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ABSTRACT

Policy makers often express concern about the impact of carbon taxes on employment and GDP. Focusing on European countries that have implemented carbon taxes over the past 30 years, we estimate the macroeconomic impacts of these taxes on GDP and employment growth rates for various specifications and samples. Our point estimates suggest a zero to modest positive impact on GDP and total employment growth rates. More importantly, we find no robust evidence of a negative effect of the tax on employment or GDP growth. We examine evidence on whether the positive effects might stem from countries that used the carbon tax revenues to reduce other taxes; while the evidence is consistent with this view, it is inconclusive. We also consider the impact of the taxes on emission reductions and find a cumulative reduction on the order of 4 to 6 percent for a $40/ton CO2 tax covering 30% of emissions. We argue that reductions would likely be greater for a broad-based U.S. carbon tax since European carbon taxes do not include in the tax base those sectors with the lowest marginal costs of carbon pollution abatement.

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Economists widely agree that putting a price on carbon emissions is the most cost-effective way to reduce greenhouse gas emissions. The two most straightforward ways to apply a price are a carbon tax and a cap and trade system. A carbon tax can be levied on fossil fuels and other sources of greenhouse gas emissions based on their emissions; a cap and trade system limits emissions to some overall amount (the cap) and allows polluters to trade the rights to those scarce emission rights. In the current Congress there are numerous bills to establish national carbon tax systems and a few cap and trade bills. The filed bills reflect a growing consensus that action is needed at the national level to curb our carbon pollution and that a carbon tax is the most straightforward way to do that. The bills also reflect a broad consensus among economists, as typified by the more than 3,500 economists who signed the Climate Leadership Council's statement in calling for a carbon tax as "the most cost-effective lever to reduce carbon emissions at the scale and speed that is necessary."[1]

A major stumbling block to pricing carbon pollution is concern about the economic impact of the policy. The Trump Administration's retreat from a climate policy is emblematic. In initiating a process to withdraw the United States from the global Paris Agreement, for example, the President claimed that the cost to the economy would be "close to $3 trillion in lost GDP and 6.5 million industrial jobs…" (Trump, 2017).

How should we assess the economic costs of a carbon tax? Until recently, most analyses were based on modeling from large scale computable general equilibrium models. But we now have enough experience with carbon tax systems around the world to carry out statistical

[1] The statement was published in *The Wall Street Journal* on Jan. 17, 2019 and is available at https://clcouncil.org/economists-statement/. Both of the authors of this paper are signatories of that statement.

analyses of existing systems. The first carbon tax was implemented in 1990 so there is now up to three decades of data to draw on.

In this paper we carry out an analysis of the 31 countries in Europe that are part of the EU wide emissions trading system (EU-ETS). While all of these countries price a portion of their emissions through this cap and trade system, fifteen of these countries also impose a carbon tax, mostly on emissions not covered by the EU-ETS. By limiting our analysis to countries that are part of the EU-ETS, we can identify the incremental impact of carbon taxes on emissions, output, and employment by leveraging the variation in carbon tax systems within this group of countries. This paper builds on a previous analysis in Metcalf and Stock (2020). We build on that analysis in a number of ways including, importantly, measuring the impact of the carbon taxes on emissions as well as economic growth.

We find the following. For a wide range of specifications, we find no evidence of adverse effects on GDP growth or total employment. We also test and generally cannot reject the hypothesis that the carbon tax has no long run effect on growth rates. This finding is consistent with macroeconomic theory that suggests growth rates are driven by fundamentals, such as technological progress, which are unaffected by changes in relative prices. It is also consistent with most general equilibrium modeling of climate policy. Finally, we find cumulative emission reductions on the order of 4 to 6 percent for a tax of $40 per ton of CO_2 covering 30% of emissions. We argue that this is likely to be a lower bound on reductions for a broad-based carbon tax in the U.S. since European carbon taxes do not include in the tax base those sectors with the lowest marginal costs of carbon pollution abatement. European carbon taxes generally exclude the electricity sector and carbon intensive industries since those emissions are covered under the EU Emission Trading System.

The next section provides background and a literature review that places our paper in context. Section III surveys European carbon taxes. Section IV details our data and the econometric approach we take assess the impact of European carbon taxes. Section V presents results from the analysis. The next section presents some robustness results. We provide some concluding remarks in section VII.

II. Previous Literature

Most analyses of the economic impact of carbon taxes rely on large-scale computable general equilibrium models. One representative model is the E3 model described in Goulder and Hafstead (2017). They estimate that a $40 per ton carbon tax for the United States starting in 2020 and rising at 5 percent real annually would reduce GDP by just over one percent in 2035 relative to a no-tax counterfactual. While different models give different results, most find very modest reductions (if at all) in GDP from implementing a carbon tax.[2] Goulder et al. (2019) also consider a U.S. carbon tax starting at $40 per ton and rising at 2 percent annually. They find the GDP costs over the 2016 – 2050 period discounted at 3 percent equal to less than one-third of one percent of GDP.

[2] Trump cited a NERA (2017) study commissioned by an industry group to analyze how meeting an 80 percent reduction by 2050 would affect various industry sectors. Among other issues, the headline number cited by Trump (7 percent reduction in GDP) is from a NERA scenario in which sector specific regulations are imposed with very different marginal abatement costs across sectors. If marginal abatement costs are allowed to equalize across sectors in that study, the costs are reduced by over two-thirds.

Turning to the empirical literature, Metcalf (2019) finds no adverse GDP impact of the British Columbia carbon tax based on a difference-in-difference analysis of a panel of Canadian provinces over the time period 1990 – 2016. Using a panel of European countries over the time period 1985 – 2017, he finds, if anything, a modest positive impact on GDP. That imposing a carbon tax might have positive impacts on GDP is not implausible once one considers the governments' use of carbon tax revenue. In the early 1990s, for example, carbon taxes were imposed in a number of Scandinavian countries as a revenue source to finance reductions in marginal tax rates for their income taxes (see Brannlund and Gren, 1999, for background on these reforms). Variation in the use of revenues from newly enacted carbon taxes could differentially impact economic growth and is something we explore in this paper.

Bernard et al. (2018) use a vector autoregression (VAR) to estimate the impact of the BC carbon tax on provincial GDP, controlling for the pre-tax price of gasoline (or diesel) and US economic variables; they find no impact of the tax on GDP. In earlier work with a more limited version of the data set used in this paper, we (Metcalf and Stock (2020)) use local projections to estimate the impact of carbon taxes in European countries on GDP and found no adverse impacts of the tax on economic growth or employment. These results are consistent with Yamazaki (2017) analysis of the employment effects of the British Columbia carbon tax. Yamazaki found modest positive impacts on employment in the province. While aggregate impacts were small, he found significant job shifting from carbon intensive to non-carbon intensive sectors.

Focusing on emissions, Lin and Li (2011) estimate difference-in-difference regressions comparing individual countries with carbon taxes (Finland, the Netherlands, Norway, Denmark, and Sweden) with a set of control countries and find mixed results. In 4 of the 5 countries, the growth rate of emissions falls by between 0.5 and 1.7. Only the estimate for Finland is statistically significant at the 10 percent level, with the coefficient suggesting a drop in the growth rate of emissions of 1.7 percent.

Martin et al. (2014) assess the United Kingdom's Climate Change Levy's (CCL) impact on energy and emissions indicators for various manufacturing sectors. As discussed in Metcalf (2019), the CCL is not a true carbon tax given its differential taxation of fossil fuels. While CO_2 emissions fall by 8.4 percent, but imprecisely estimated, their results are also consistent with the CCL leading to fuel substitution away from electricity and toward coal. This follows from the lower tax rate on coal than natural gas.

A recent paper by Andersson (2019) focuses on the impact of Sweden's carbon tax on transportation emissions. He focuses on transportation as this is the sector most impacted by the Swedish carbon tax. He finds an emissions reduction on the order of 11 percent. While this might appear modest given the fact that Sweden has the highest carbon tax in the world, most analysts argue that the transportation sector is the most difficult sector to decarbonize given the efficiency of the internal combustion engine.

Turning to British Columbia, Rivers and Schaufele (2015) find that the province's carbon tax, which covers gasoline, diesel, and natural gas, significantly reduces gasoline consumption. They estimate that the carbon tax has a stronger impact on gasoline demand – by a factor of four – than a comparable increase in the price of gasoline, a surprising finding that the authors attribute to the high salience of the carbon tax. Metcalf (2019) estimated difference-in-difference regressions using Canadian province data and find that the BC tax reduced emissions on the order of 5 to 8 percent since it's imposition in 2008. Prettis (2019) estimates a 5 percent reduction in transportation emissions from the BC carbon tax, with potentially larger long-run emissions, but does not detect an economy-wide emissions reduction attributable to the tax.

As noted at the outset, this paper builds on Metcalf and Stock (2020). In addition to considering additional econometric model specifications for employment and GDP, we also assess the carbon taxes impacts on country emissions. We also test whether macroeconomic outcomes are affected by the use of carbon tax revenue. Specifically, we consider whether green tax reforms – reforms where carbon tax revenues are used to lower existing distortionary tax rates – has a different impact on macro outcomes than when the revenue is simply added to general revenue.[3]

III. Carbon Taxes in Europe

Carbon taxes were first enacted in Europe with Finland leading the way in 1990. Following an early wave of carbon tax enactments primarily in the Nordic countries, more countries enacted carbon taxes and currently sixteen European countries have carbon taxes in place. We focus on the so-called EU+ countries that are also part of the EU-ETS and so exclude Ukraine from our analysis. We focus on EU+ countries to control consistently for the impact of the ETS on growth. The ETS went into effect with a pilot phase (Phase I) in 2005. In Phase I, power stations and certain energy intensive sectors were subject to the cap.[4] Phase II (2008 –

[3] We can't rule out the possibility that adding carbon tax revenues to general revenue allows a country to avoid a future tax increase as opposed to an increase in spending. In that case, we would not expect a different outcome than when the revenue is explicitly earmarked for reductions in distortionary tax rates.

[4] The sectors are power stations and other combustion plants of at least 20 MW, oil refineries, coke ovens, iron and steel plants, cement clinker, glass, lime, bricks, ceramics, pulp, and paper and board. Aluminum, petrochemicals, ammonia, nitric, adipic, and glyoxylic acid production. and CO_2 capture, transport, and storage were added in Phase III.

2012) added domestic aviation (in 2012), and Phase III (2013 – 2020) added various additional sectors.[5]

Countries with carbon taxes are as follows (listed in chronological order of enactment):[6]

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.[7] 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

[5] Twenty-five of the thirty-one countries in our sample have been subject to the ETS from its inception. Romania and Bulgaria joined in 2007 while Norway, Iceland, and Liechtenstein joined the ETS starting with Phase II in 2008. Croatia joined the ETS as of Phase III in 2013. See European Commission (2015) for a history and membership of the ETS.

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

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

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 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).[8]

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

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

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): Slovenia was the first former Soviet block country to implement a carbon tax. 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 investments or distributed generation – geothermal primarily – investments (Carl and Fedor, 2016, and OECD, 2019).[9]

[9] 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.

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.[10] 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).

[10] 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.

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 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.

Table 1 summarizes information about carbon taxes across these EU+ countries. Figure 1 shows the time trend of carbon tax rates in the EU+ countries since their enactment. There is considerable variation in rates as well as time of enactment for the taxes. (Note that the scale of the top graph differs from that of the next two.)

Figure 2 shows GDP per capita growth rates before and after each country's enactment of the carbon tax. The dots indicate mean values and bars 90 percent confidence intervals. There is no clear pattern in changes in growth rates following enactment of the carbon tax.[11] We therefore turn next to an econometric analysis.

[11] The event study graphs are based on regressions without controls and simply illustrate the importance of undertaking a more systematic analysis. Graphs for employment and emissions are included in the Appendix.

IV. Data and Econometric Approach

Our data on real GDP and carbon tax rates come from the World Bank Group (2019a).[12] Employment data are from the EU Eurostat database. Data on the share of greenhouse gas emissions covered by the tax come from World Bank Group (2019a), and energy price and energy excise tax data are from the International Energy Agency (2019). Data on country carbon dioxide emissions from fuel consumption are from Eurostat and cover the years 1990 through 2018. We focus on carbon dioxide emissions from fuel combustion in road transport, the commercial and institutional sector, and the household sector. These are sectors most typically included in country level carbon taxes.

Identifying the dynamic causal effect of a carbon tax on GDP growth is complicated by the possibility of simultaneity: poor economic outcomes could lead the tax authorities to reduce the rate or to postpone a planned increase.[13] As discussed in Metcalf and Stock (2020), it is useful to think of changes to a carbon tax as having two components, one responding to historical economic growth, the other being unpredicted by past growth. Changes in the latter category could include tax changes based on historically legislated schedules, changes in ambition based on the environmental preferences of the party in power, or responses to international climate policy pressure. Our identifying assumption is that this latter category of

[12] Real carbon tax rates are nominal tax rates divided by the GDP deflator (home country currency), converted to US dollars at 2018 exchange rates. We used national statistical agency data for GDP and prices, instead of World Bank data, for Ireland and Norway. For Ireland, we used adjusted Gross National Income, which eliminates distortions from intellectual property inflows due to Ireland's status as a tax haven (Worstall, 2016), and the CPI. Norway maintains dual accounts, onshore and offshore, the latter including oil revenues; we use onshore GDP and its deflator to avoid spuriously confounding carbon tax effects with Norway's offshore oil production.

[13] British Columbia, for example, has announced a delay in the 2020 scheduled increase in its carbon tax due to the COVID-10 pandemic shock to the economy. See information at https://www2.gov.bc.ca/gov/content/environment/climate-change/planning-and-action/carbon-tax, accessed on June 5, 2020.

changes – those not predicted by historical own-country GDP growth and current and past international economic shocks – are exogenous. This assumption allows us to estimate the dynamic effect on GDP growth of the unexpected component of a carbon tax using the Jordà (2005) local projection (LP) method, adapted to panel data. Specifically, we use OLS to estimate a sequence of panel data regressions,

$$(1) \qquad 100\Delta ln(GDP_{it+h}) = \alpha_i + \Theta_h \tau_{it} + \beta(L)\tau_{it-1} + \delta(L)\Delta\, ln(GDP_{it-1}) + \gamma_t + u_{it}.$$

where τ_{it} is the real carbon tax rate for country *i* at date *t* and Θ_h is the effect of an unexpected change in the carbon tax rate at time *t* on annual GDP growth *h* periods hence.

In all regressions, the tax rate is interacted with its 2019 share of its emission coverage. This specification assumes that any damage (or benefit) of the tax to an economy would be, in the first instance, proportional to the covered share of the economy.

All regressions include both country and year fixed effects. Including the former addresses the possibility that countries with higher mean growth rates might be the ones more likely to adopt and increase a carbon tax, in which case the tax could spuriously appear beneficial. In principle, under our exogeneity assumption it should not be necessary to include year effects, but we do so for two reasons. First, because the countries are all European, they share common political pressures, which could induce common changes in carbon prices, and have common economic influences. These common influences, even if exogenous, could appear as confounders, so we identify the effect of the tax increase from country-level surprises in carbon prices after controlling for common movements (year effects). Second, even if year effects are not needed for identification, because of common macroeconomic movements (such as the global recession of 2009), including year effects could reduce standard errors. Standard errors are heteroskedasticity-robust (Plagborg-Moller and Wolf (2019)).

We also estimate panel structural VAR (SVAR) regressions with the tax rate and GDP growth as dependent variables, four annual lags of each as regressors, and country and year fixed effects. This is a panel version of the standard time series structural VAR. The identification conditions are the same as in the LP regression. In population the estimand is the same. Although the SVAR and LP methods have the same identifying condition and the same estimand, in finite samples they can differ and they will have different standard errors. Thus, using the SVAR estimator provides a robustness check on the LP estimator. SVAR standard errors are computed by parametric bootstrap.[14]

In Metcalf and Stock (2020), we also estimated distributed lag regressions. These regressions require the stronger identification condition that the carbon tax is strictly exogenous, that is, there is no feedback from GDP growth to the tax rate. We test this condition by computing a test of feedback from GDP growth to the tax rate, that is, a panel Granger Causality test of the coefficients on GDP growth in a regression of the carbon tax rate on its lags and lagged GDP growth. To ensure stationary regressors so that standard F critical values can be used, we compute this test using the growth rate of the variables. As discussed in the next section, the test tends to reject lack of feedback to the tax rate (at least at the 10 percent level), indicating that the distributed lag identifying conditions are not supported by the data. Accordingly, we do not present distributed lag results here.

[14] See Stock and Watson (2018) and Plagborg-Moller and Wolf (2019) for details on methodology and relation between VARs and LPs.

We consider the counterfactual of a one-time permanent increase in the carbon tax by $40, for a tax that covers 30% of the country's emissions, a coverage rate that is close to the sample mean. We compute this dynamic response from the LP and SVAR impulse responses using the method in Sims (1986), which entails computing the sequence of shocks necessary to yield the specified counterfactual carbon tax increase. In practice, the carbon tax series is highly persistent so the dynamic effects we estimate here are close to the (scaled) structural impulse response functions at the horizons we consider.

A key issue in the dynamic model is the long run effect of the carbon tax on the growth rate of GDP, that is, whether a carbon tax permanently changes not just the level of GDP but also the slope of the GDP growth path. The standard theory underlying computable dynamic equilibrium models of a carbon tax models the long-run growth rate as determined by fundamentals, and that those fundamentals are not affected by the relative price change induced by carbon tax. If so, the tax might affect GDP growth in the short run but would revert to the long run growth rate in time. In effect, the tax would shift GDP to a new level after which it would move in parallel with its path had the carbon tax not been imposed, see for example the Goulder and Hafstead (2017) E3 model or Nordhaus's DICE model.[15]

This "parallel path" hypothesis imposes a testable restriction on the LP and SVAR specifications, specifically that the long-run effect of a shock to the carbon tax on GDP growth is zero. We estimated the LP and SVAR specifications both with this zero long-run growth effect restriction imposed ("restricted" case) and not imposed ("unrestricted"). In both the SVAR and

[15] Models have been developed that allow the long run growth rate of GDP to be affected by climate damages. See, for example, Moyer et al. (2014). But this is more the exception than the rule.

LP specifications, in the unrestricted case τ enters in levels, in the restricted case, τ enters in first differences. For the SVAR, the restriction is that the long-run structural impulse response from the tax to GDP growth in the levels specification is zero, which we test directly. Because the LP approach computes impulse responses out to a maximum finite horizon h in equation (1), it does not estimate the long-term effect at arbitrarily distant horizons. Consequently, for the LP test of the long-run restriction, we approximate the long-term effect by the effect at the 8-year horizon.

The discussion in this section has focused on the effect of a carbon tax on GDP growth. We use the same methods to analyze the effect on the growth rate of employment and emissions.

V. Results

We begin with results for GDP, then turn to employment and emissions.

A. GDP

Figure 3 shows the IRF for the LP model for real GDP, estimated using all 31 countries over the full 1985-2018 sample, where the carbon tax rate is interacted with the share of emissions covered by the tax. Figure 3a shows results from the unrestricted model, that is, the model that allows for a nonzero long-term effect of the tax on GDP growth. The predicted effect is positive in each year through year 6 except for year 4. In no year, however, is the effect significant at the 5% level (in most years it is within one standard error of zero). The results for the restricted model (figure 3b), in which a zero long-term effect of the tax rate on GDP growth is imposed, are similar to those for the unrestricted model. Again, the point estimate is generally no more than one standard deviation away from zero.

Figure 4 shows the IRFs for the SVAR model. The unrestricted IRF (figure 4a) is always positive and near constant at about 0.4 percentage points. The restricted IRF (figure 4b) is much closer to zero and, in fact, the period 6 estimate is essentially zero (though not imposed explicitly by the model). In general, the SVAR results are very similar to the LP results. In all cases, the standard error bands in the SVAR restricted models approach zero in later years. For the restricted models, this is a consequence of the joint stationarity of GDP growth and the change in the carbon tax. For the unrestricted models, this convergence of the IRF to zero need not be the case, but the restriction is supported by the data so the unrestricted and restricted estimates are similar. The SVAR and LP models are consistent estimators of the same objects in population, but even so it is striking how similar the empirical results are using the two methods. This is true generically for these data, across dependent variables and regressors. We therefore henceforth only report LP results in the text, relegating selected SVAR estimates for key specifications in the Appendix.

Table 2 summarizes the results for tests of the restriction that the long-run effect on the growth rate of GDP of the tax is zero. Neither the LP nor SVAR tests reject this hypothesis: For the LP model, the test statistic equals 0.33 (p-value = 0.75). For the SVAR model, the test statistic is 1.34 (p-value = 0.18). We find similar test results for other cuts of the data (discussed below) and report results in Table 2.

Table 3 reports tests of the hypothesis that the carbon tax rate is strictly exogenous (Granger causality tests). The test statistic equals 2.21 for our full sample and has a p-value of 0.066, rejecting strict exogeneity at the 10 percent level. We reject strict exogeneity for the GDP regressions at the 10 percent level or lower for other cuts of the data (see Table 3).

The results illustrated in Figures 3 and 4 do not suggest particularly large positive impacts of a carbon tax on GDP. But neither do they support a claim of large adverse impacts. It is possible, however, that effects accumulate over time. Figure 5 shows cumulative IRSs for the LP model. The unrestricted model cumulative IRF (top panel) shows a positive impact on growth by year 6 of roughly 2 percentage points but standard error bands are large with the 95 percent confidence interval ranging from -2 to +6 percentage points. When restricting the long-run growth rate to be zero, the impact is now negligible in all six years. In this and subsequent sub-samples, we find no evidence to support the view that European carbon taxes have had a significant impact on GDP, either positive or negative.

B. Total Employment

Figure 6 shows IRFs for total employment. In both the unrestricted and restricted cases, employment initially rises and then subsequently falls. The cumulative impact (Figure 7) is positive over a six year period with a point estimate of 1.15 percentage points in the unrestricted LP model and 0.35 percentage points in the restricted model. In neither model do we reject a zero cumulative impact. Results (in the Appendix) for manufacturing employment are similar to total employment but the estimates are less precise. As with GDP, we can reject significant negative employment impacts from the carbon tax.

C. Emissions

Impulse response functions measure annual changes in the variables of interest following a policy change such as the $40 per ton carbon tax modeled throughout. We focus on the effect of the carbon tax on the level of CO_2 emissions in road transport and the commercial, institutional, and household sectors. This levels effect is estimated by the cumulative structural impulse response function, because emissions enter in growth rates. Unlike GDP and employment, there is no a priori expectation of a "parallel path" hypothesis, that is, that in the long run the growth rate of emissions would be unaffected by the carbon tax. In fact, a basic premise of climate policy is that a tax could help bend the curve on emissions growth rates (through innovation and green technological progress). But we would be surprised if we found evidence of a change in the long run emissions growth rate given the length of our sample and the magnitude of most country tax rates. While we can reject the hypothesis of zero long-run changes in the emissions growth rate for the full sample in the LP model, we cannot reject it in the SVAR model nor can we reject the zero long-run change in other samples for either model (Table 3).

Results for the full sample are shown in Figure 8. Emissions fall by 6.5 percentage points by the end of year 6 in the unrestricted model (top panel) though standard error bands are wide and we cannot reject no change in emissions. In the restricted model (bottom panel), emissions fall by as much as 5.6 percentage points in the first 4 years but stabilize at a 3.8 percent reduction by year 6. The estimates are imprecise, with a 95% confidence interval including both no emissions reductions and larger emissions reductions.

We also note that while strict exogeneity is rejected in some or all of the samples (at a 10 percent level or better) for GDP and employment measures, it is generally not rejected for emissions. This is perhaps not surprising since we would expect that adverse macro shocks would be readily observable to decision-makers and might lead to policy changes in climate policy. While a transitory increase in emissions might, through the political process, spur greater ambition, the empirical evidence does not suggest that this channel is a significant determinant of tax rate changes.

VI. Robustness

The finding of an overall slight positive effect on economic activity is intriguing, and raises the question as to whether this positive effect could arise from the use of the carbon tax revenue to improve the overall efficiency of the tax system, giving rise to a double dividend. Another possibility is that countries with a long experience with the carbon tax have a different response than countries with less experience. There is in fact considerable variation in tax rates, use of revenues, or the length of time the carbon tax has been in effect. We explore in this section whether any of these factors matter for GDP or employment growth as well as emissions.

A. Revenue Recycling

We begin by asking whether growth impacts are larger for those countries that stated an intention to recycle the carbon tax revenue through cuts in income or payroll tax rates. The Double Dividend Hypothesis suggests this should be efficiency enhancing and, presumably, improve growth prospects (e.g. Goulder, 1995). There is limited data on how countries actually use carbon tax revenues. Many early moving countries (Denmark, Sweden, Norway, Finland) enacted carbon taxes as part of a Green Tax Reform designed to reduce marginal income tax rates. Switzerland explicitly earmarked two-thirds of carbon tax revenue for tax cuts. Portugal also earmarked revenue for tax cuts as part of a Green Tax Reform. We treat this group of six countries as a group that partially or fully used carbon tax revenue to lower existing income tax rates. While our designation is necessarily imprecise and recognizing that tax revenues are fungible, we investigate whether growth impacts are larger for this group of countries relative to the full sample of carbon tax enacting countries. Note too that we consider countries to be revenue recycling based on stated intentions rather than actual outcomes. Regardless of what countries *say* they are going to do, we cannot observe the counterfactual outcome had the carbon taxes not been implemented and it is possible that some of these countries used carbon tax revenue for non-revenue recycling purposes (and vice versa for those countries that have not stated an intention to recycle carbon tax revenues through lower tax rates).

Figure 9 shows the results for GDP growth (top panel) and total employment (bottom panel) from the LP regressions focusing on these six countries relative to countries with no carbon tax. GDP growth is initially a bit larger in this subsample (0.5 percent growth in GDP rate in year 2 versus 0.2 percent in full carbon tax sample as per figure 3b) but the coefficients are imprecisely estimated, and we cannot reject that the growth rates are the same (and both equal to zero). The employment impacts are initially larger (bottom panel) than in the full sample (compare to Figure 6b). The growth rate in year 2 is 0.9 percentage points higher whereas in the full sample for the comparable regression, it is 0.5 percentage points higher. The cumulative impact by year 6 is 0.8 percentage points higher employment growth versus 0.4 percentage points in the full sample. As with GDP growth, we can't reject that they are the same (and equal to zero). With only six countries in the treatment group (and short spans of the carbon tax for Switzerland and Portugal), it is difficult to make definitive statements about revenue recycling with our data.

Another way to get at this question is to look at those countries that are not deemed revenue recycling countries. This is a larger group and perhaps we can observe meaningful differences here. Figure 10 shows GDP growth impacts (top panel) and total employment impacts. The estimates are quite noisy but suggest an initial decline in GDP and employment followed by a rebound in years 3 – 5. The effect fades away by year 6. The cumulative impact for GDP is positive but barely exceeds its standard error. The cumulative impact by year six for total employment is negative but less than its standard error. The point estimates provide some modest support for growth enhancing benefits of recycling carbon tax revenues through tax cuts, but standard errors are large and our measure of revenue recycling reflects only stated initial intentions, not actual use of the revenues, so one should be cautious before drawing conclusions about the efficiency benefits of revenue recycling through tax cuts based on these regressions.

Emissions initially fall faster in the non-revenue recycling countries relative to the revenue recycling countries, but emissions reductions begin to converge: emissions are 4.9 percent lower in the non-revenue recycling countries by year 6 while they are 3.1 percent lower in the revenue recycling countries (Figure 11). As in the full sample, the estimates are imprecise, and we cannot reject no change in cumulative emissions.[16]

B. Large Carbon Taxes

Countries also differ in the magnitude of their carbon tax rates. We would expect larger impacts in countries with higher tax rates, holding all else equal. Here we focus on those countries whose share-weighted carbon tax rates are at least $10 per ton in at least one year

[16] Results look somewhat different in the regressions where we allow the long run growth rate of emissions to change. Cumulative emissions fall in both samples with a larger cumulative decline in the non-revenue recycling countries. Emissions fall by 3.7 percent in the revenue recycling countries by year 6 and by 18.6 percent in the non-revenue recycling countries. For this latter set of countries, the 95 percent confidence interval in year 6 runs from -4.7 to -32.6 percent.

(thus corresponding to $30/ton covering one-third of emissions). Those countries are Denmark, Finland, France, Ireland, Norway, Sweden, and Switzerland. Figure 12 shows the impact of the tax in these countries on GDP growth. In both the unrestricted model (top panel) and restricted model (bottom panel) the GDP growth impact is initially positive, dips negative in years 3 and 4, and then returns to positive. The cumulative impact by year 6 is 1.75 percentage points in the unrestricted model and -0.16 percentage points in the restricted model. A similar pattern holds for employment (not shown).

Surprisingly, emissions fall by only 2 percent in the unrestricted and restricted models by year 6 (Figure 13); this is a smaller amount than in the full sample where emissions fell by 6.5 percent in the unrestricted model and 3.8 percent in the restricted model. As with the full sample, coefficient estimates are imprecisely estimated.

C. Scandinavia

We also considered whether our results are being driven by the early Scandinavian adopters (Denmark, Finland, Norway and Sweden). The GDP and total employment impulse response functions for the Scandinavian countries are quite noisy and hover around zero (with large standard errors). Dropping these countries from the EU data set also increase the standard errors considerably. While the Scandinavian countries are not driving results, they help reduce standard errors considerably. We report those results in the appendix.

D. Alternative Tax Rate Measures

Our tax rate series is based on data collected by the World Bank and uses the highest carbon tax rate (per ton CO_2) when there are multiple rates. In most cases, this highest rate is the rate on gasoline and diesel for road use. We multiply that rate by the share of emissions covered by the carbon tax in 2018. Recently Dolphin et al. (2019) have constructed a series of tax rates on carbon dioxide emissions built up from fuel level tax rates. Working with sector and fuel specific data, they compute the share of various fossil fuels in each sector covered by a carbon tax and construct an *emissions weighted carbon price* (ECP) as the weighted average of sector-fuel specific carbon tax rates, weighted by their emissions share in 2013. We re-estimated our regressions using their data, and selected results are shown in the Appendix.[17] Despite differences in the base year for fixing emissions shares, exchange rates, and different methodologies for constructing the share weighted tax rates, the results using the Dophin et al (2019) emissions-weighted carbon price are very similar to those reported using our price derived from World Bank data. We conclude from this that our results are robust to how carbon taxes are measured – whether based on country reported carbon tax rates or built up from sector specific excise tax rates for taxing carbon.

VII. Conclusion

Placing a price on carbon pollution is widely viewed as the most cost-effective approach to reducing emissions. Resistance to this approach is significant in part due to concerns about the economic impact on jobs and growth. Using variation in the use of carbon taxes in European countries that are all part of the EU Emission Trading System (ETS), we find no evidence to support claims that the tax would adversely impact employment or GDP growth. We find modest evidence for emissions reductions arising from the tax. It is worth noting, however, that since the sectors for which emission reductions are least costly are already

[17] We thank the authors for sharing the country aggregate tax rates with us.

covered by the ETS and so not subject to the carbon tax, emission reductions in countries that apply a broad-based carbon tax should view these reductions as lower bounds on potential emission reductions.

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Table 1. EU+ Carbon Taxes

Country	Year of Enactment	Rate in 2018 (USD per metric ton)	Intended Revenue Recycling?	Share of Greenhouse Gas Emissions in 2019 Covered by Tax	Carbon Tax Revenue in 2018 (USD Millions)
Denmark (DNK)	1992	24.92	Yes	40%	543.4
Estonia (EST)	2000	3.65	No	3%	2.8
Finland (FIN)	1990	70.65	Yes	36%	1,458.6
France (FRA)	2014	57.57	No	35%	9,263.0
Iceland (ISL)	2010	25.88	No	29%	44.0
Ireland (IRL)	2010	24.92	No	49%	488.8
Latvia (LVA)	2004	9.01	No	15%	9.1
Norway (NOR)	1991	49.30	Yes	62%	1,659.8
Poland (POL)	1990	0.16	No	4%	1.2
Portugal (PRT)	2015	11.54	Yes	29%	154.9
Slovenia (SVN)	1996	29.74	No	24%	83.1
Spain (ESP)	2014	30.87	No	3%	123.6
Sweden (SWE)	1991	128.91	Yes	40%	2,572.3
Switzerland (CHE)	2008	80.70	Yes	33%	1,177.7
UK (GBR)	2013	25.71	No	23%	1,091.0

Notes: Coverage is the share of a country's emissions covered by the carbon tax. See text for revenue recycling details.

Source: World Bank Group (2019a)

Table 2. Test of Long Run Effect of Carbon Tax on Growth Rates and Emissions

	GDP	GDP per Capita	Total Employment	Manufacturing Employment	Emissions
Full Sample					
LP	0.33	-0.17	-0.63	-3.37	-2.09
	0.75	0.87	0.53	0.001	0.04
SVAR	1.34	2.07	0.62	-0.51	-1.26
	0.18	0.04	0.53	0.61	0.21
Revenue Recycling Countries					
LP	0.05	-0.44	-0.72	-3.59	-0.95
	0.96	0.66	0.47	0.000	0.34
SVAR	1.39	2.43	0.17	-0.46	-0.40
	0.16	0.02	0.87	0.65	0.69
Large Carbon Tax Countries					
LP	-0.41	-0.36	0.14	-3.29	-0.53
	0.69	0.72	0.89	0.001	0.60
SVAR	1.00	0.92	1.23	-0.16	-0.34
	0.32	0.36	0.22	0.87	0.73
Scandinavian Countries					
LP	-0.44	-0.60	0.80	-2.20	0.19
	0.66	0.55	0.42	0.03	0.85
SVAR	0.95	1.00	1.04	0.16	0.16
	0.34	0.32	0.30	0.87	0.87

Table reports results of the test that there is no long-run change in the growth rate. Failure to reject the null supports the no long-run change hypothesis. The table reports the t-statistic for the test in the top row and its p-value in the second row. See text for description of test.

Table 3. Test of Strict Exogeneity

	GDP	GDP per Capita	Total Employment	Manufacturing Employment	Emissions
Full Sample	2.21 0.066	2.53 0.038	1.04 0.384	0.82 0.51	0.65 0.63
Revenue Recycling Countries	1.98 0.094	2.02 0.089	1.05 0.38	0.63 0.64	0.70 0.59
Large Carbon Tax Countries	3.86 0.004	4.09 0.003	2.41 0.047	1.97 0.096	1.57 0.18
Scandinavian Countries	2.55 0.037	2.54 0.038	3.65 0.006	1.60 0.17	3.81 0.004

Table reports results of a strict exogeneity test that there is no feedback from shocks to GDP to tax rates. The table reports the F statistic with (8, inf) degrees of freedom in the top row and its p-value in the second row. See text for description of test.

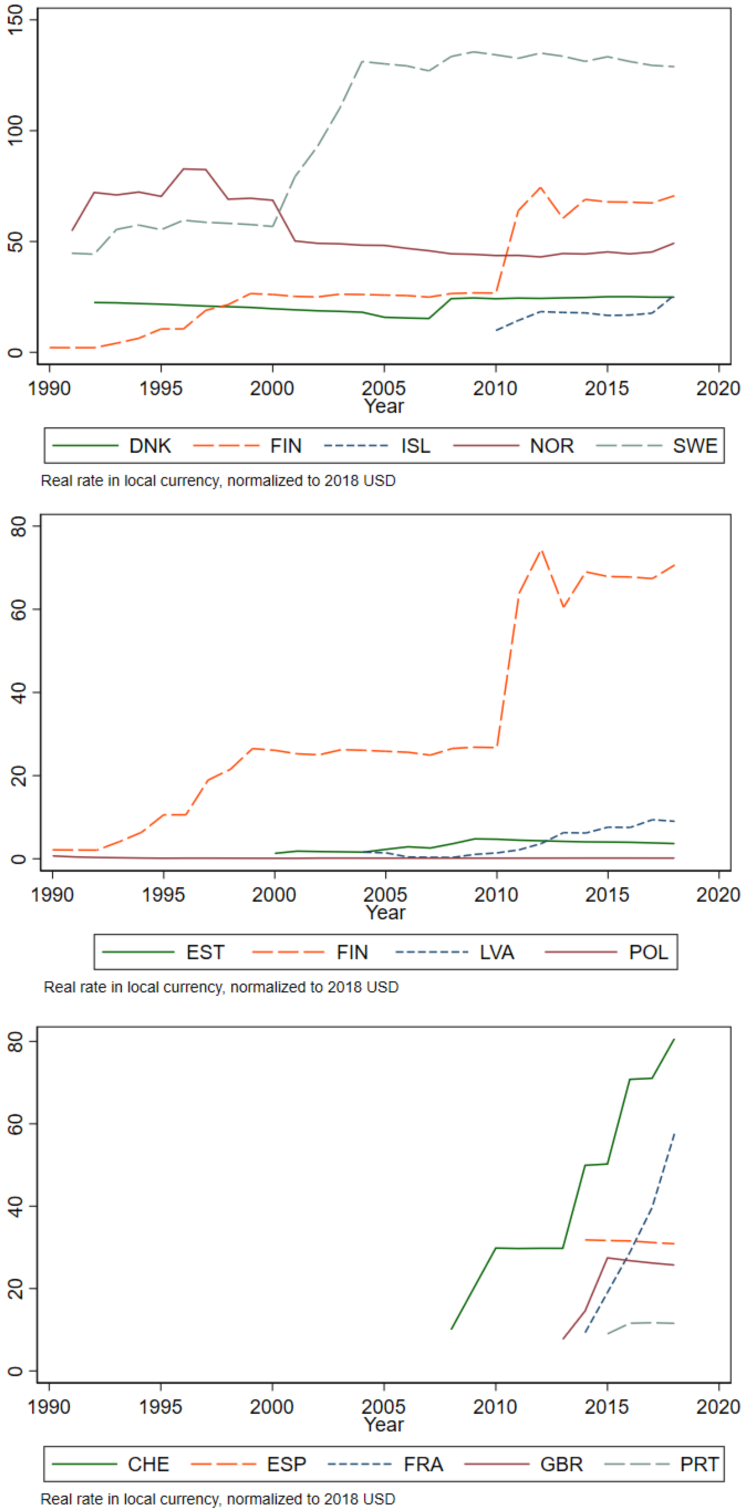

Figure 1. Real Carbon Tax Rates Over Time
(See Table 1 for Country Abbreviations)

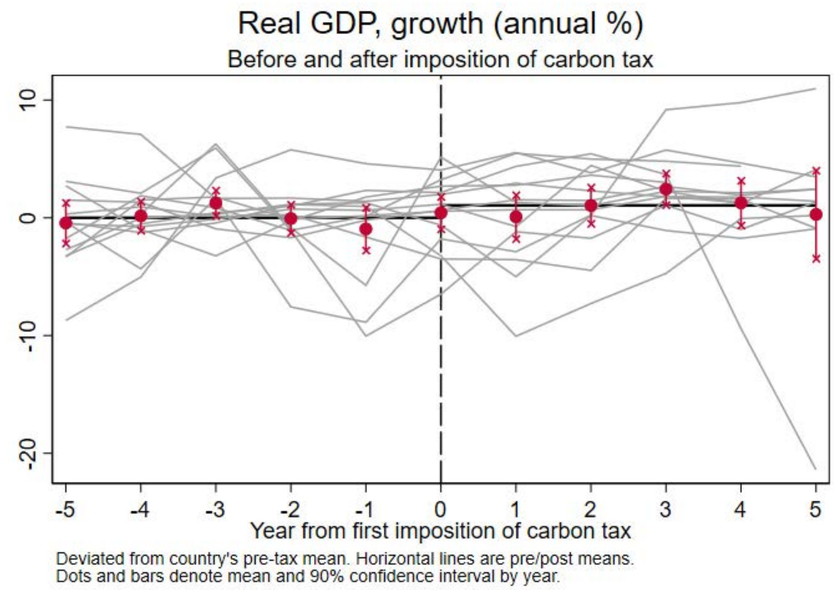

Figure 2. Carbon Tax Enactment and GDP Per Capita Growth Rate

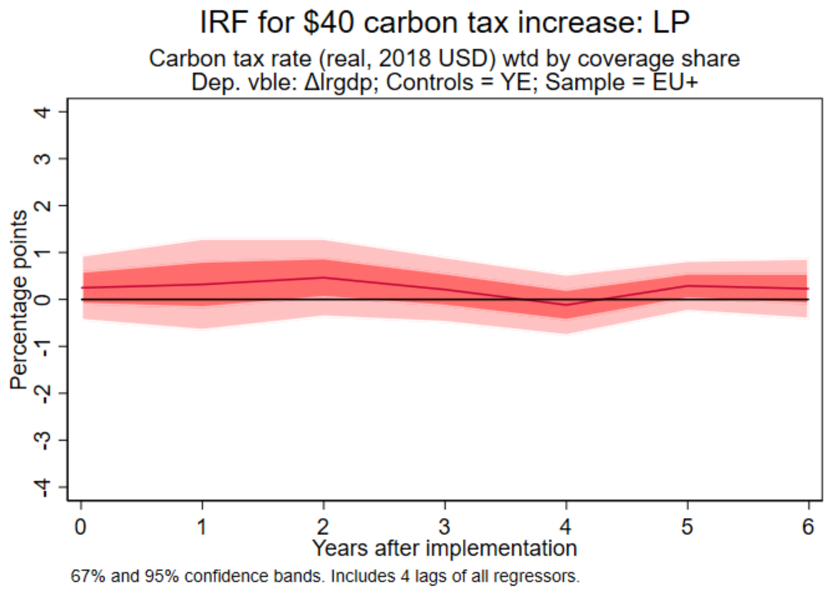

Figure 3a. GDP IRF for LP Regression – Unrestricted

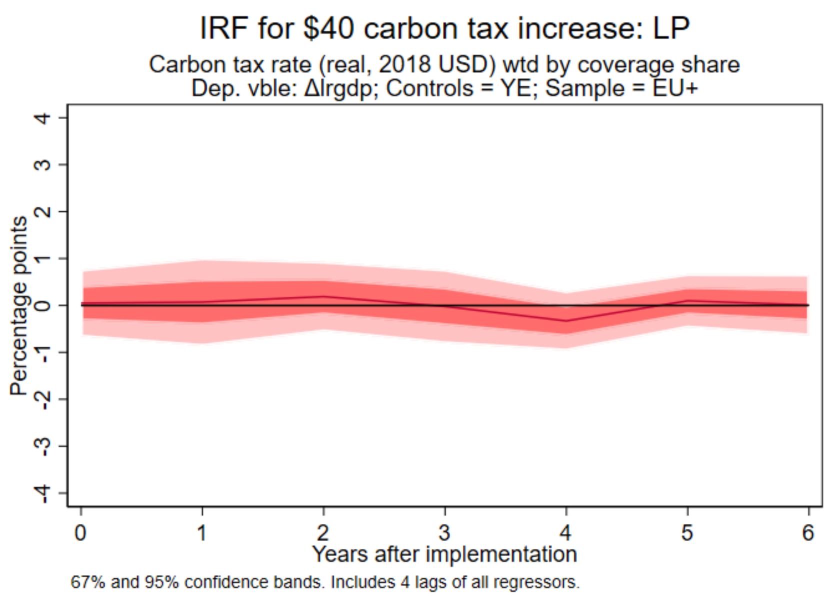

Figure 3b. GDP IRF for LP Regression – Restricted

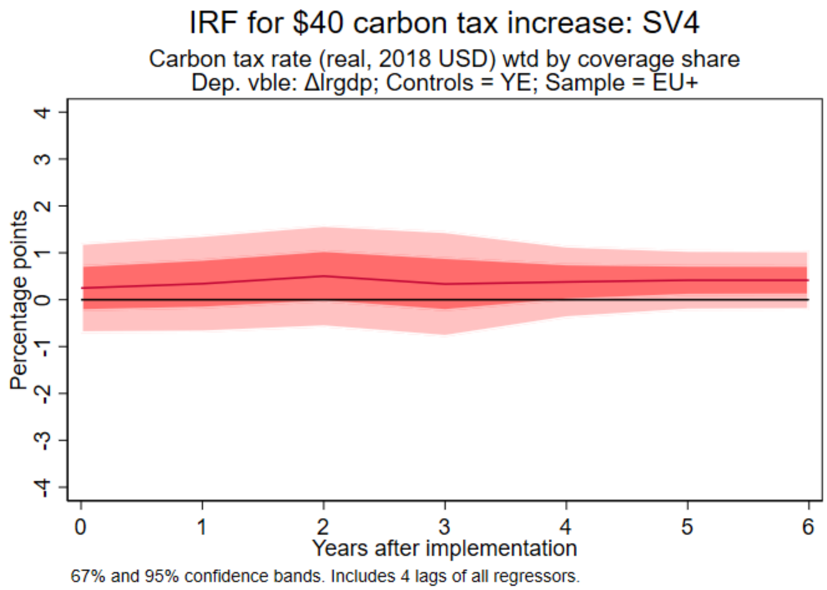

Figure 4a. GDP IRF for SVAR Regression – Unrestricted

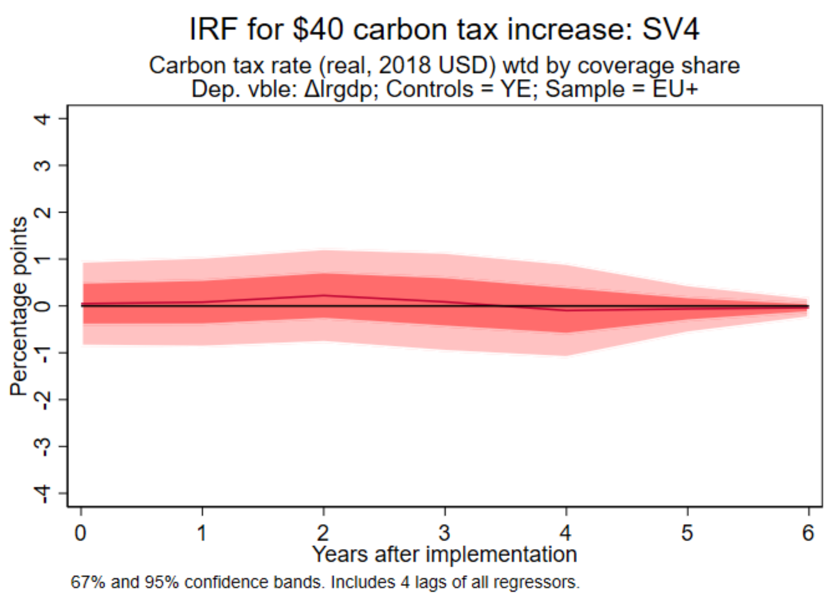

Figure 4b. GDP IRF for SVAR Regression – Restricted

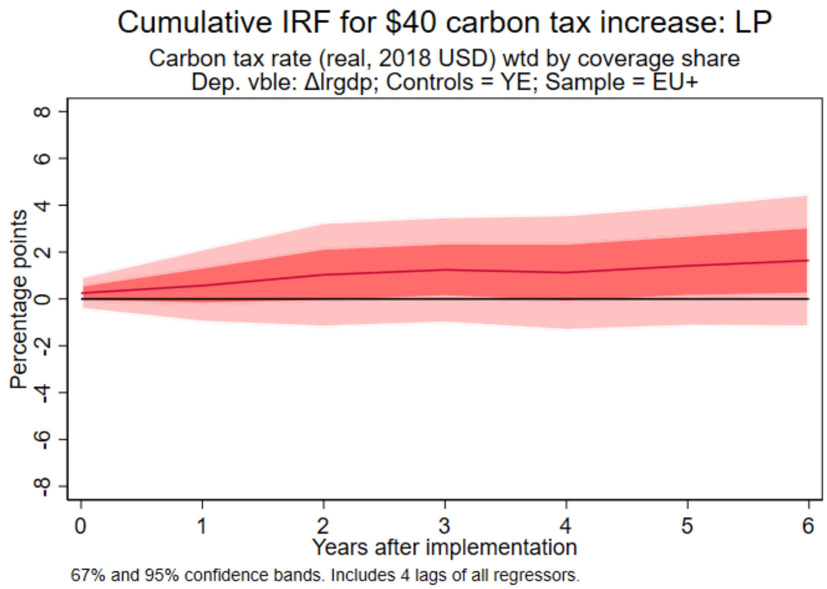

Figure 5a. GDP CIRF for LP Regression – Unrestricted

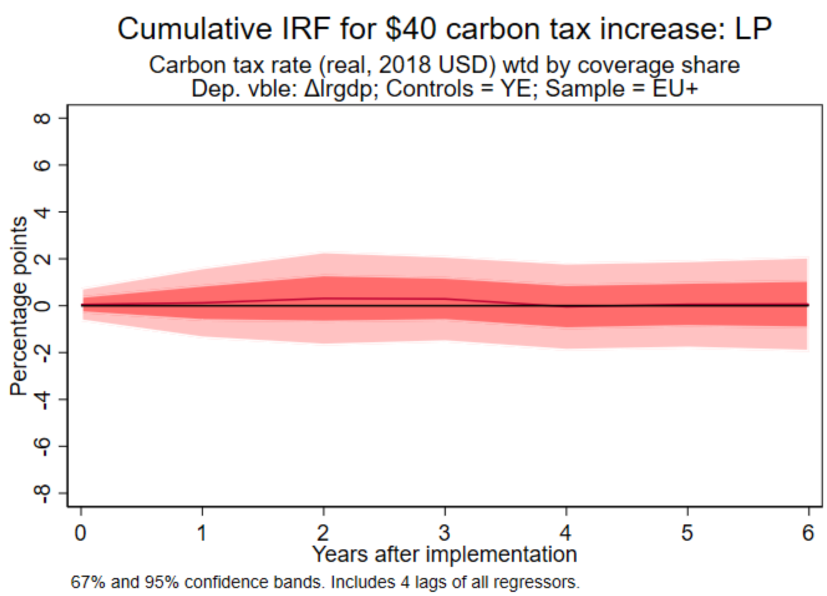

Figure 5b. GDP CIRF for LP Regression – Restricted

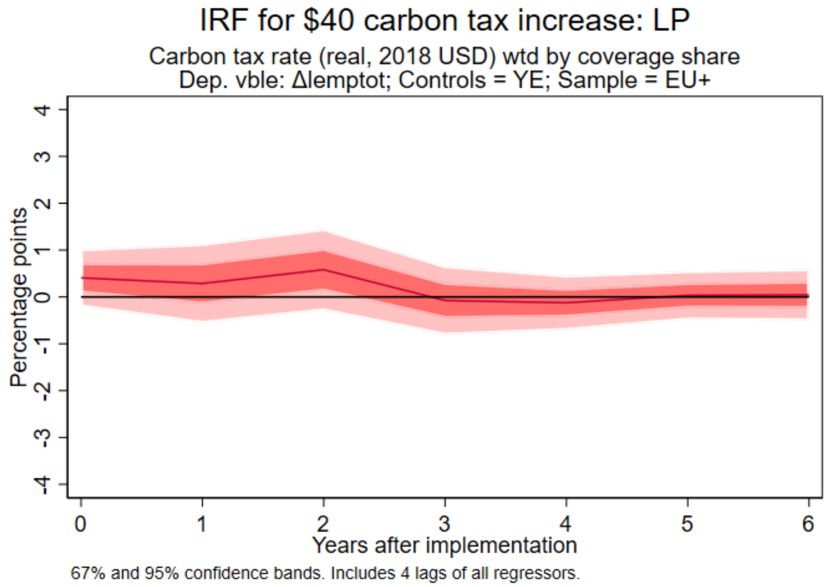

Figure 6a. Total Employment IRF for LP Regression – Unrestricted

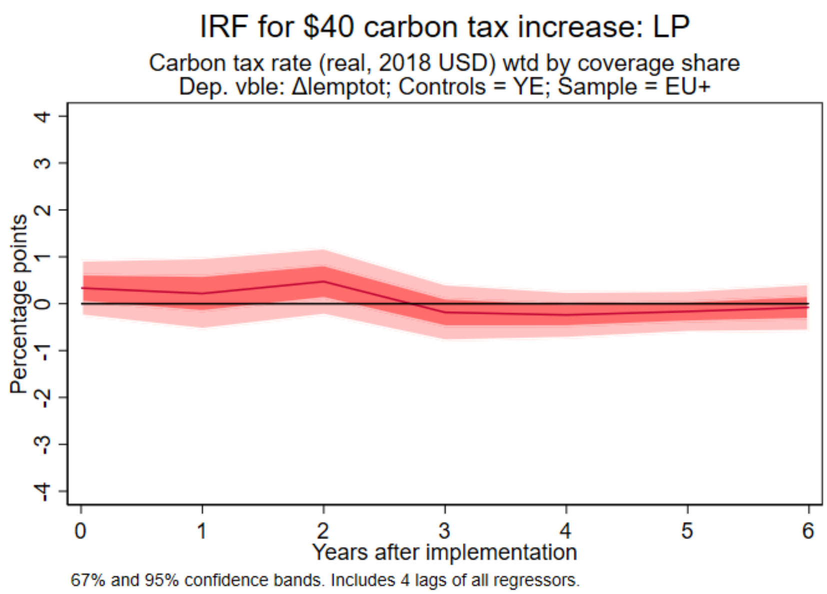

Figure 6b. Total Employment IRF for LP Regression – Restricted

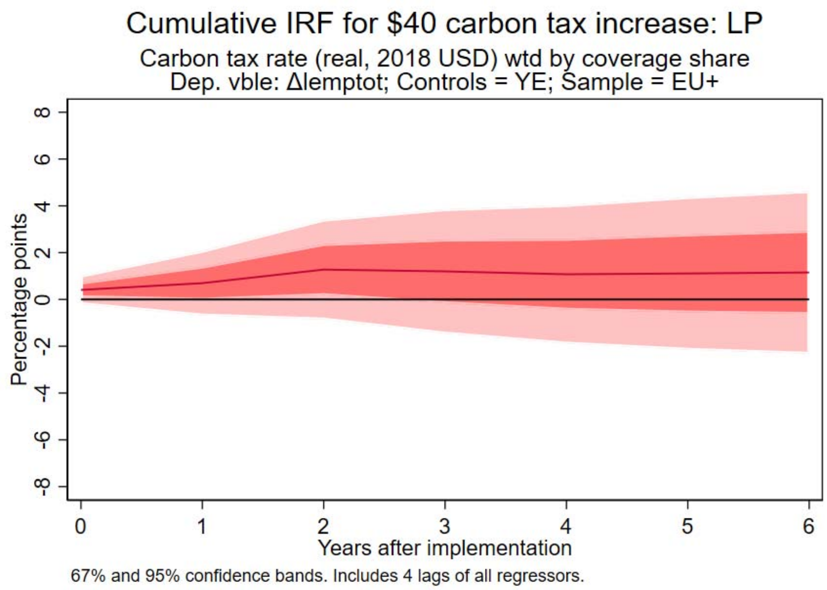

Figure 7a. Total Employment CIRF for LP Regression – Unrestricted

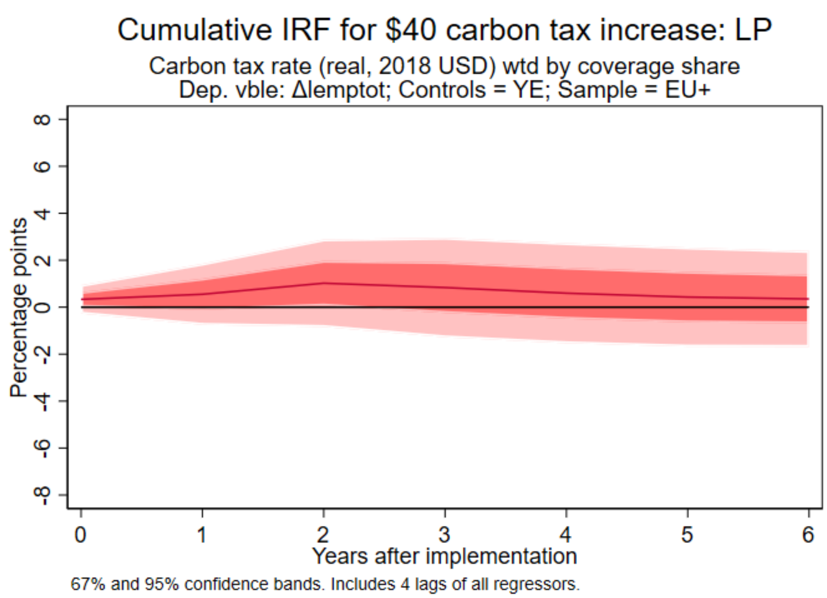

Figure 7b. Total Employment CIRF for LP Regression – Restricted

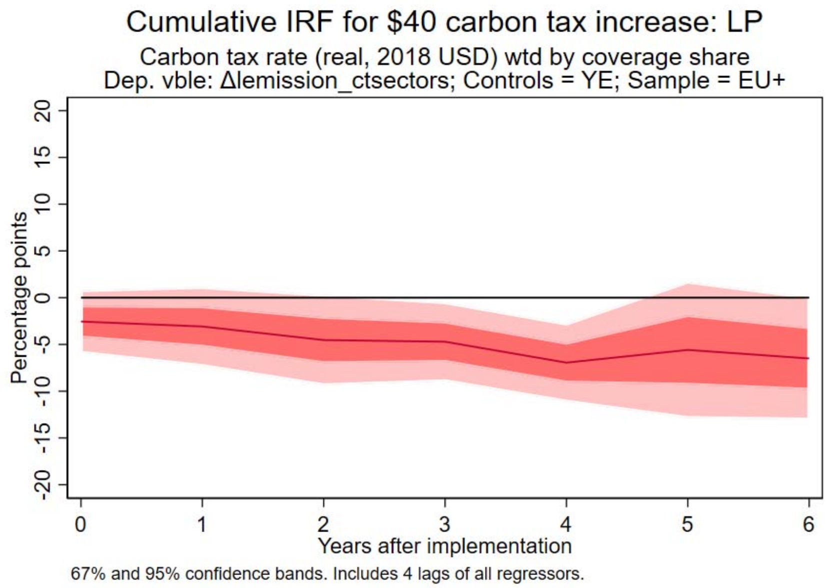

Figure 8a. Emissions CIRF for LP Regression – Unrestricted

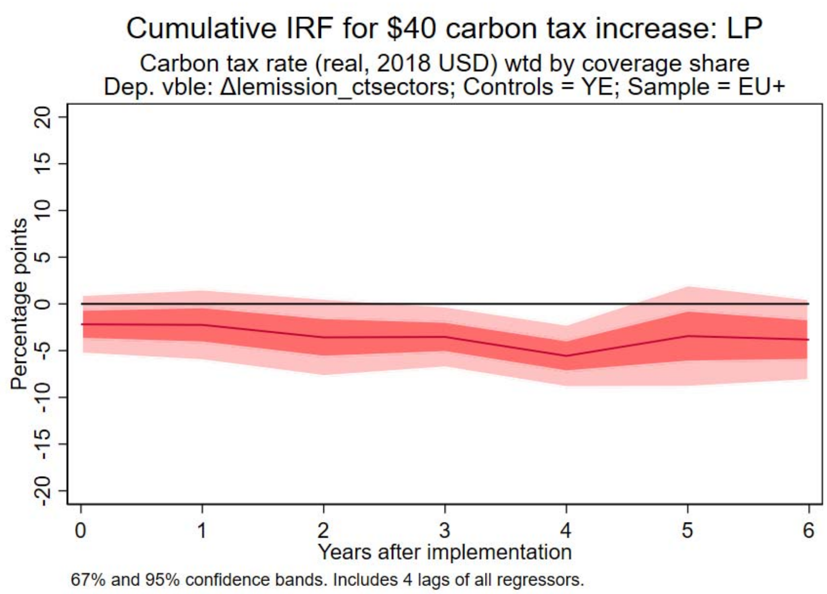

Figure 8b. Emissions CIRF for LP Regression – Restricted

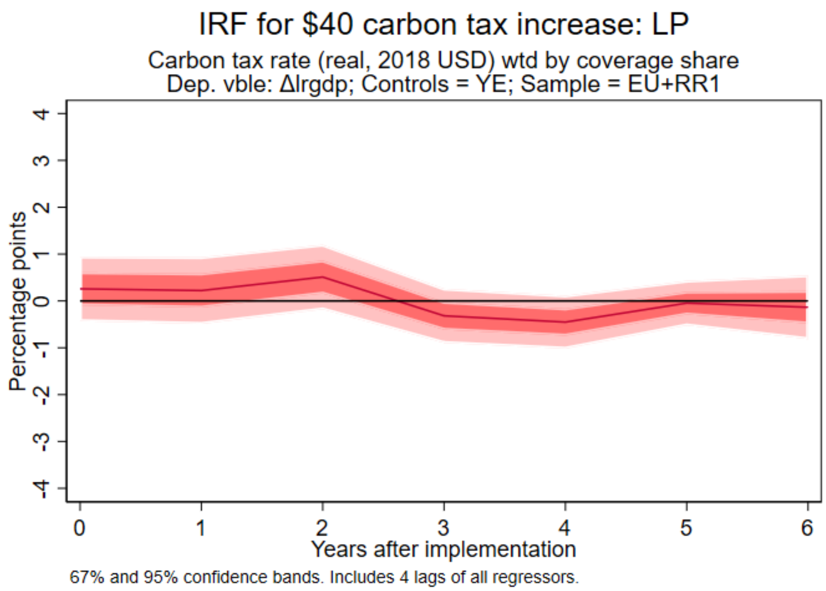

Figure 9a. GDP IRF for LP Regression – Restricted:
Revenue Recycling Carbon Tax Countries Only

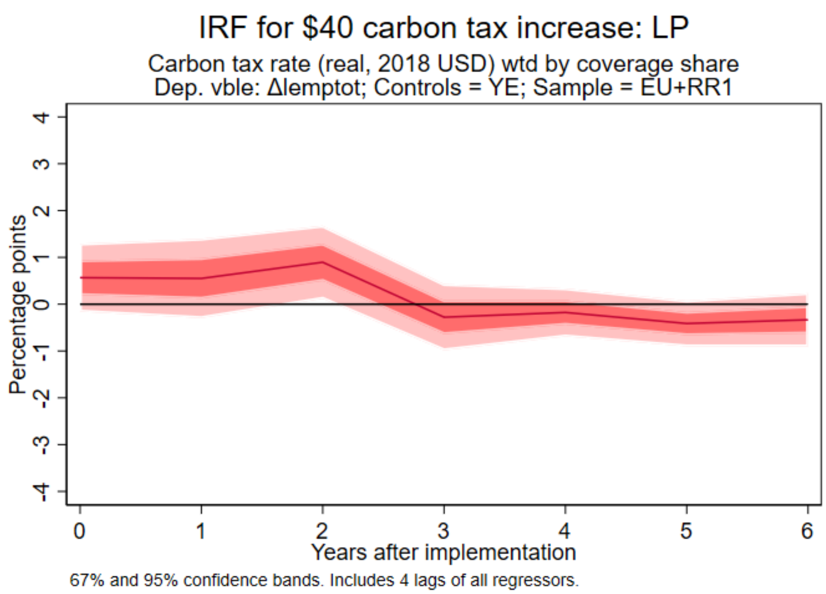

Figure 9b. Total Employment IRF for LP Regression – Restricted:
Revenue Recycling Carbon Tax Countries Only

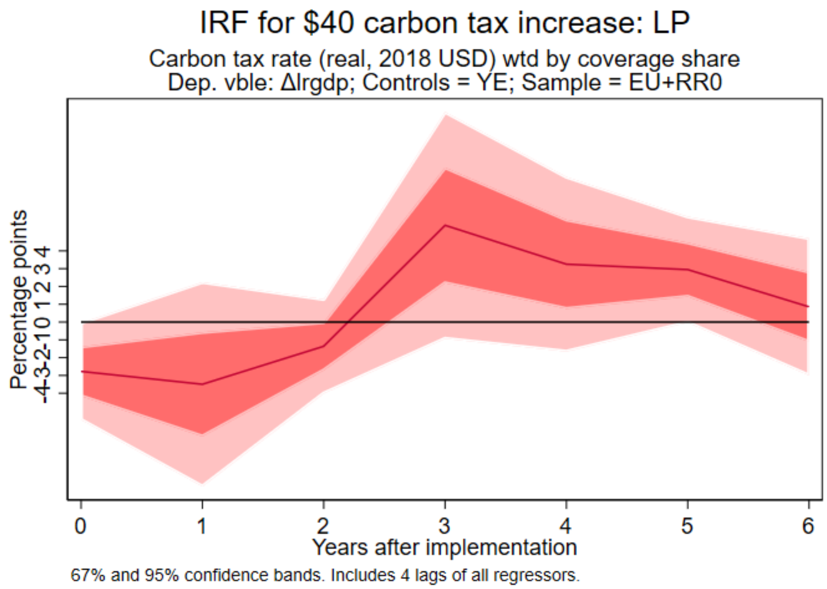

Figure 10a. GEP IRF for LP Regression – Restricted: Non-Revenue Recycling Carbon Tax Countries Only

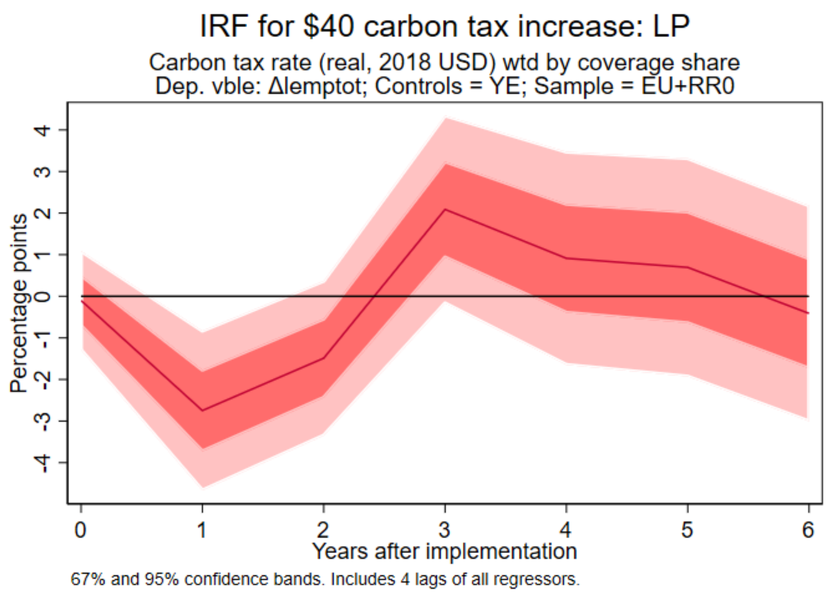

Figure 10b. Total Employment IRF for LP Regression – Restricted: Non-Revenue Recycling Carbon Tax Countries Only

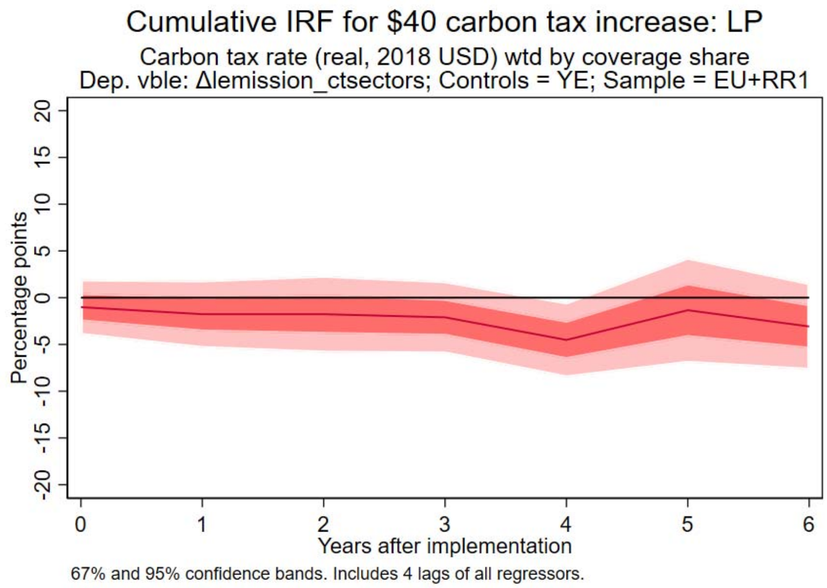

Figure 11a. Emissions CIRF for LP Regression – Restricted: Revenue Recycling Countries

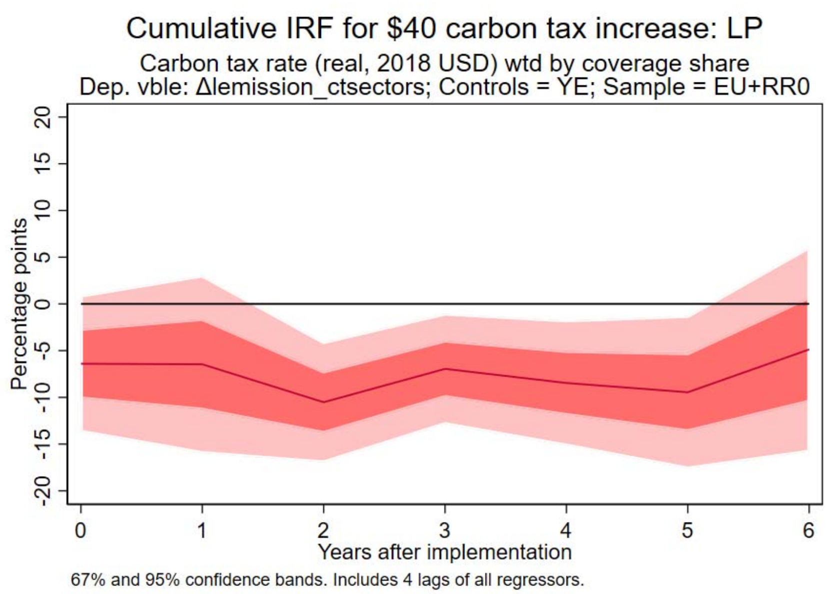

Figure 11b. Emissions CIRF for LP Regression – Restricted: Non – Revenue Recycling Countries

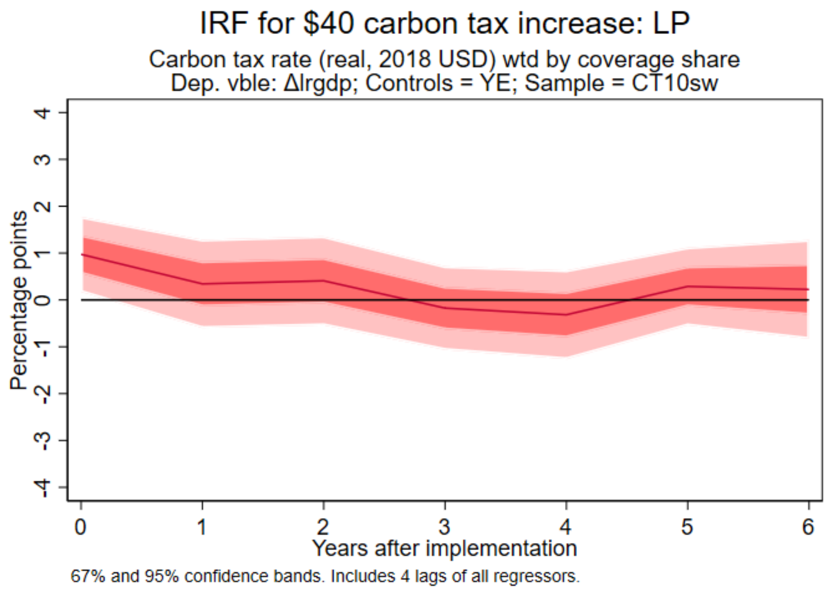

Figure 12a. GDP IRF for LP Regression – Unrestricted:
Large Carbon Tax Countries Only

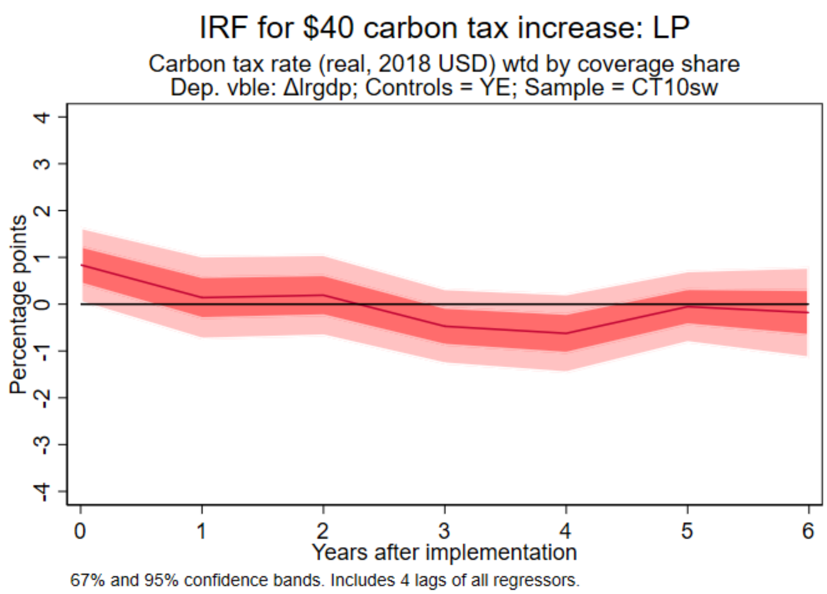

Figure 12b. GDP IRF for LP Regression – Restricted:
Large Carbon Tax Countries Only

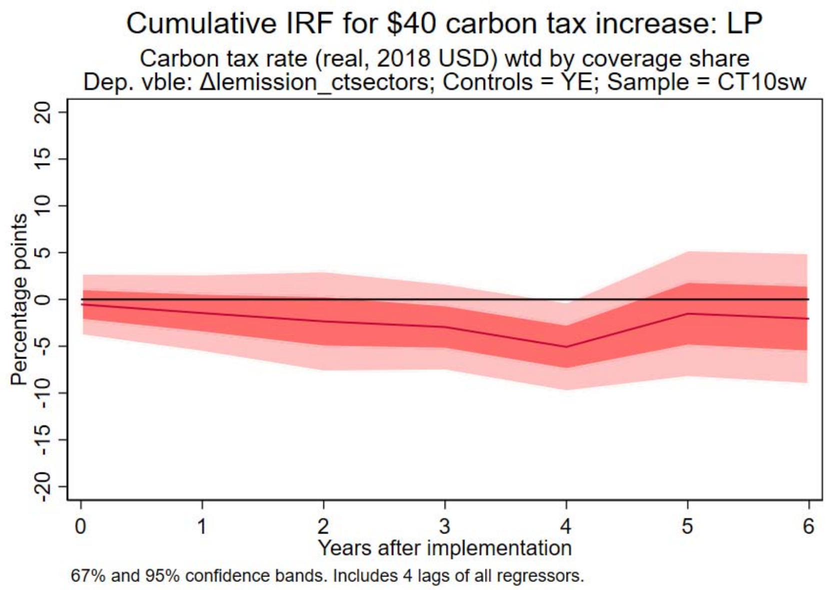

Figure 13a. Emissions CIRF for LP Regression – Unrestricted: Large Carbon Tax Countries

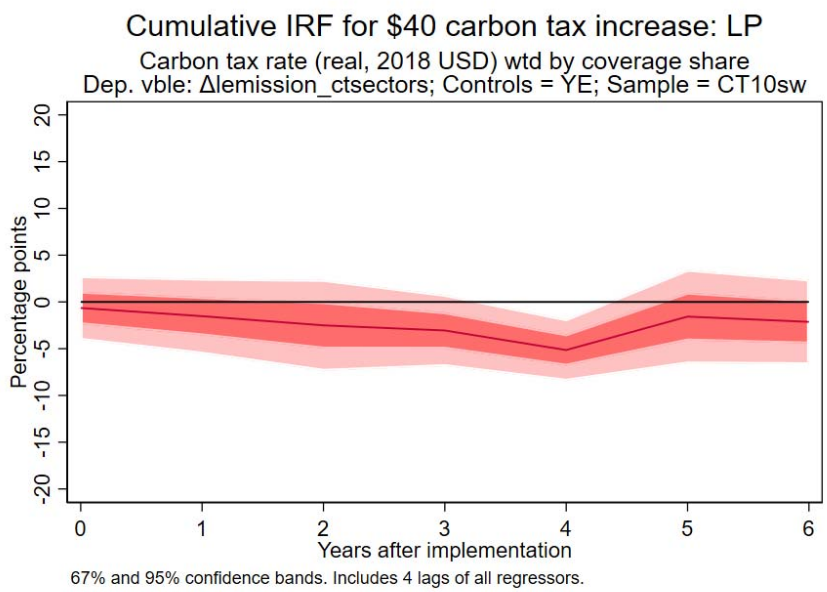

Figure 13b. Total Emissions CIRF for LP Regression – Restricted: Large Carbon Tax Countries

Appendix – Additional Tables and Figures

I. Event Study Figures

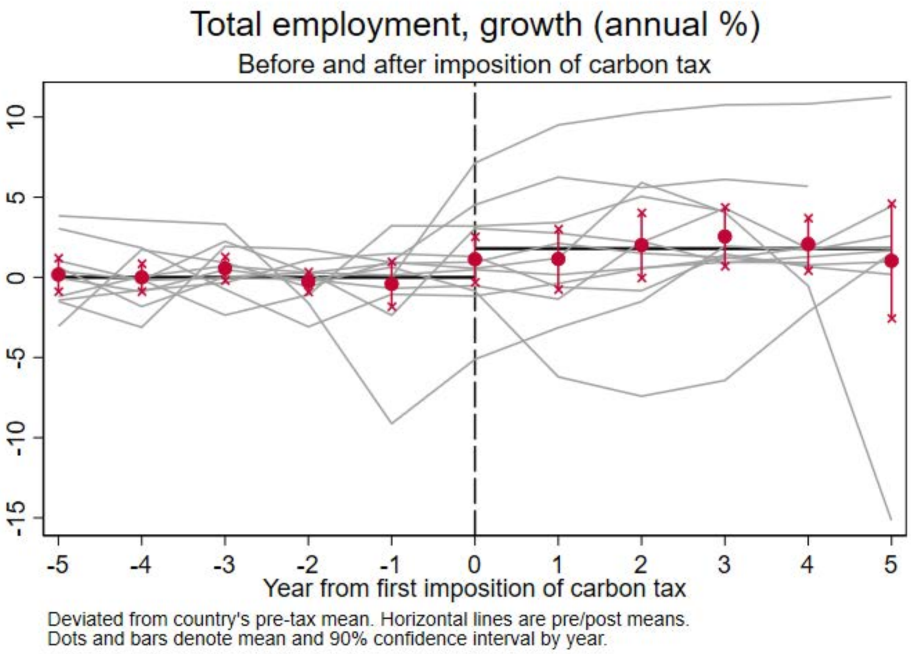

Figure A1. Carbon Tax Enactment and Total Employment Growth Rate

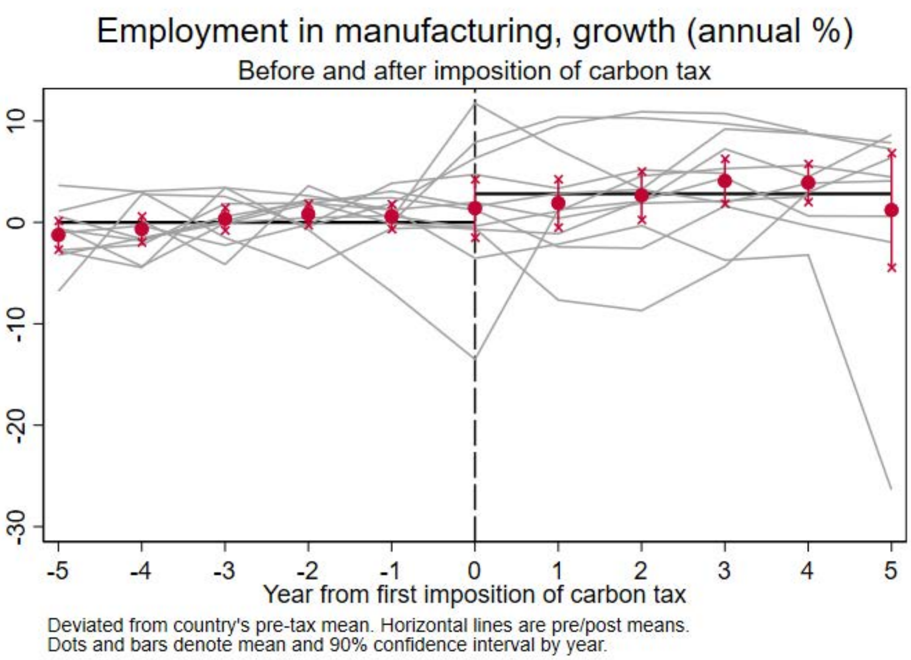

Figure A2. Carbon Tax Enactment and Manufacturing Employment Growth Rate

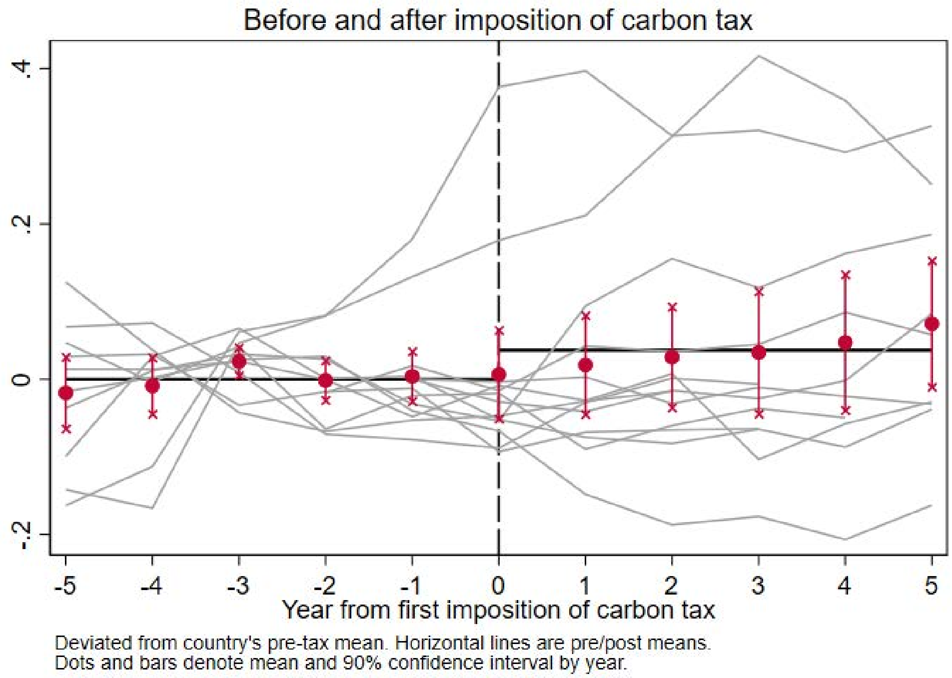

Figure A3. Carbon Tax Enactment and CO_2 Emissions

II. Impulse Response Functions – Manufacturing Employment

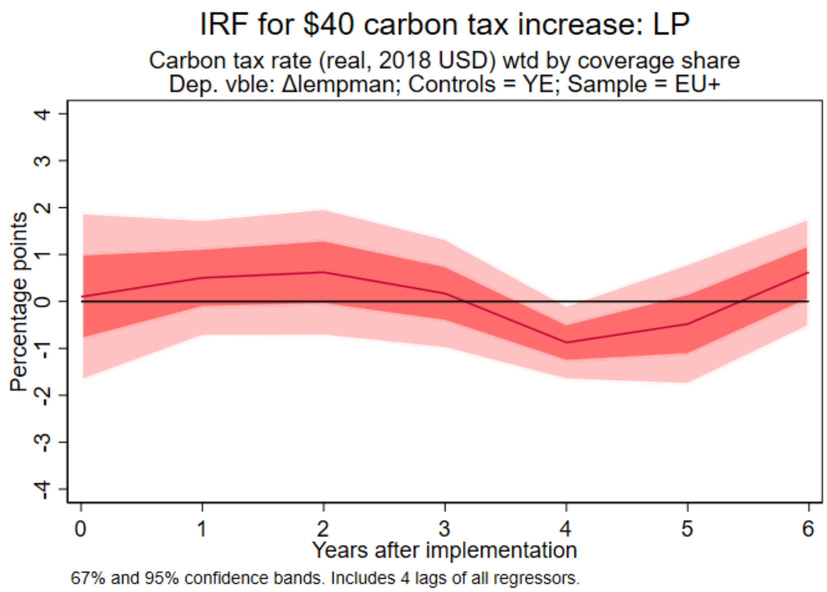

Figure A4. Manufacturing Employment IRF for LP Regression – Unrestricted

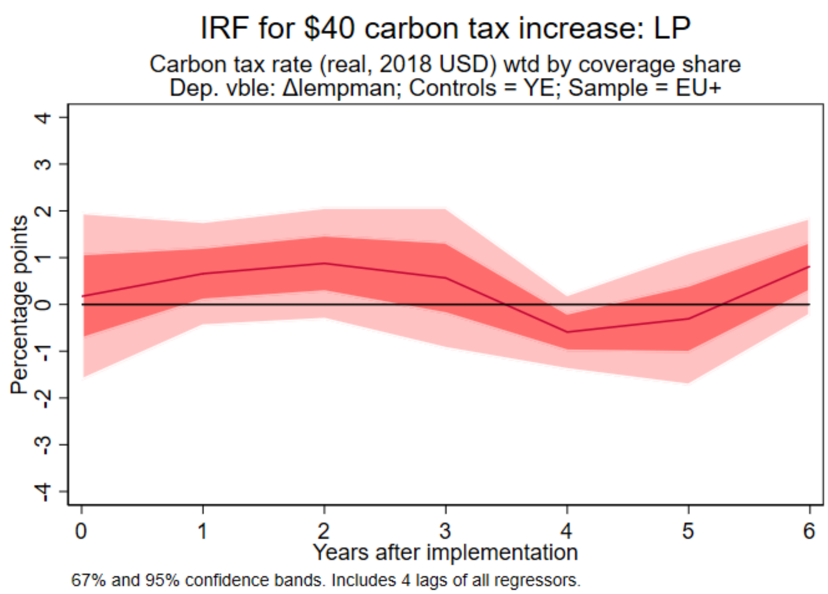

Figure A5. Manufacturing Employment IRF for LP Regression – Restricted

III. Impulse Response Functions Focusing on Role of Scandinavian Countries

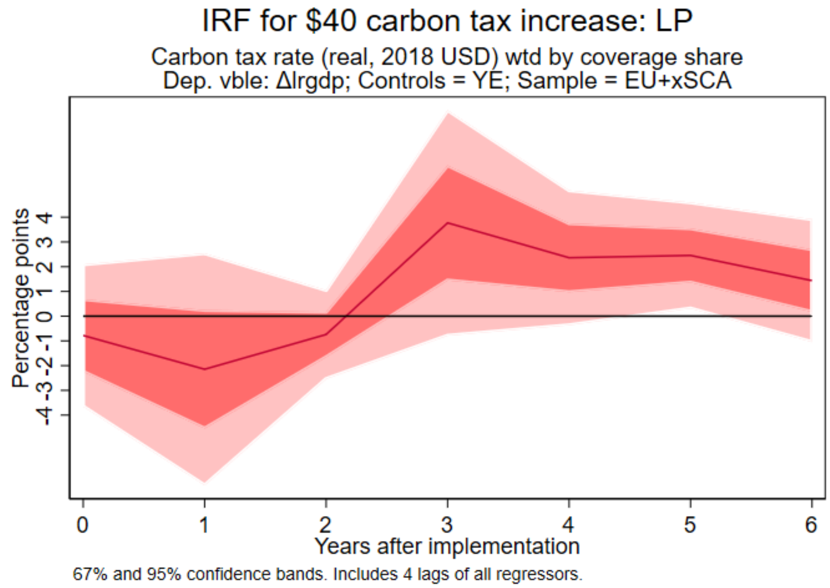

Figure A6. GDP IRF for LP Regression – Restricted: Excluding Scandinavian Countries

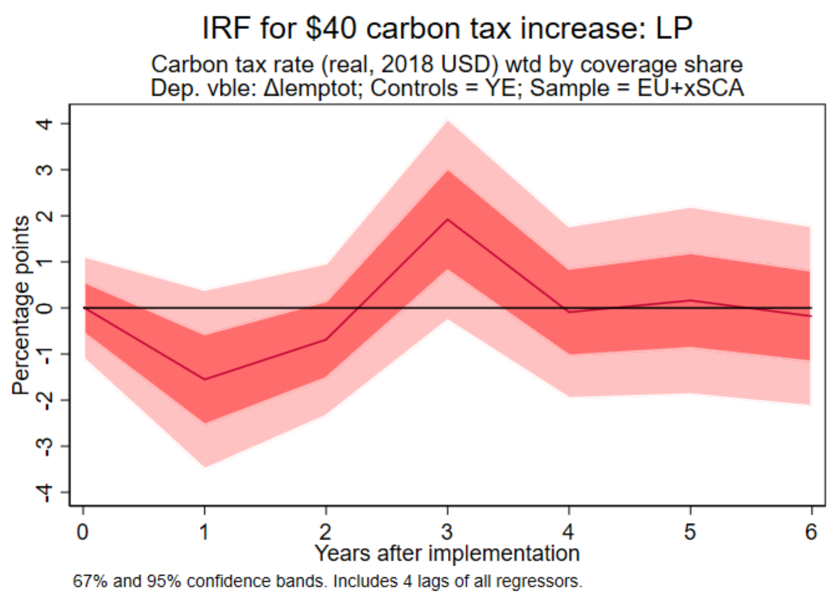

Figure A7. Total Employment IRF for LP Regression – Restricted: Excluding Scandinavian Countries

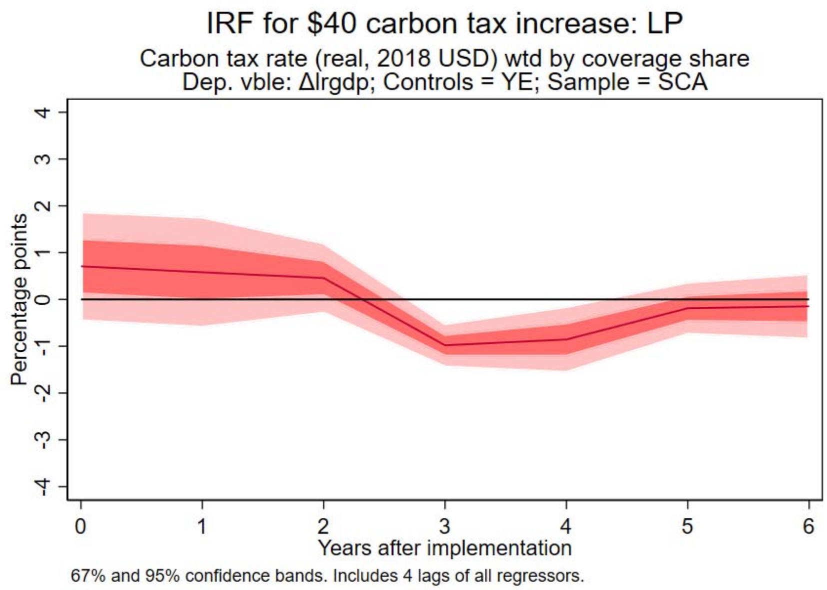

Figure A8. GDP IRF for LP Regression – Restricted:
Scandinavian Countries Only

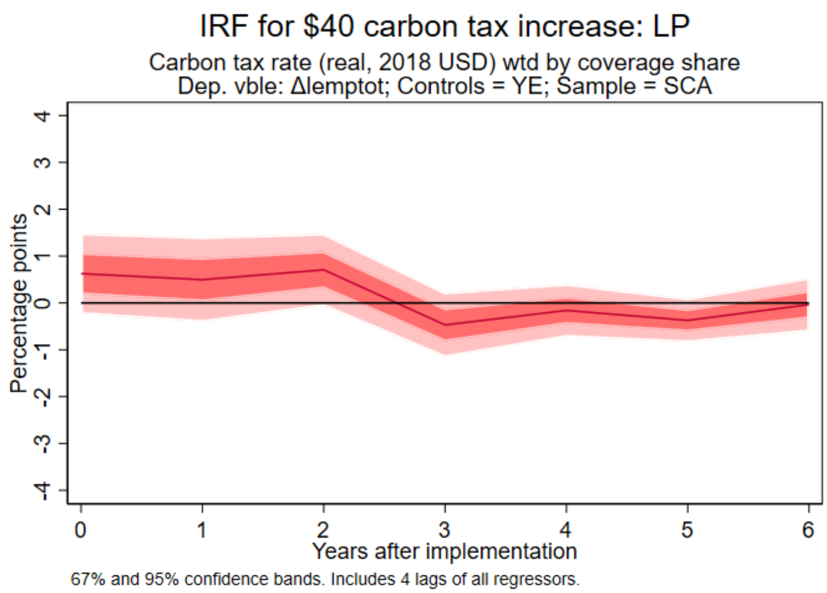

Figure A9. Total Employment IRF for LP Regression – Restricted:
Scandinavian Countries Only

IV 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.[18] The three figures that follow should be compared to figures 3b, 6b, and 8b respectively in the paper.

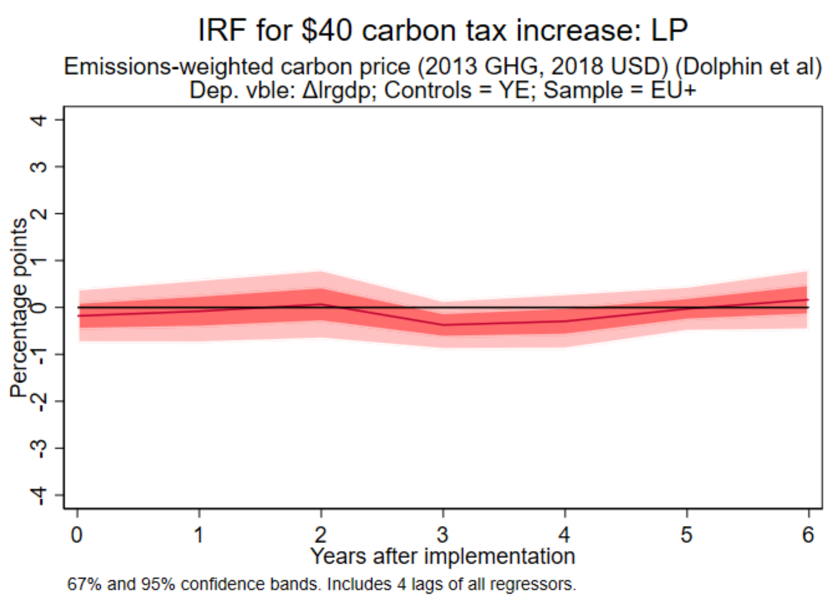

Figure A10. GDP IRF for LP Regression – Restricted:
ECP tax data used

[18] Personal communication with Geoffroy Dolphin on June 3, 2020.

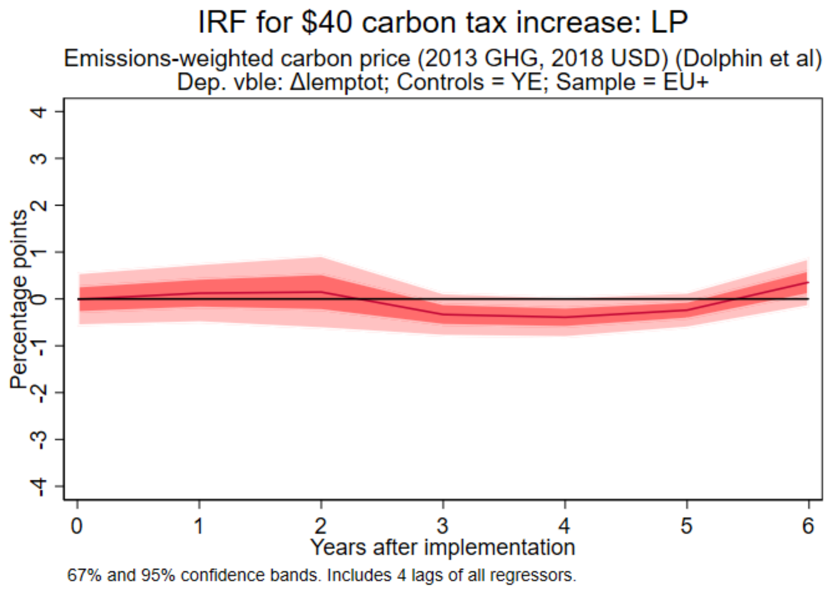

Figure A10. Total Employment IRF for LP Regression – Restricted:
ECP tax data used

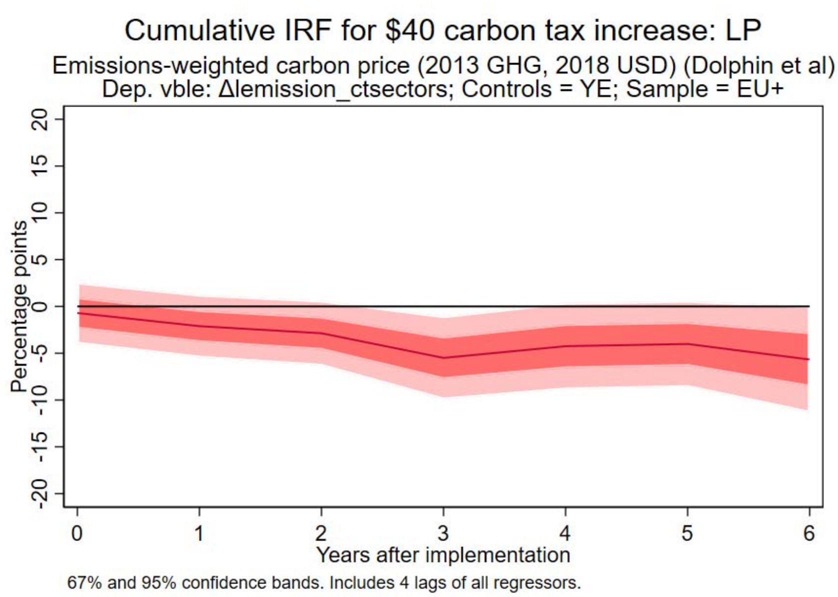

Figure A11. Emissions CIRF for LP Regression – Restricted:
ECP tax data used