansion of the value added tax to cover gasoline and diesel.

Denmark (1992): Denmark is another country that implemented a carbon tax as part of a broader tax reform movement in the early 1990s. Like other Nordic countries, the taxes go into general revenue and are not earmarked though it is understood that they, in part, make up for lost income tax revenue from lowering income tax rates. The tax covers oil, gasoline, and natural gas in the transportation and industrial sectors (primarily) with modest contributions from agriculture as well as the residential and commercial sectors (OECD, 2018).

Slovenia (1996): Revenues are earmarked, in part, for green spending (at least in 2005). The tax falls primarily on emissions from the buildings and transport sector.

Estonia (2000): Estonia has a modest carbon tax that applies primarily to transport fuels (OECD, 2018). Revenues are not earmarked but go into general revenue.

Latvia (2004): Latvia's carbon tax applies to emissions from industry and the power sector not subject to the EU ETS (World Bank Carbon Pricing Dashboard). Carbon tax revenue is applied to general revenue.

Switzerland (2008): While Switzerland is not part of the EU-ETS, it has its own cap and trade system (since 2008) and has formally linked its system with the EU-ETS as of 2019. Its carbon tax applies to energy related CO_2 emissions not covered by the country's ETS. Firms in trade exposed sectors with large carbon tax burdens can opt out of the system if they commit to a set reduction in emissions by given dates. Switzerland earmarks one-third of the carbon tax revenue for subsidize energy reduction in the building sector, either through energy efficiency

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[3] Emissions from offshore oil and gas production are subject both to the EU-ETS and the carbon tax (Svenningsen et al., 2019, p. 80).

investments or distributed generation – geothermal primarily – investments (Carl and Fedor, 2016, and OECD, 2019).[4]

Ireland (2010): Ireland enacted a carbon tax in the wake of the 2008 fiscal crisis that confronted the country with the risk of collapse of the Irish banking system and collapse of property values (Convery et al., 2013). Revenues enter the general budget though there is some minor earmarking for environmental projects.[5] The tax applies to all fossil fuel emissions and can overlap with coverage of the ETS. Firms, however, are eligible for a rebate of the carbon tax for emissions subject to the ETS.

Iceland (2010): Like Ireland, Iceland enacted a carbon tax following the financial crisis of 2008. Initially, it pegged the tax rate to the EU-ETS allowance price but soon raised the rate to raise additional revenue for the national budget (Svenningsen, et al., 2019). The carbon tax applies to fossil fuel consumption in the country; given the extensive use of geothermal and hydropower for power generation (nearly all) and household heating (over 90 percent), the carbon tax is primarily a tax on transport fuels.

United Kingdom (2013): The UK Carbon Price Floor (CPF) applies to power generators subject to the EU-ETS and is designed to set a floor price on power-related CO_2 emissions. Revenues are part of general revenue and are not earmarked. Confusingly, the UK also applies a Climate Change Levy which is not a true carbon tax as it applies different rates per ton of carbon dioxide to different fuels with, for example, coal taxed at half the rate of natural gas (Martin et al., 2014).

Spain (2014): Spain's carbon tax is a tax on fluorinated gases. The tax is applied when equipment is recharged and can be rebated to the extent the gases are recovered and recycled. Revenue enters the general revenue with no earmarking.

France (2014): France's carbon tax covers nearly all fossil fuels not subject to the EU-ETS. Certain industrial process emissions are exempt from the tax. Initially, revenue from the tax was

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[4] Liechtenstein is required as a result of a bilateral treaty with Switzerland to enact the same environmental laws as in Switzerland. As a result, it also enacted a carbon tax in 2008. All revenues are added to general revenue. Similar exemptions exist as in Switzerland. We have not included Liechtenstein in the empirical analysis.

[5] In the December 2009 Financial Statement of the Irish Minister for Finance, the Minister stated that the revenue would be used "to boost energy efficiency, to support rural transport and to alleviate fuel poverty. The Carbon Tax will also allow us to maintain or reduce payroll taxes." See the Statement at http://budget.gov.ie/Budgets/2010/FinancialStatement.aspx#item9, accessed on March 29, 2020. In the absence of explicit earmarking, we view this statement as consistent with using the revenue to contribute to general revenue and avoid a payroll tax increase.

earmarked to finance green spending (Carl and Fedor, 206). Over time the share of earmarked revenue has declined with the share allocated to general revenue rising.

Portugal (2015): Portugal's carbon tax generally applies to emissions from sectors not covered by the EU-ETS. A unique feature of Portugal's tax is that the rate is indexed to the average allowance price of the EU-ETS from the previous year (World Bank Carbon Pricing Dashboard and Pereira et al., 2016). The carbon tax was enacted as part of a broader set of tax reforms and revenue from the tax was used to lower existing income taxes.

I. Event Study Figures
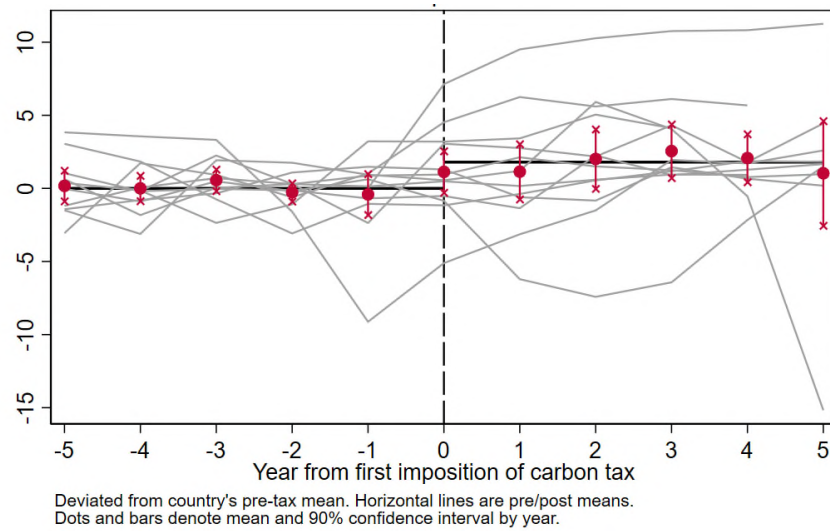
Figure A1. Carbon Tax Enactment and Total Employment Growth Rate
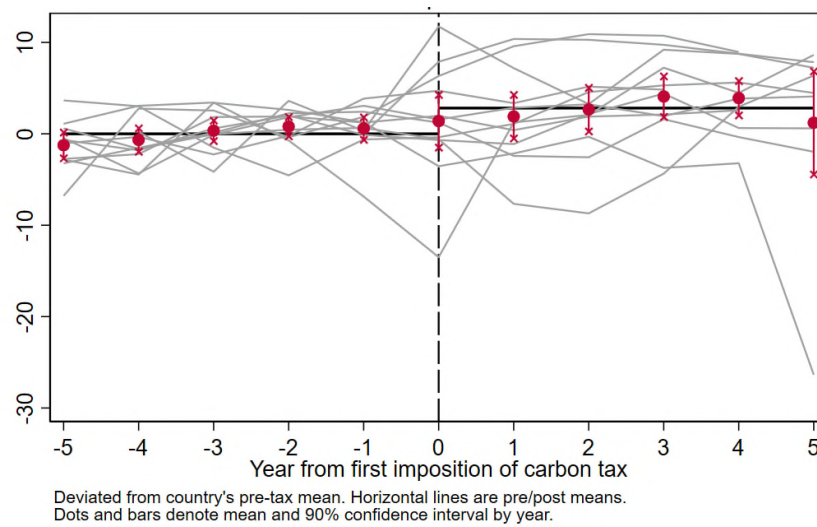
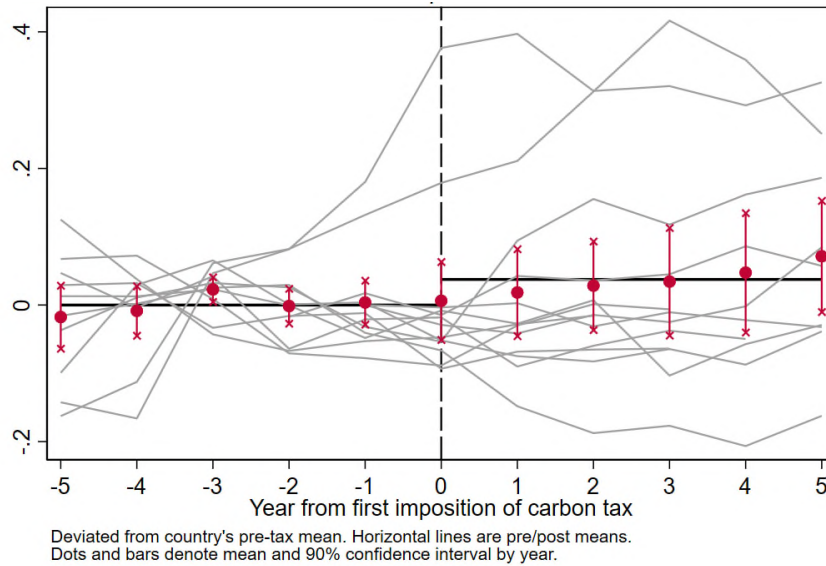Figure A2. Carbon Tax Enactment and Manufacturing Employment Growth Rate

Deviated from country's pre-tax mean. Horizontal lines are pre/post means.
Dots and bars denote mean and 90% confidence interval by year.

Figure A3. Carbon Tax Enactment and CO_2 Emissions

II. Modeling the Carbon Tax Policy

We model the carbon tax policy as an initial shock of $40 per ton with a sequence of subsequent small adjustments. The small adjustments keep the carbon tax at $40 instead of tracking its own IRF with respect to its own shock. That IRF is nearly a step function, which is why the adjustments are small. Figure A4 below models the tax shock in levels (blue) and first differences (red). The own-IRF goes to 1 by construction so at step 0 has 0 standard error. The upper plot is the cumulation of the lower plot, with SEs computed properly. As the figure illustrates, the shock to carbon tax rates is highly persistent – a shock raising the carbon tax rate by one dollar maintains the rate increase at one dollar.
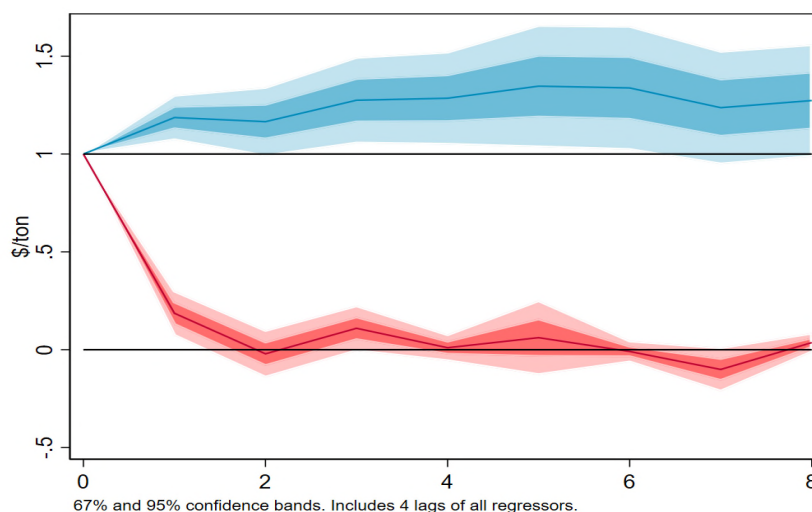
6

Figure A4. Response of Carbon Tax per $1 Carbon Tax Shock

III. Excluding Year Effects

One concern with our model is the inclusion of time fixed effects. Including those means that we are estimating a "relative causal effect" and that in the presence of cross-country spillovers, our results may differ depending on whether time fixed effects are included or not. To check for that possibility, we reran all regressions dropping year fixed effects. We find that the results are essentially unchanged whether we include year fixed effects or not. Thus, it does not appear that our results are contaminated by the possibility of cross-country spillovers.

We show a few representative results for the main set of regressions. Figure A5 below is the impact of the carbon tax shock on GDP growth without year effects. This can be compared with figure 3a in the main text. Figure A6 shows the impact of the tax shock on total employment growth without year effects. This can be compared with figure 6a in the main text. Now employment initially falls in the first year before equilibrating around zero. In figure 6a, employment initially rises and then settles back to zero. In both regressions, one can't reject zero change in all years. Figure A7 shows the IRF for manufacturing employment (compare with figure 8a in the main text). Again, the pattern is similar and in both cases, the impact on manufacturing employment growth is imprecisely estimated and in most cases we can't reject zero. Also, in both cases, manufacturing employment growth is positive in year 6 (albeit statistically insignificant when year fixed effects are included).

Figure A8 shows the IRF for the tax policy shock on the level of covered emissions when year effects are omitted. This can be compared to Figure 10a in the main text. Again, the results are quite similar whether year effects are included on the analysis or not.
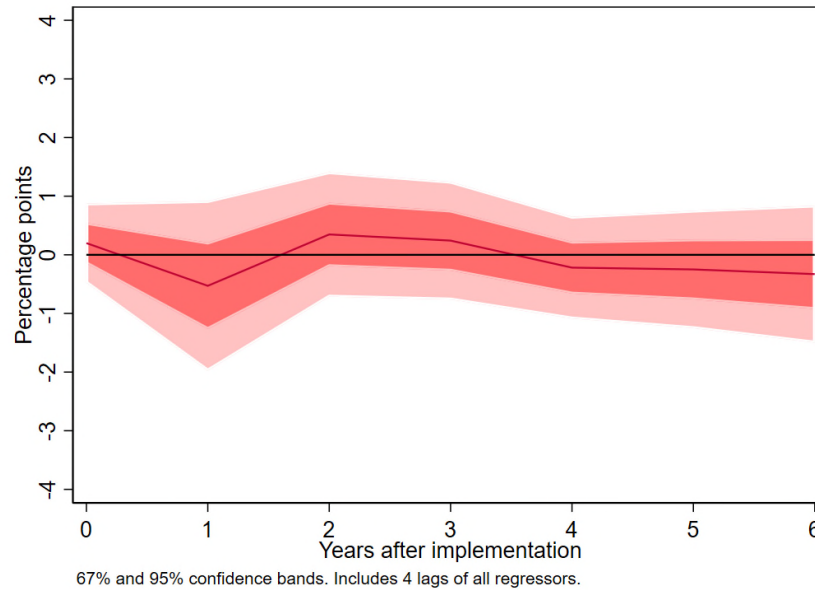

67% and 95% confidence bands. Includes 4 lags of all regressors.

Figure A5. Effect on GDP growth of a $40 carbon tax covering 30% of emissions:
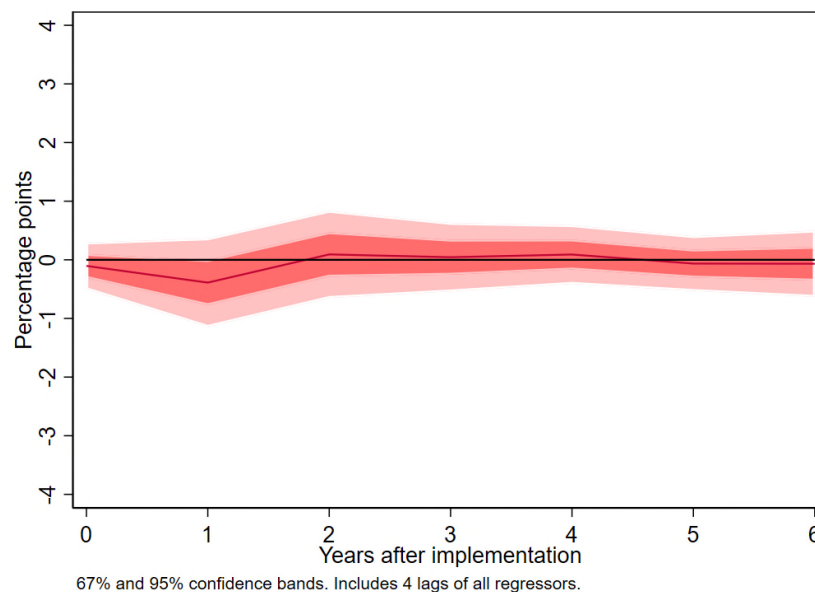LP Regression – Unrestricted – No Year Effects

67% and 95% confidence bands. Includes 4 lags of all regressors.

Figure A6. Effect on total employment growth of a $40
carbon tax covering 30% of emissions:
LP Regression – Unrestricted – No Year Effects

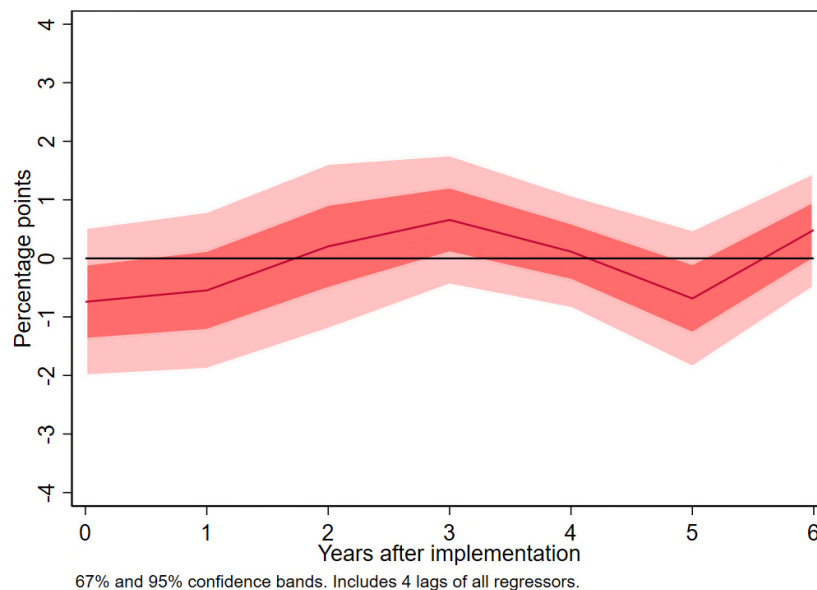67% and 95% confidence bands. Includes 4 lags of all regressors.

Figure A7. Effect on manufacturing employment growth
of a $40 carbon tax covering 30% of emissions:
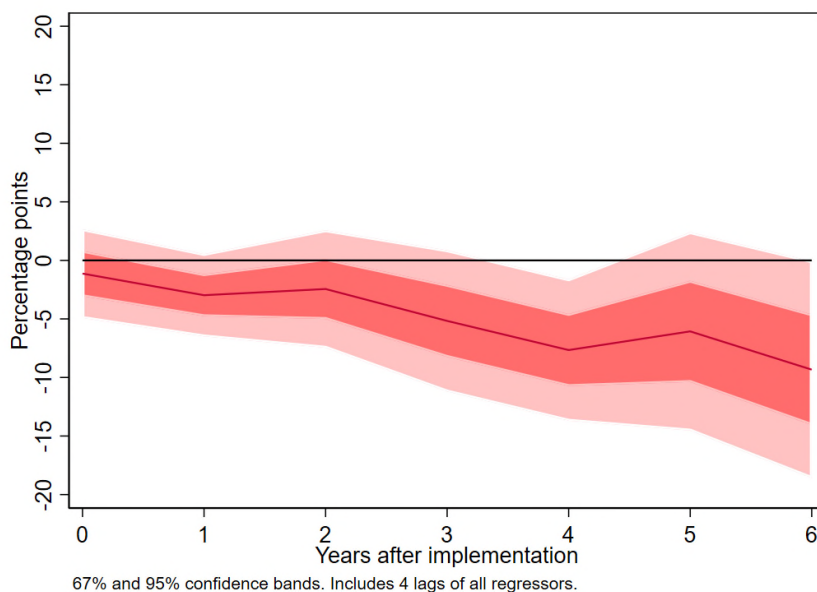LP Regression – Unrestricted – No Year Effects

67% and 95% confidence bands. Includes 4 lags of all regressors.

Figure A8. Effect on level of emissions in covered sectors:
LP Regression – Unrestricted – No Year Effects

IV. Impulse Response Functions Focusing on Role of Scandinavian Countries
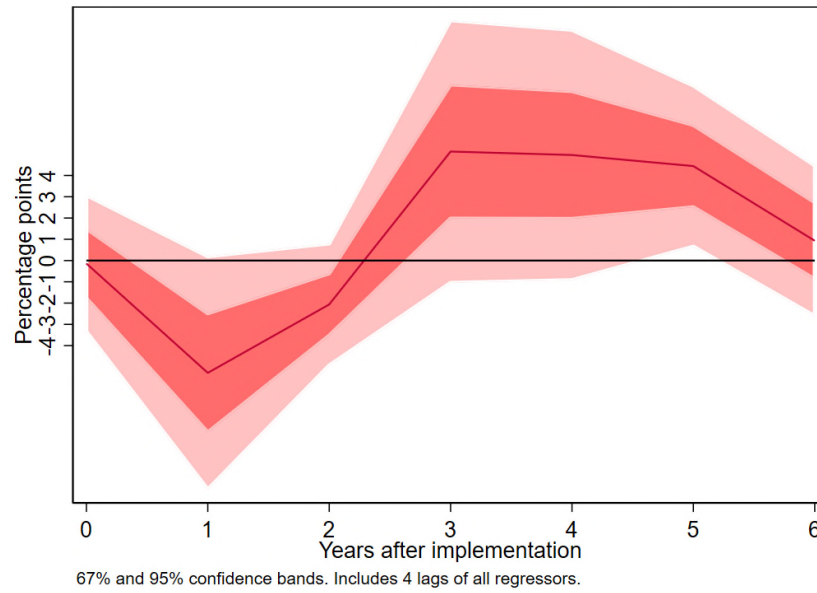

Figure A9. Effect on GDP growth, LP Regression – Restricted:
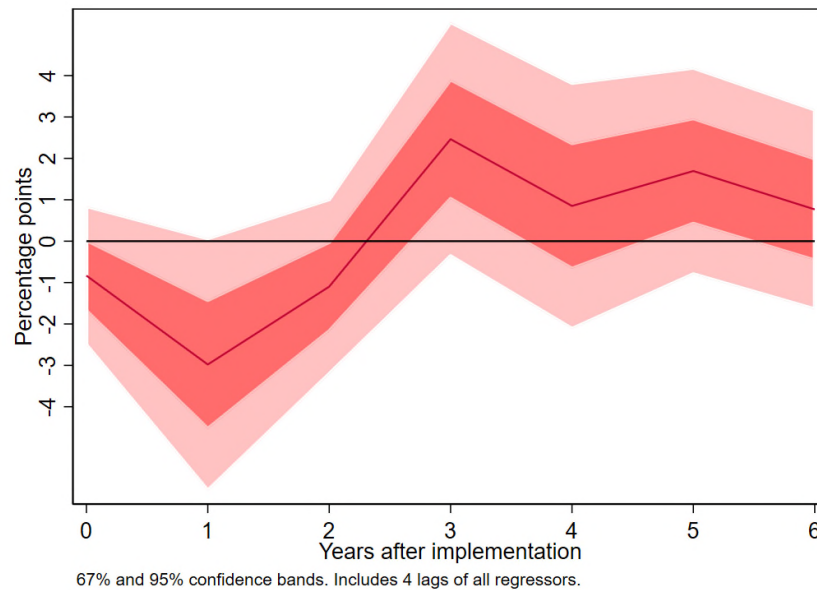Excluding Scandinavian Countries

Figure A10. Effect on growth of total employment growth, LP Regression – Restricted:
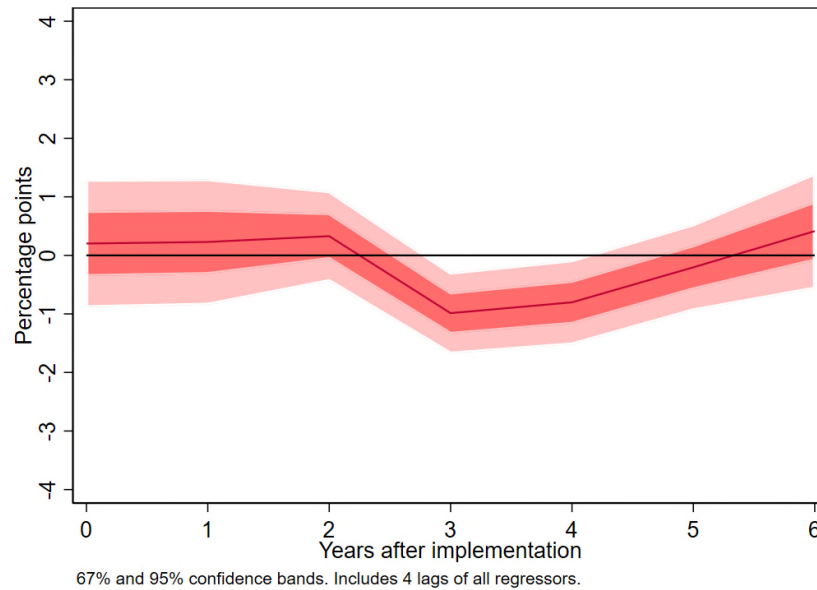Excluding Scandinavian Countries

Figure A11. Effect on GDP growth, LP Regression – Restricted:
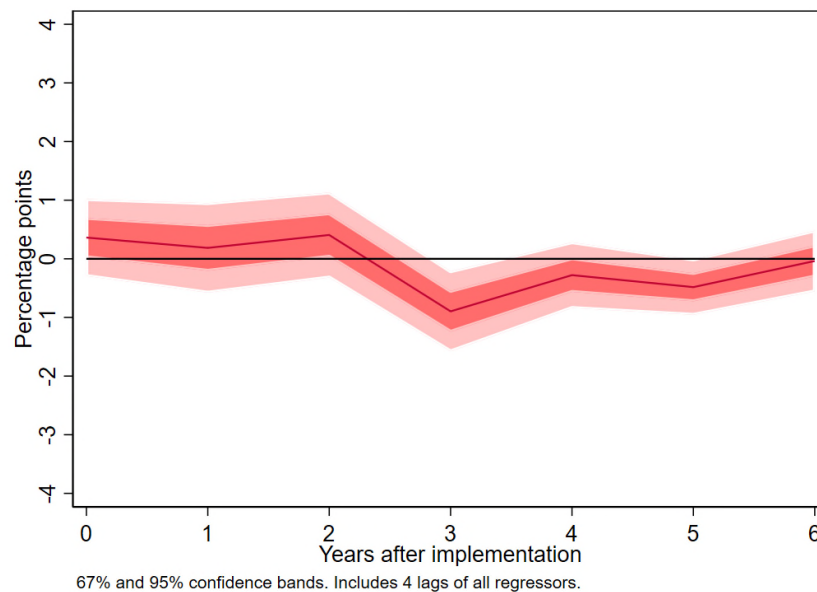Scandinavian Countries Only

Figure A12. Effect on growth of total employment, LP Regression – Restricted:
Scandinavian Countries Only

V Results Using Emissions Weighted Carbon Prices from Dolphin et al. (2019)

Below are impulse response functions for the GDP and Total Employment growth rates and a cumulative impulse response function for total emissions for the LP restricted model using Dolphin et al.'s emissions weighted carbon prices. Results are very similar when the LP unrestricted or SVAR approaches are used. These results are roughly comparable to ours since the mean emissions share in the Dolphin et al. data for their fixed-weight carbon price is 34 percent.[6] The three figures that follow should be compared to figures 3b, 6b, and 10b respectively in the paper.

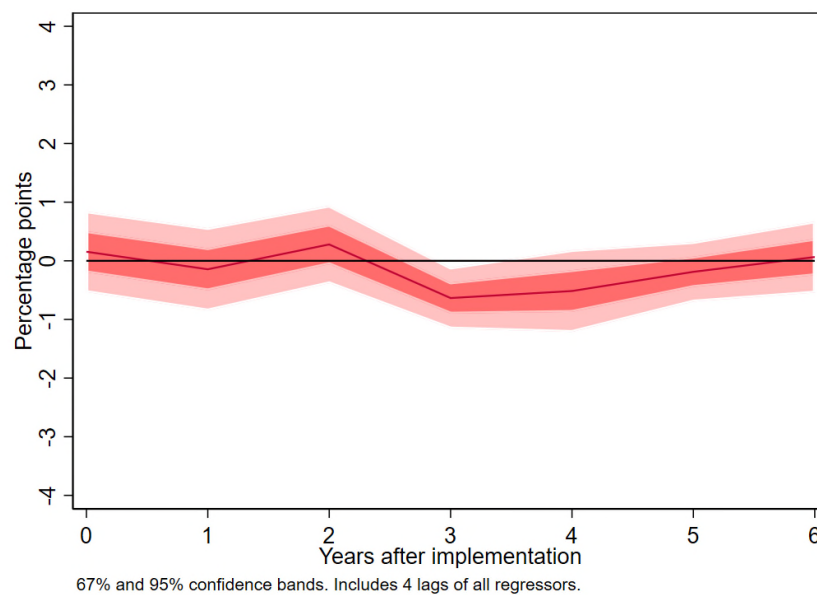67% and 95% confidence bands. Includes 4 lags of all regressors.

Figure A13. Effect on GDP growth, LP Regression – Restricted:
ECP tax data used

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[6] Personal communication with Geoffroy Dolphin on June 3, 2020.
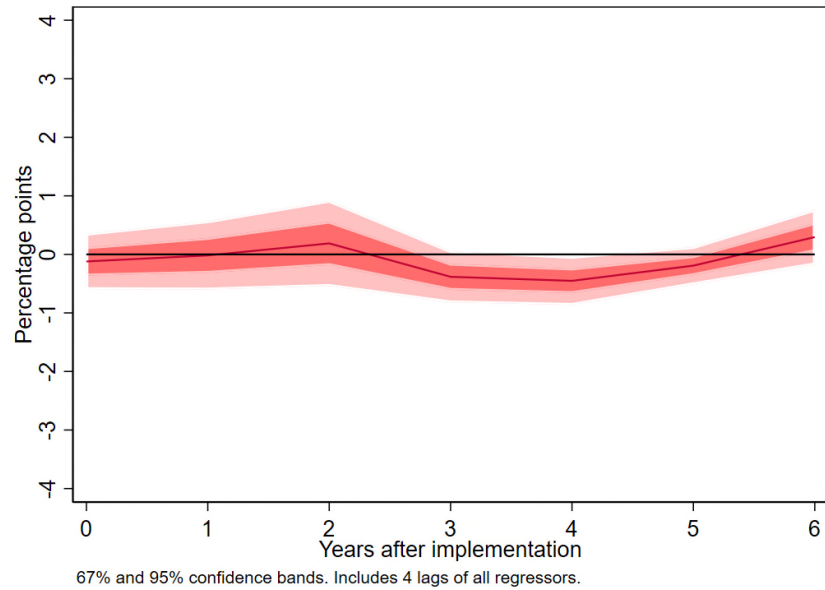
Figure A14. Effect on growth of total employment, LP Regression – Restricted:
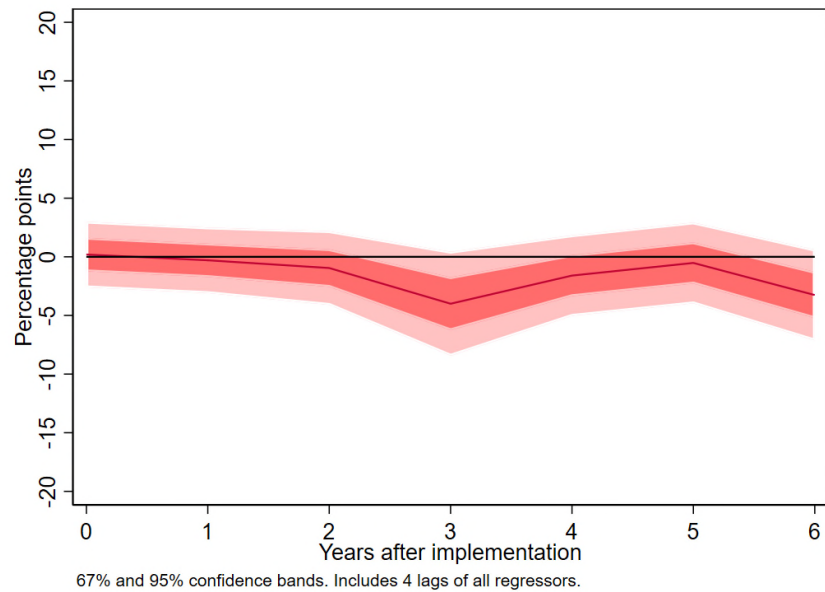ECP tax data used

Figure A15. Effect on level of emissions, LP Regression – Restricted:
ECP tax data used

VI Results for nonlinear specifications

Here we report results for the nonlinear specifications discussed in Section IV.E. In the first ("nonlinear specification A"), the LP regression is augmented by the sqaure of the share-weighted carbon tax and its lags, so that the dynamic effect of a tax increse depends on the share-weighted tax rate. In the second ("nonlinear specification B"), the LP regression is augmented by the share-weighted carbon tax times the share, so that the dynamic effect of a given tax increse depends on the coverage share. In the third ("nonlinear specification C"), we interact the share-weighted carbon tax with a lag of GDP growth to check whether there is evidence that the carbon tax has a different impact during a boom than a bust.

The first step in computing the dynamic effects is computing the impulse response functions (IRFs) for a unit increase in the share-weighted carbon tax. These IRFs are then used to compute the dynamic effect of the sequence of tax rate shocks that yield the constant $40 tax rate. Here, we compare linear and nonlinear specifications by focusing on the first step, the IRFs, which are not directly comparable to the dynamic effect plots which use the second step.

Selected results are shown in Figures A16 – A24. Figure A16 provides the impulse response function (IRF) for the effect of a carbon tax increase on the growth of GDP, for a tax covering 30% of emissions, for a $20 and $100 tax increase. Figures A17 and A18 provides the analogous figures, but for the growth of total employment and the growth of emissions, respectively. The nonlinear regressions shade confidence bands in blue and are plotted along with the linear specification bands (in red). The bands in the non-linear specification overlap those of the linear specificatoin whether we assume a low tax increase ($20) or a high increase ($100). Figures A19 – A21 examine the second nonlinear specification, and consider a $40 tax increase for a coverage share of 20% and 50%. Figures A22 – A24 examine the third nonlinear specificaiton, and consider a $40 tax increase for low GDP growth (10th percentile for GDP growth) and for high GDP growth (90th percentile for GDP growth).

For the shown results, the linear and the nonlinear IRFs are generally quite similar, and are similar across different values of the variables in which they are nonlinear. One exception is the GDP growth IRF for a small increase in the carbon tax for specification A (Figure A11, upper); like the linear IRF, the nonlinear IRF oscilates around zero, but with a different pattern, however the nonlinear confidence band contains the linear confidence band at most horizons. Another exception is that the IRFs for nonlinear specification B are very imprecisely estimated

for small coverage shares. These results are typical for other dependent variables and other evaluation points (values of the nonlinear variables), and lead us to conclude that these IRFs do not show evidence of either nonlinearity. Nor do we see evidence of economically or statistically significant differences between carbon tax impacts in low versus high growth economies (specification C).
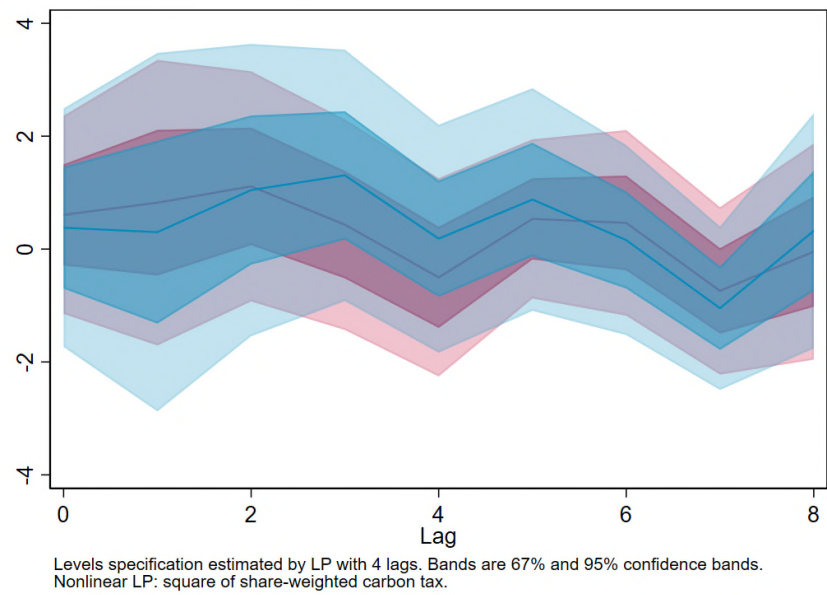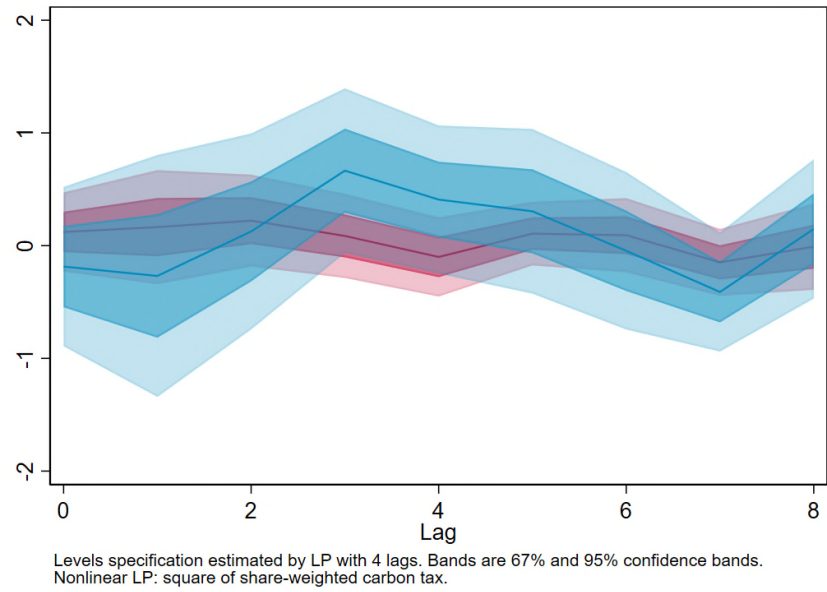
Levels specification estimated by LP with 4 lags. Bands are 67% and 95% confidence bands.
Nonlinear LP: square of share-weighted carbon tax.

Levels specification estimated by LP with 4 lags. Bands are 67% and 95% confidence bands.
Nonlinear LP: square of share-weighted carbon tax.

Figure A16. Dynamic effect on GDP growth for a carbon tax with 30% coverage (red: linear; blue: nonlinear specification A): $20 tax increase (upper) and $100 tax increase (lower)

Levels specification estimated by LP with 4 lags. Bands are 67% and 95% confidence bands.
Nonlinear LP: square of share-weighted carbon tax.

Levels specification estimated by LP with 4 lags. Bands are 67% and 95% confidence bands.
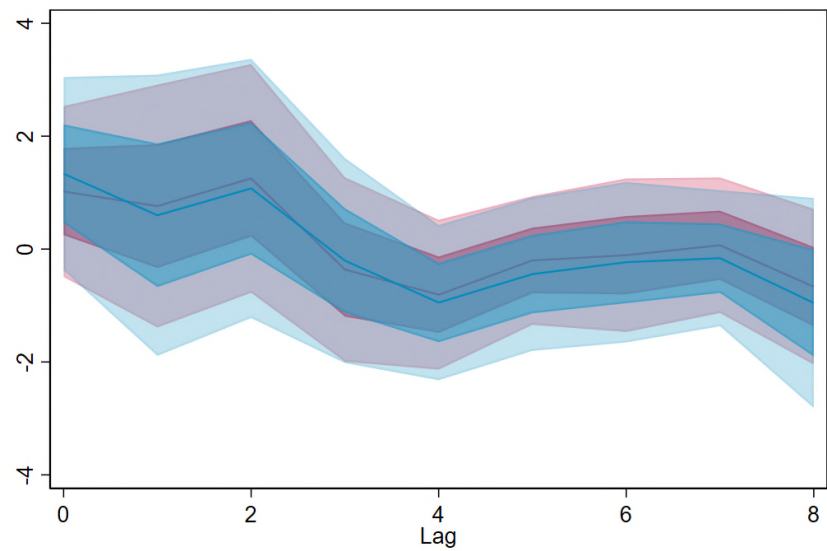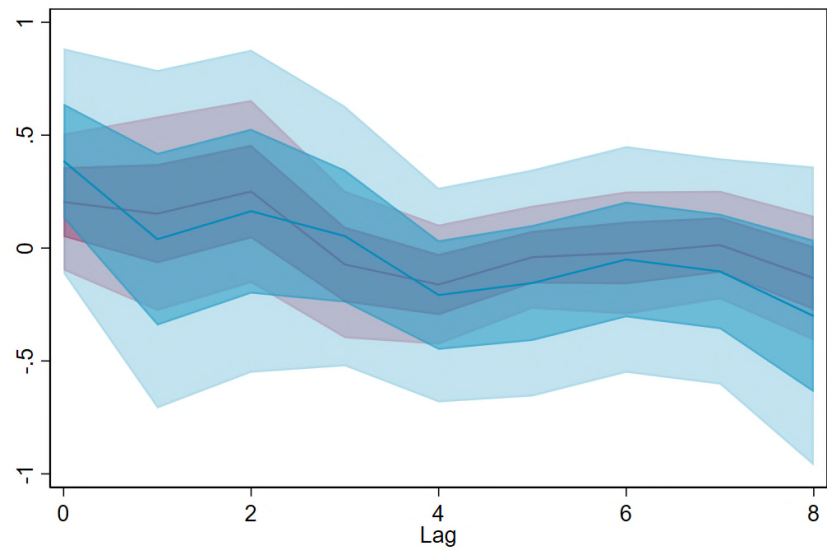Nonlinear LP: square of share-weighted carbon tax.

Figure A17. Dynamic effect on employment growth for a carbon tax with 30% coverage (red: linear; blue: nonlinear specification A): $20 tax increase (upper) and $100 tax increase (lower)

Levels specification estimated by LP with 4 lags. Bands are 67% and 95% confidence bands.
Nonlinear LP: square of share-weighted carbon tax.

Levels specification estimated by LP with 4 lags. Bands are 67% and 95% confidence bands.
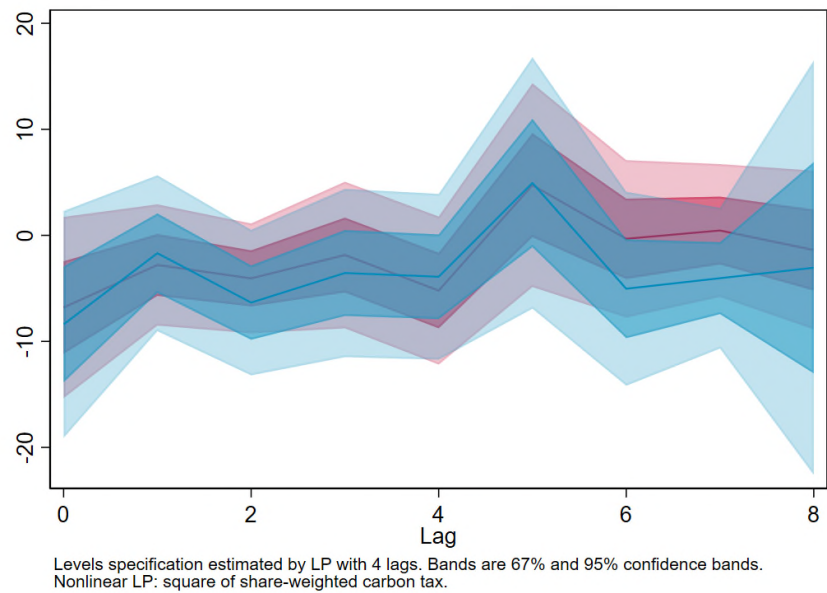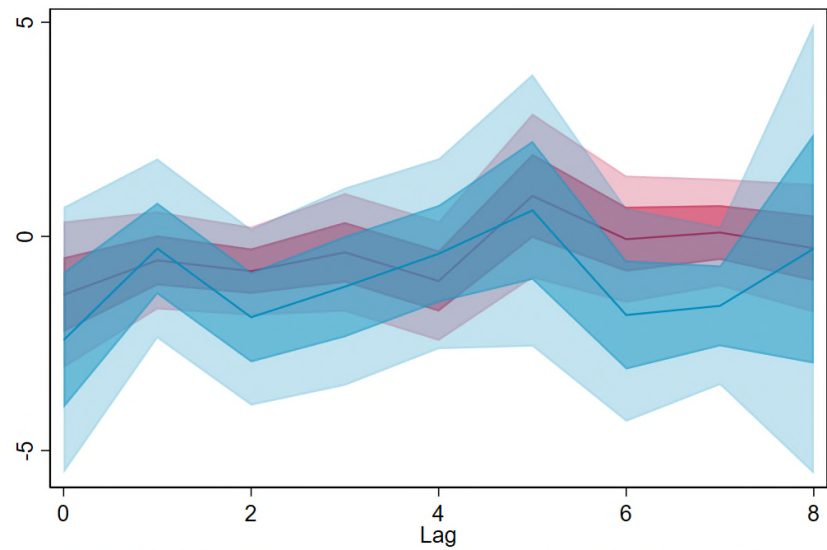Nonlinear LP: square of share-weighted carbon tax.

Figure A18. Dynamic effect on emissions growth for a carbon tax with 30% coverage (red: linear; blue: nonlinear specification A): $20 tax increase (upper) and $100 tax increase (lower)

Levels specification estimated by LP with 4 lags. Bands are 67% and 95% confidence bands.
Nonlinear LP: includes coverage share interacted with share-weighted carbon tax.

Levels specification estimated by LP with 4 lags. Bands are 67% and 95% confidence bands.
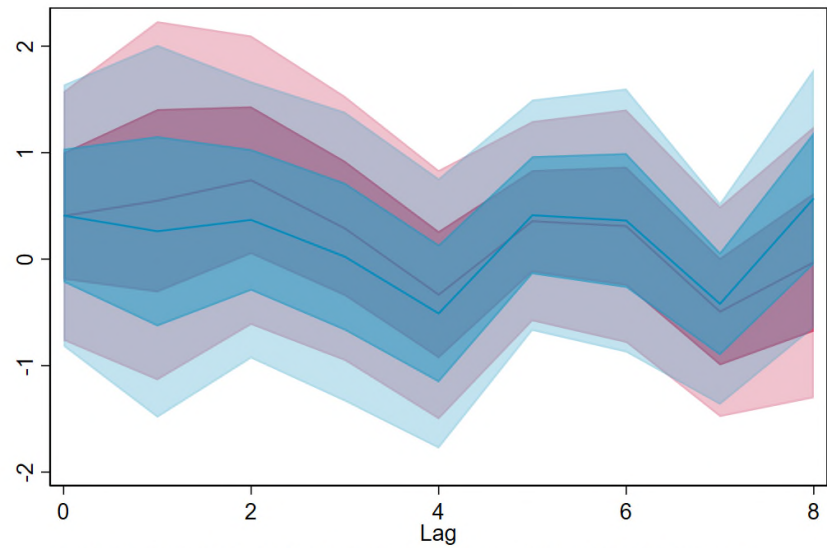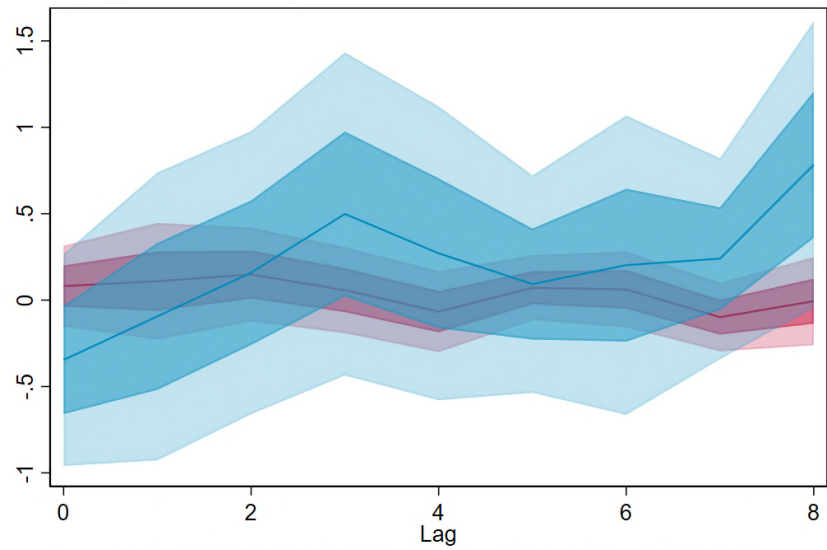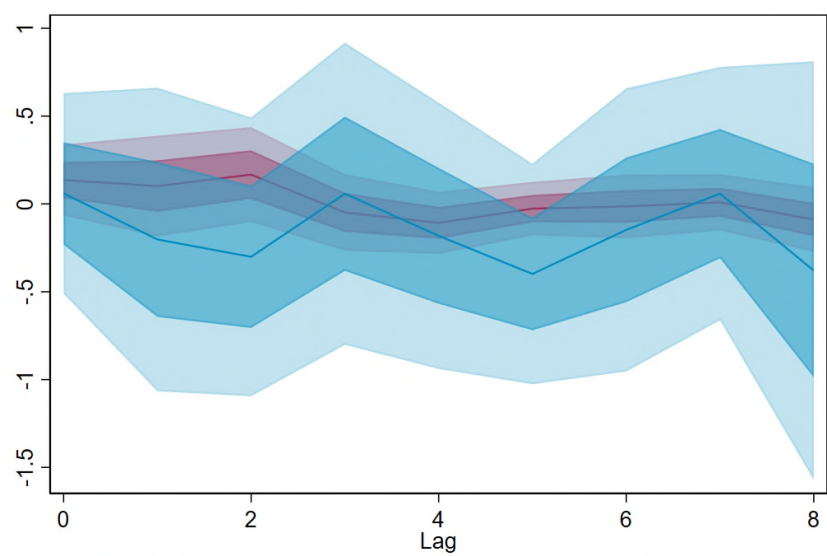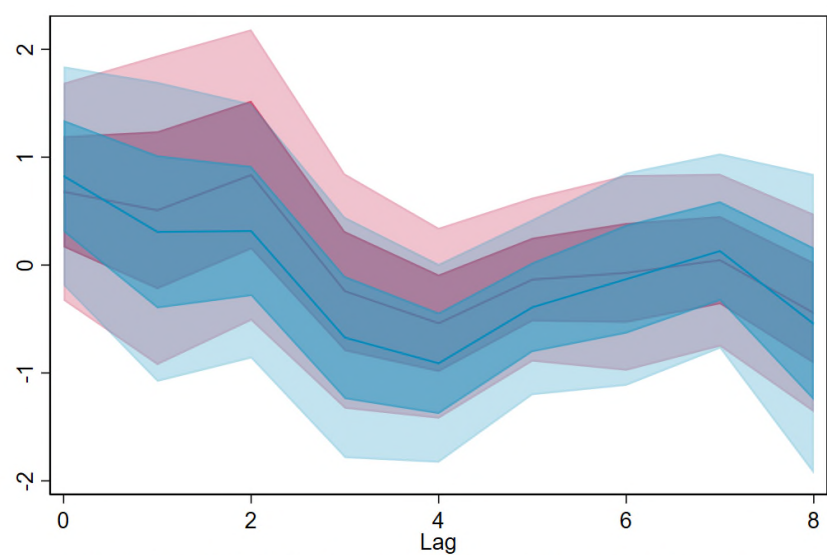Nonlinear LP: includes coverage share interacted with share-weighted carbon tax.

Figure A19. Dynamic effect on GDP growth for a carbon tax increase of $40 (red: linear; blue: nonlinear specification B): 10% emissions coverage (upper) and 50% emissions coverage (lower)

Levels specification estimated by LP with 4 lags. Bands are 67% and 95% confidence bands.
Nonlinear LP: includes coverage share interacted with share-weighted carbon tax.

Levels specification estimated by LP with 4 lags. Bands are 67% and 95% confidence bands.
Nonlinear LP: includes coverage share interacted with share-weighted carbon tax.

Figure A20. Dynamic effect on employment growth for a carbon tax increase of $40 (red: linear; blue: nonlinear specification B): 10% emissions coverage (upper) and 50% emissions coverage (lower)

Levels specification estimated by LP with 4 lags. Bands are 67% and 95% confidence bands.
Nonlinear LP: includes coverage share interacted with share-weighted carbon tax.

Levels specification estimated by LP with 4 lags. Bands are 67% and 95% confidence bands.
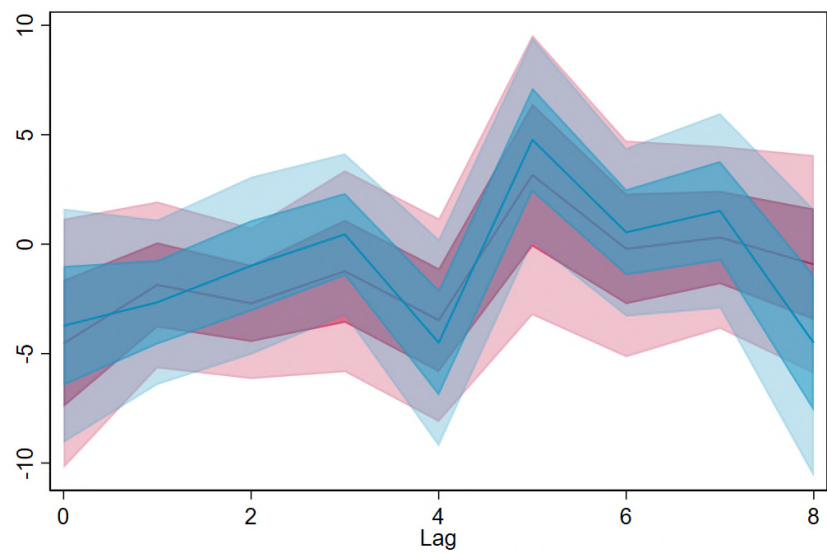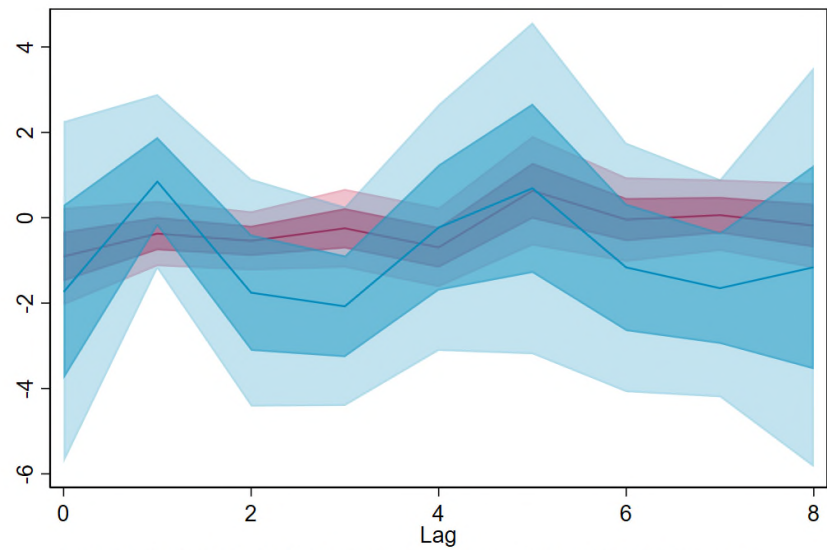Nonlinear LP: includes coverage share interacted with share-weighted carbon tax.

Figure A21. Dynamic effect on emissions growth for a carbon tax increase of $40 (red: linear; blue: nonlinear specification B): 10% emissions coverage (upper) and 50% emissions coverage (lower)
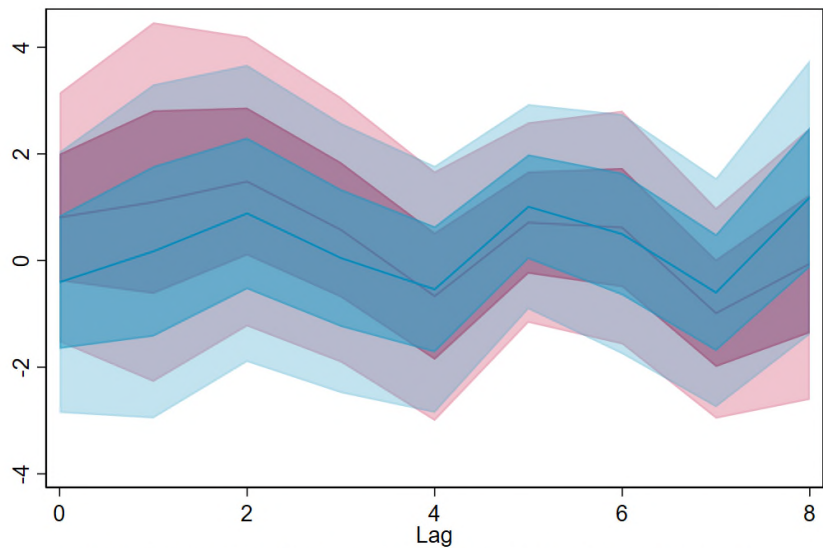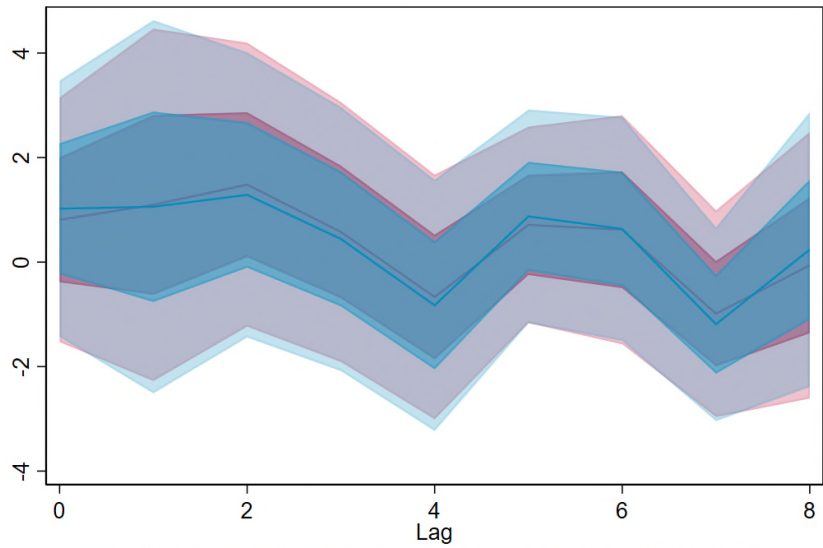
Levels specification estimated by LP with 4 lags. Bands are 67% and 95% confidence bands.
Nonlinear LP: lagged GDP growth interacted with share-weighted carbon tax.

Levels specification estimated by LP with 4 lags. Bands are 67% and 95% confidence bands.
Nonlinear LP: lagged GDP growth interacted with share-weighted carbon tax.

Figure A22. Dynamic effect on GDP growth for a carbon tax increase of $40 (red: linear; blue: nonlinear specification C): low GDP growth (10th percentile) (upper) and high GDP growth (90th percentile) (lower)

Levels specification estimated by LP with 4 lags. Bands are 67% and 95% confidence bands.
Nonlinear LP: lagged GDP growth interacted with share-weighted carbon tax.

Levels specification estimated by LP with 4 lags. Bands are 67% and 95% confidence bands.
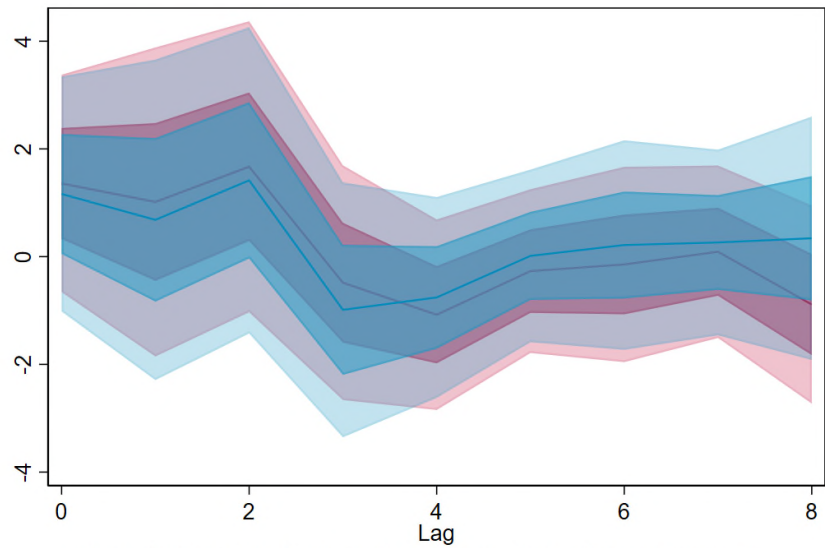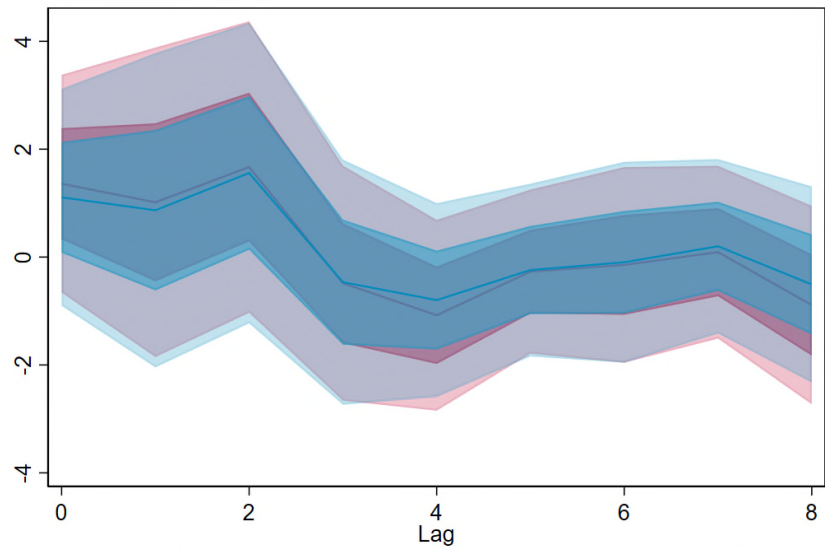Nonlinear LP: lagged GDP growth interacted with share-weighted carbon tax.

Figure A23. Dynamic effect on employment growth for a carbon tax increase of $40 (red: linear; blue: nonlinear specification C): low GDP growth (10th percentile) (upper) and high GDP growth (90th percentile) (lower)

Levels specification estimated by LP with 4 lags. Bands are 67% and 95% confidence bands.
Nonlinear LP: lagged GDP growth interacted with share-weighted carbon tax.

Levels specification estimated by LP with 4 lags. Bands are 67% and 95% confidence bands.
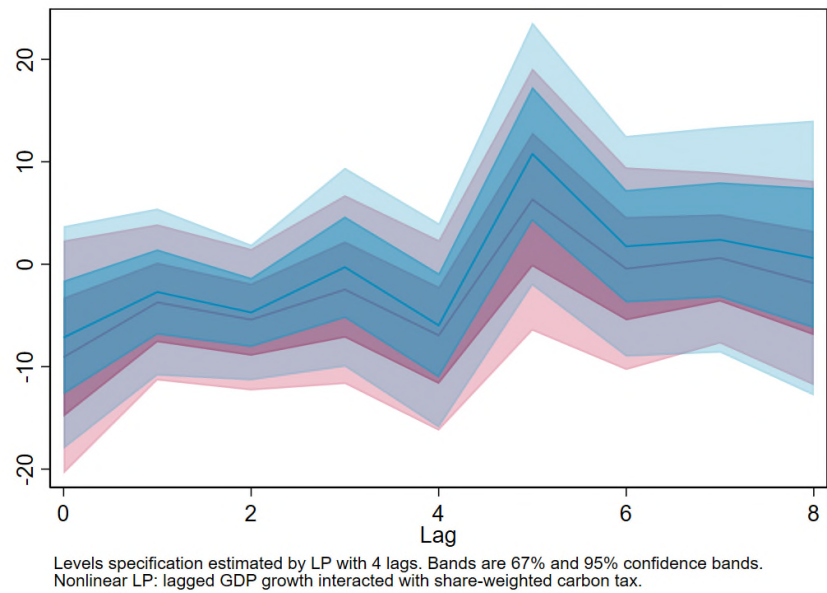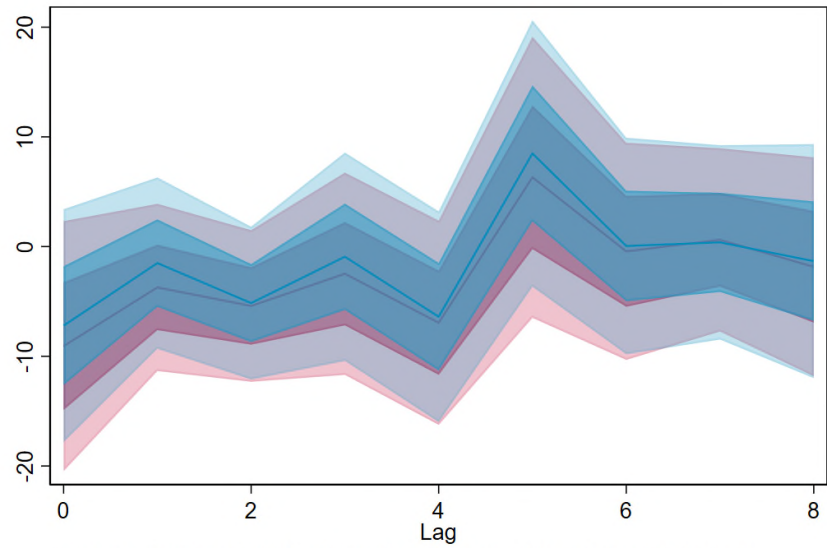Nonlinear LP: lagged GDP growth interacted with share-weighted carbon tax.

Figure A24. Dynamic effect on emissions growth for a carbon tax increase of $40 (red: linear; blue: nonlinear specification C): low GDP growth (10th percentile) (upper) and high GDP growth (90th percentile) (lower)

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