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The Macroeconomic Impact of Europe's Carbon Taxes†

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We estimate the macroeconomic impacts of carbon taxes on GDP and employment growth rates using 30 years of data on carbon taxation in various European countries. We find no evidence for a negative impact on employment or GDP growth but rather find a zero to modest positive impact. We also find a cumulative emissions reduction on the order of 4 to 6 percent for a \$40/ton CO_2 tax covering 30 percent of emissions. Reductions would likely be greater for a broad-based US carbon tax since European carbon taxes typically do not cover those sectors with the lowest marginal abatement costs. (*JEL* E23, E24, H23, Q54, Q58)

Economists widely agree that putting a price on carbon emissions is a key element of a set of economically efficient policies 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 recent years, members of Congress have filed 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).

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

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 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, 15 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.[2]

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 of GDP, emissions, and employment; that is, the tax potentially shifts the long-run path of the log levels of those variables, but those paths are parallel to the no-tax path. This finding is consistent with macroeconomic theory that suggests growth rates are driven by fundamentals, such as aggregate 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 percent of emissions. We argue that this is likely to be a lower bound on reductions for a broad-based carbon tax in the United States 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 carbon tax is left to reduce emissions from sectors with higher than average marginal abatement costs (transportation and buildings, in large measure). We show that these estimated emissions reductions are in line with estimated price elasticities of demand in the transportation sector.

Our approach differs from the existing (scant) empirical literature on the impact of carbon taxes by focusing on macroeconomic time-series econometric methods rather than the more typical event study methods used in microeconomic assessments. Our approach identifies the effect of the tax from the response to changes in the tax that are not predicted by past values of the tax or other macroeconomic variables. These unpredicted components, or innovations, are identified in the time series data, and our identification thus should be thought of as time-series identification. Identification in event studies using control countries (or synthetic controls) hinges on the relevance of those control countries and the absence of preexisting trends. In

[2] This paper builds on a previous limited analysis in Metcalf and Stock (2020). Relative to that paper, the work here includes an examination of the effect of the tax on emissions, in addition to GDP and employment; fleshes out dynamic responses; allows for possible nonlinear responses; examines how the response is affected by the use of the revenues, the magnitude of the tax rate, and the fraction of covered emissions; and tests and rejects one of the specifications in Metcalf and Stock (2020).

our framework, the introduction of the tax plays no special role; it is just another instance of a change in the tax rate (in this case, from zero). Our macroeconomic approach is designed to respond to policy maker concerns that a carbon tax could hurt the economy. In particular, unlike microeconomic analyses focused on individual sectors, our analysis accounts for the fact that the tax's adverse impacts in one sector can be offset by positive impacts on other sectors. While distributional impacts are certainly relevant, focusing only on the impacts on sectors directly bearing the tax can overstate the adverse macroeconomic impacts of carbon pricing.

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 assesses 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.

I. 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 1 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.[3] Goulder et al. (2019) also consider a US 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.

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 Brännlund and Andréasson 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 and Kichian (2021) use a vector autoregression (VAR) to estimate the impact of the BC carbon tax on provincial GDP, controlling for the pretax price of gasoline (or diesel) and US economic variables; they find no impact of the tax on

[3] Trump cited a NERA study (Berstein et al. 2017) 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.

GDP. In earlier work with a more limited version of the dataset 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 an analysis of the employment effects of the British Columbia carbon tax by Yamazaki (2017). 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.[4]

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 and the lack of cost-competitive alternatives.

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 (2021) 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.

[4] Using firm-level data to analyze the BC carbon tax, Azevedo, Wolff, and Yamazaki (2019) find similar results of a negligible aggregate employment impact but significant job shifting across sectors. Carbone et al. (2020) also find significant job shifting across sectors. Using individual data, Yip (2018) finds an increase in the unemployment rate from the BC carbon tax and a shift away from low-skill toward higher-skill employment. Azevedo, Wolff, and Yamazaki (2019) find the increase in the unemployment rate implausibly high and argue that the parallel trends assumption is violated given other macro shocks occurring around the time of the implementation of the BC carbon tax. As discussed at the end of section IV, our approach avoids this potential problem given our time-series identification.

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 macroeconomic outcomes than when the revenue is simply added to general revenue.[5]

II. 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 16 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 consistently control any effect of the ETS on growth and emissions. 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.[6] Phase II (2008–2012) added domestic aviation (in 2012), and Phase III (2013–2020) added various additional sectors.[7]

Table 1 summarizes information about carbon taxes across this set of countries. Appendix I provides detailed information about each country's carbon tax. 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.[8] We therefore turn next to an econometric analysis.

III. Data and Methods

Data.—Our data on real GDP and carbon tax rates come from the World Bank Group (2019).[9] Employment data are from the EU Eurostat database. Data on the

[5] We cannot 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.

[6] 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.

[7] 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.

[8] 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.

[9] 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

Table 1—EU+ Carbon Taxes

Country	Year of enactment	Rate in 2018 (US$ per metric ton)	Intended revenue recycling?	Share of greenhouse gas emissions in 2019 covered by tax	Carbon tax revenue in 2018 (US$ 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 (2019)

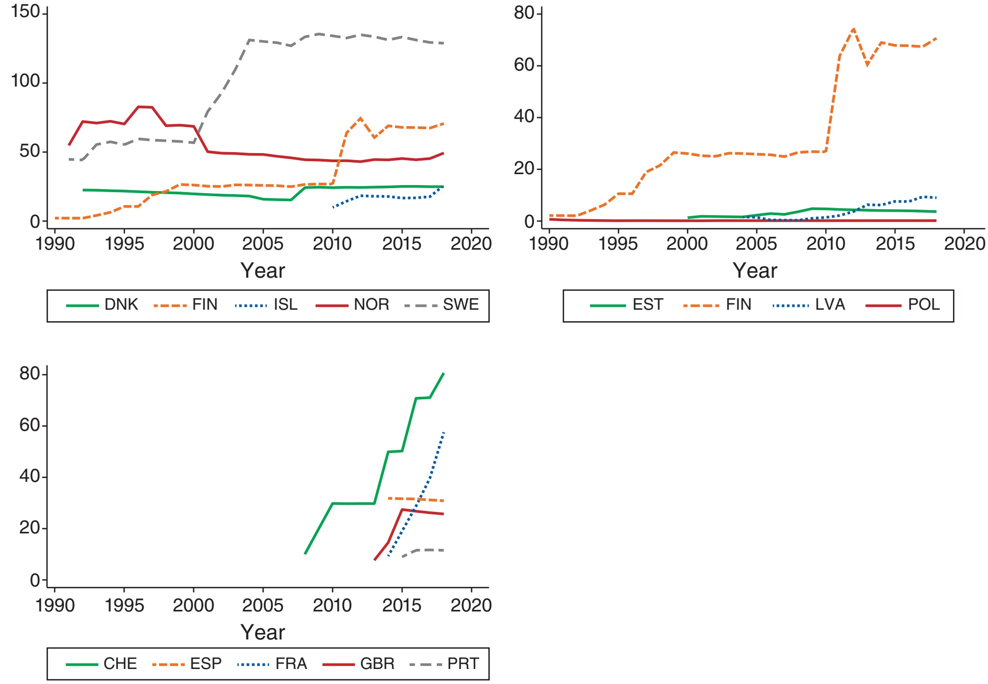

Figure 1. Real Carbon Tax Rates over Time (See Table 1 for Country Abbreviations)

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.

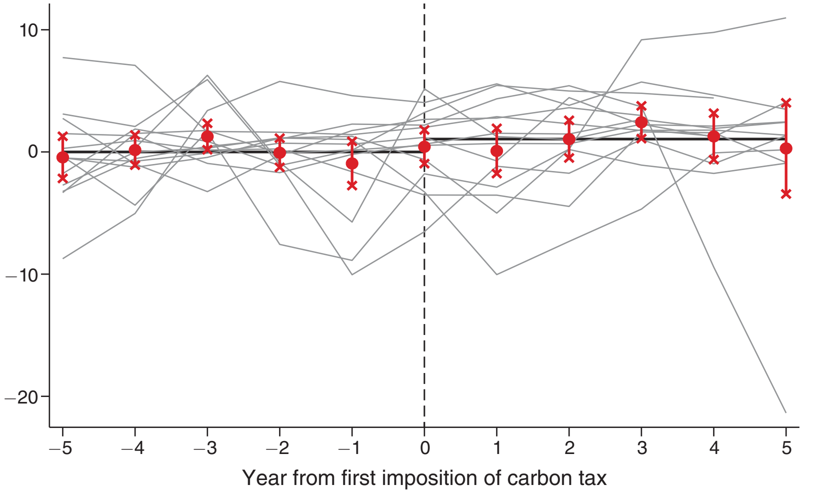

FIGURE 2. CARBON TAX ENACTMENT AND GDP PER CAPITA GROWTH RATE

Notes: Deviated from country's pretax mean. Horizontal lines are pre/post means. Dots and bars denote mean and 90 percent confidence interval by year.

share of greenhouse gas emissions covered by the tax come from the World Bank Group (2019), 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.

Identification and Estimation.—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.[10] 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 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

[10] British Columbia, for example, announced a delay in the 2020 scheduled increase in its carbon tax due to the COVID-19 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.

the Jordà (2005) local projection (LP) method, adapted to panel data. Specifically, we use OLS to estimate a sequence of panel data regressions,

$$(1)\quad 100\Delta \ln\left(GDP_{it+h}\right) = \alpha_i + \Theta_h \tau_{it} + \beta(L)\tau_{it-1} + \delta(L)\Delta \mathbf{X}_{it-1} + \gamma_t + u_{it},$$

where τ_{it} is the coverage-weighted 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. The vector $\mathbf{X}_{it-1}$ includes $\ln(GDP)$, $\ln(\textit{total employment})$, $\ln(\textit{manufacturing employment})$, and the GDP price deflator. Including controls other than past GDP growth rates contributes to identification and should provide assurance that our model satisfies the assumption of invertibility.[11] The coverage-weighted tax rate is the tax rate interacted with the 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 overall tax burden as a share of the economy, which in turn is approximately proportional to the share of emissions covered times the tax rate.

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.[12] Similarly, because identification comes from time series variation (identification of the carbon tax innovations), identification does not rely on including the 16 EU countries that do not have a carbon tax in our sample; those countries are included to improve estimator precision. Standard errors are heteroskedasticity-robust (Plagborg-Møller and Wolf 2021).

As a check on our results, we also estimate bivariate panel LP and 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 corresponding bivariate LP regression. In population the estimand

[11] We use the same set of controls for total employment and manufacturing employment regressions below. Emissions regressions also include past growth rates of emissions. We do not include emission growth rates in the GDP and employment regressions given the limited coverage of emissions in our dataset (coverage begins in 1990). Adding emissions to these regressions reduces our sample size substantially and yields imprecisely estimated coefficients.

[12] One could argue that including time fixed effects could lead to different outcomes in the presence of cross-country spillovers. We test for this by rerunning all regressions dropping the year fixed effects and find that the results are essentially unchanged. We include some representative results from the main specification in the Appendix.

is the same. Although the SVAR and LP methods have the same identifying condition and the same estimand (Plagborg-Møller and Wolf, 2021), 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.[13]

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.

We then consider the counterfactual of a one-time permanent increase in the carbon tax by \$40, for a tax that covers 30 percent 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. Specifically, we model a \$40 policy shock with a sequence of small adjustments. The small adjustments keep the carbon tax at \$40 instead of tracking its own IRF with respect to its own shock. In the Appendix we show the small adjustments that constitute our policy experiment. Most of the change occurs in the first period (when the shock is applied) with small adjustments to maintain the tax rate at \$40.

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.[14]

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 multivariate and bivariate LP and bivariate SVAR specifications both with this zero long-run growth effect restriction imposed

[13] See Stock and Watson (2018) and Plagborg-Møller and Wolf (2021) for details on methodology and relation between VARs and LPs. We only estimate bivariate SVARs because of the large number of parameters in five or six variable SVARs.

[14] 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.

("restricted" case) and not imposed ("unrestricted"). In both the SVAR and 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 eight-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. It is worth noting how our approach differs from event study methods. The LP method used here identifies the effect of the tax from the response to changes in the tax that are not predicted by past values of the tax or other macroeconomic variables. These unpredicted components, or innovations, are identified in the time series data, and our identification thus should be thought of as time series identification. Using multiple countries improves precision but does not provide identification. In contrast, event study methods using control countries (or synthetic controls) to identify the effect of the introduction of the tax and identification hinges on the relevance of those control countries and the absence of preexisting trends. In our framework, the introduction of the tax plays no special role, it is just another instance of a change in the tax rate (in this case, from zero).

IV. Results

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

A. *GDP*

Figure 3 shows the dynamic effect on GDP growth of a \$40 permanent increase in the carbon tax, covering 30 percent of emissions, estimated by LP using all 31 countries over the full 1985–2018 sample. Figure 3, panel A 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 years 3 and 4. In no year, however, is the effect significant at the 5 percent level (in most years it is within one standard error of zero). The results for the restricted model (Figure 3, panel B), 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 same dynamic effects on GDP growth as Figure 3, except estimated using a bivariate panel LP (Figure 4, panel A) and SVAR (Figure 4, panel B), both for the restricted case. The bivariate LP result is very similar to the multivariate LP result in Figure 3, and the bivariate LP and SVAR results are similar to each other. The standard error bands in the SVAR restricted models approach zero in later years because of the imposed joint stationarity of GDP growth and the change in the carbon tax. 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

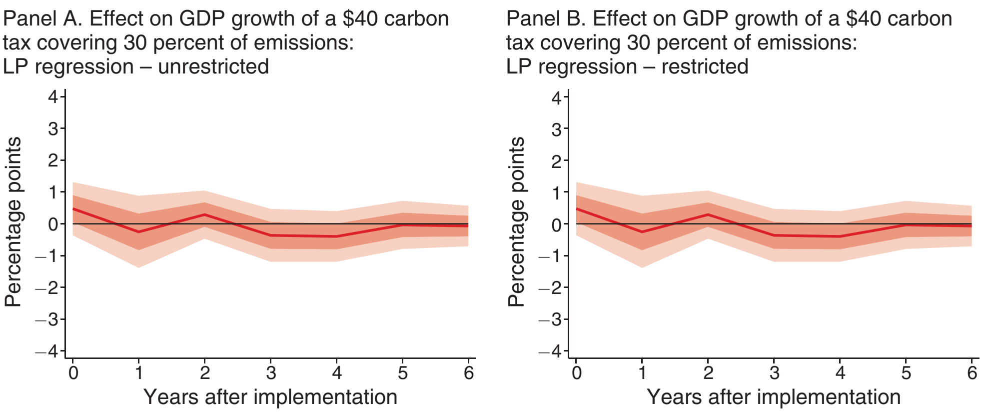

Figure 3. Effect on GDP Growth of a $40 Carbon Tax Covering 30 percent of Emissions

Notes: Sixty-seven percent and 95 percent confidence bands. Includes four lags of all regresssors.

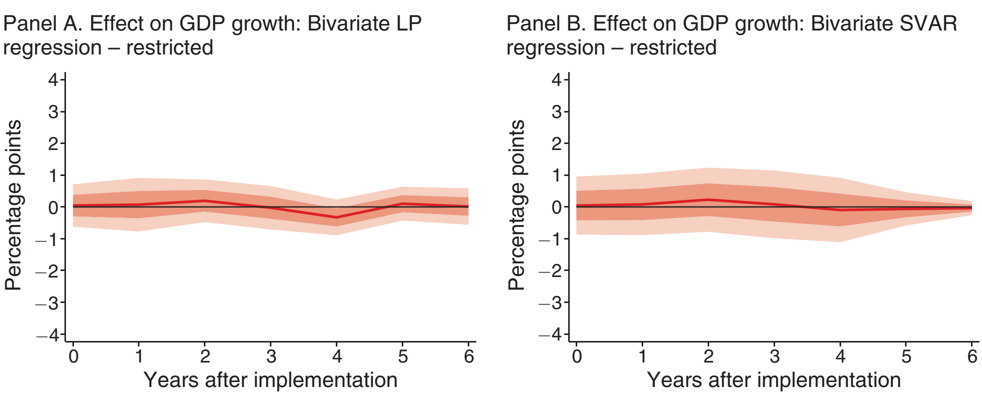

Figure 4. Effect on GDP Growth

Notes: Sixty-seven percent and 95 percent confidence bands. Includes four lags of all regresssors.

the two methods. This is true generically for these data, across dependent variables and regressors. We therefore henceforth only report LP results.

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 0.02 (p-value $=$ 0.99). For the SVAR model, the test statistic is -0.01 (p-value $=$ 0.99). We find similar test results for country subsets for GDP growth, GDP per capita growth, as well as total employment (see Table 2). These test results are consistent with theory: long-run growth rates for GDP are affected by fundamentals including growth rates for the labor force and productivity. Results for manufacturing employment and emissions are discussed below.

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	0.02	0.07	−0.22	−2.54	−0.75
	0.99	0.95	0.83	0.01	0.46
SVAR	−0.01	−0.05	−0.75	−0.30	1.07
	0.99	0.96	0.45	0.76	0.29
Revenue-recycling countries					
LP	−1.03	−0.97	−0.59	−2.75	−0.61
	0.30	0.33	0.56	0.01	0.54
SVAR	−0.47	−0.18	−1.38	−1.76	0.46
	0.64	0.86	0.17	0.08	0.64
Large carbon tax countries					
LP	−1.18	−1.44	−0.39	−2.34	−0.76
	0.24	0.15	0.70	0.02	0.45
SVAR	−0.53	−0.63	−1.32	−0.53	0.34
	0.60	0.53	0.19	0.60	0.73
Scandinavian countries					
LP	−0.03	0.11	0.85	−0.43	0.36
	0.98	0.91	0.39	0.67	0.72
SVAR	−0.07	−0.26	−0.42	−0.03	−0.03
	0.94	0.80	0.67	0.98	0.97

Notes: 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	2.54	1.04	0.82	0.56
	0.065	0.038	0.384	0.51	0.693
Revenue-recycling countries	1.98	2.02	1.05	0.63	0.67
	0.094	0.088	0.38	0.638	0.610
Large carbon tax countries	3.91	4.13	2.41	1.97	1.57
	0.004	0.002	0.047	0.096	0.179
Scandinavian countries	2.62	2.61	3.65	1.60	3.81
	0.033	0.034	0.006	0.171	0.004

Notes: 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.

Table 3 reports Granger causality tests of the hypothesis that the carbon tax rate is strictly exogenous. 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). Given this set of test results, we do not use the distributed lag specification used in Metcalf and Stock (2020).

The results illustrated in Figures 3 and 4 do not suggest particularly large positive impacts of a carbon tax on GDP growth. But neither do they support a claim of large

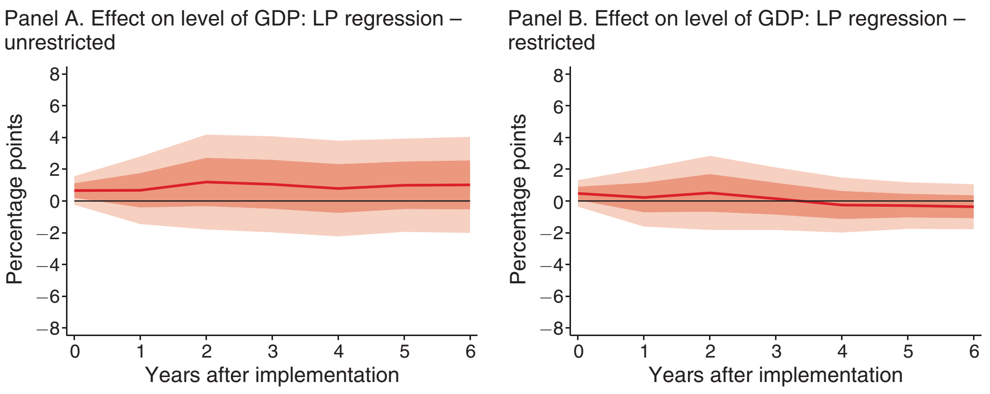

Figure 5. Effect on Level of GDP

Notes: Sixty-seven percent and 95 percent confidence bands. Includes four lags of all regresssors.

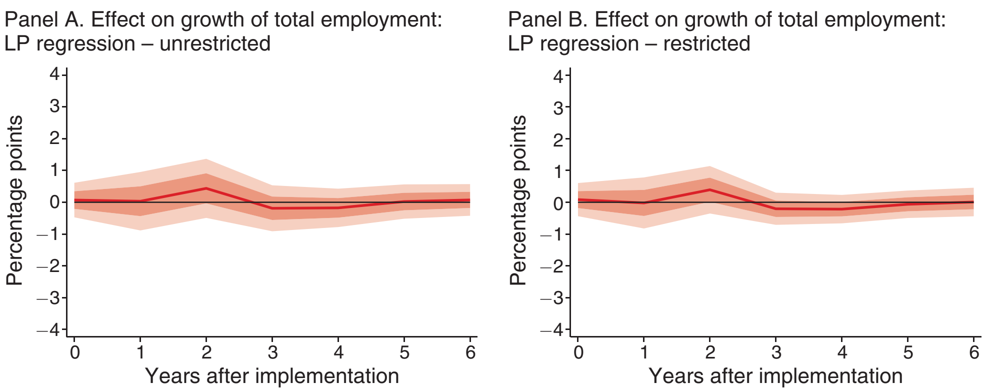

Figure 6. Effect on Growth of Total Employment

Notes: Sixty-seven percent and 95 percent confidence bands. Includes four lags of all regresssors.

adverse impacts. It is possible, however, that effects accumulate over time, affecting the level of GDP. Figure 5 shows cumulative impulse response functions for the LP model. The unrestricted model cumulative dynamic effect (left 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 +4 percentage points. When the parallel path assumption is imposed, the impact is negligible in all six years. In this and subsequent subsamples, we find no evidence to support the view that European carbon taxes have had a significant impact on GDP, either positive or negative.

One concern with our focus on European countries is the potential for spillovers from countries with a carbon tax to those without a tax. This is the essence of carbon leakage, where economic activity shifts from carbon taxing to non-carbon taxing countries. We acknowledge that this is a possibility but note that any such spillover would bias us toward finding negative impacts on GDP. The potential presence of

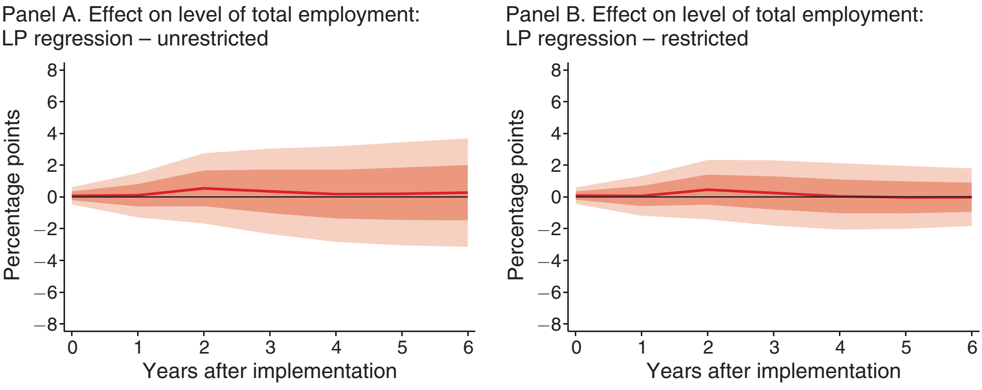

Figure 7. Effect on Level of Total Employment

Notes: Sixty-seven percent and 95 percent confidence bands. Includes four lags of all regresssors.

intercountry spillovers simply strengthens our claim that the EU+ carbon taxes have not had an adverse impact on GDP in those taxing countries.

B. *Total Employment*

Figure 6 shows dynamic effects for the growth of total employment. In both the unrestricted and restricted cases, employment growth initially rises and then subsequently falls. The cumulative impact on the level of employment (Figure 7) is essentially zero over a six-year period in either the unrestricted or restricted LP models with GDP, and there is no evidence of negative employment impacts from the carbon tax.

We also checked to see if manufacturing employment was affected. This would support employment shifting even as total employment is not affected. We find that manufacturing employment is initially flat before falling and then rising, but is not statistically distinguishable from zero. In both models, the estimates are less precise but do not show evidence of shifting out of manufacturing (Figure 8). The cumulative effect on the level of employment is also statistically insignificant and hovers around zero (Figure 9). We note that the test statistic for zero long-run effect of the carbon tax on manufacturing employment is statistically significant at the 1 percent level, giving support to the unrestricted model and the argument that a carbon tax leads to a reallocation of employment even if there is no impact on aggregate employment.

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. As noted above, these are the sectors most commonly covered by European carbon taxes. This levels

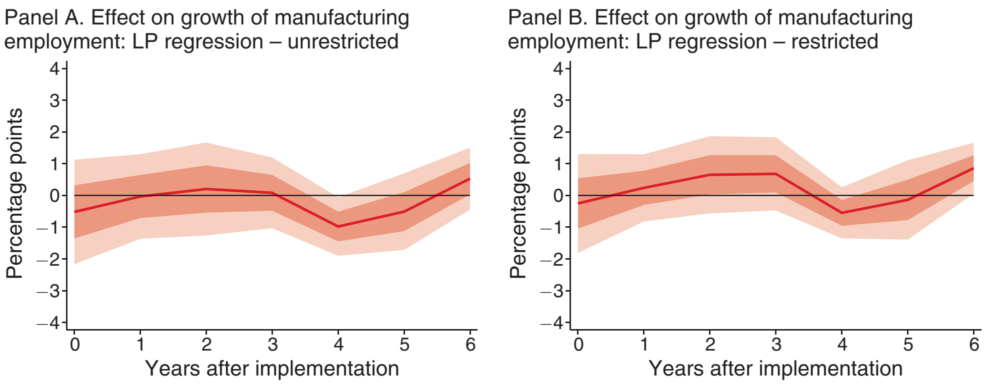

Figure 8. Effect on Growth of Manufacturing Employment

Notes: Sixty-seven percent and 95 percent confidence bands. Includes four lags of all regresssors.

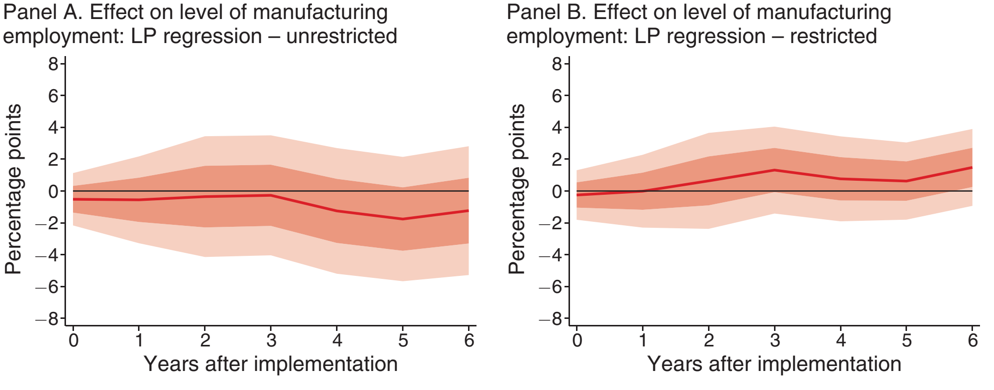

Figure 9. Effect on Level of Manufacturing Employment

Notes: Sixty-seven percent and 95 percent confidence bands. Includes four lags of all regresssors.

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. We cannot reject the hypothesis of zero long-run changes in the emissions growth rate in either the LP or the SVAR model nor can we reject the zero long-run change in other samples for either model (Table 2).

Results for the full sample are shown in Figure 10. Emissions fall by 6.4 percentage points by the end of year 6 in the unrestricted model (panel A), with a 95 percent confidence interval of (−12.5, −0.4). In the restricted model (panel B), emissions

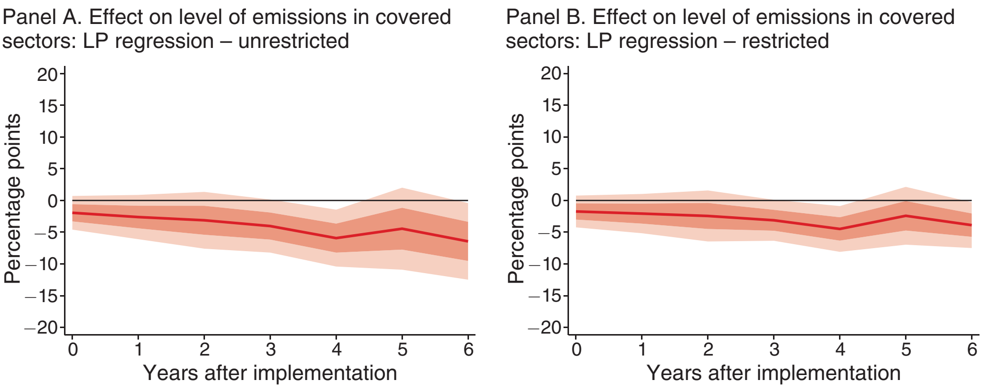

Figure 10. Effect on Level of Emissions in Covered Sectors

Notes: Sixty-seven percent and 95 percent confidence bands. Includes four lags of all regresssors.

fall by 3.9 percentage points by year 6, with a 95 percent confidence interval of $(-7.5, -0.3)$. In both the restricted and unrestricted, we reject no change in the level of emissions in year 6.

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 (Table 3), 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 predictor of tax rate changes.

V. 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.[15]

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

[15] We also checked for how these factors affect manufacturing employment. The results are the same as for total employment.

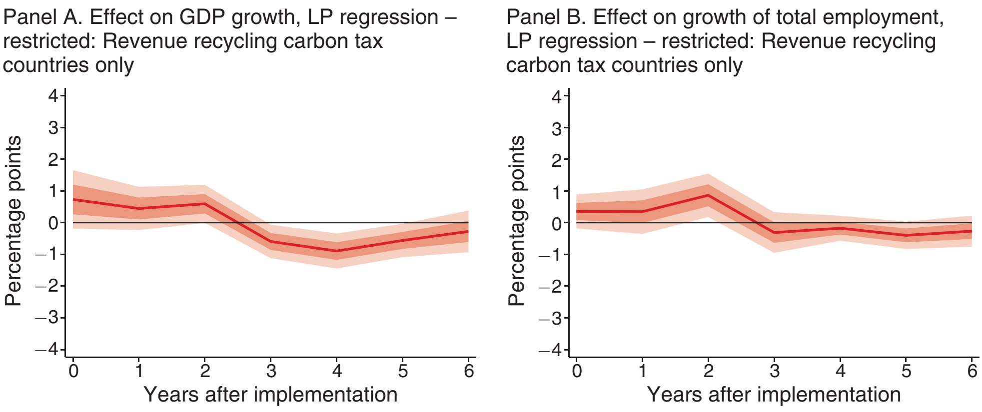

Figure 11. Effect on Growth of Total Employment

Notes: Sixty-seven percent and 95 percent confidence bands. Includes four lags of all regresssors.

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. It is possible that some of these countries used carbon tax revenue for nonrevenue-recycling purposes (and vice versa for those countries that have not stated an intention to recycle carbon tax revenues through lower tax rates).

Figure 11 shows the results for GDP growth (top panel) and total employment (bottom panel), focusing on these six countries relative to countries with no carbon tax. GDP growth is initially a bit larger in this subsample (0.6 percent growth in GDP rate in year 2 versus 0.3 percent in full carbon tax sample as per Figure 3, panel B) but the coefficients are imprecisely estimated, and we cannot reject that the growth rates are the same. The employment impacts are initially larger (bottom panel) than in the full sample (compare to Figure 6, panel B). The growth rate in year 2 is 0.9 percentage points higher, whereas in the full sample for the comparable regression, it is 0.4 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.

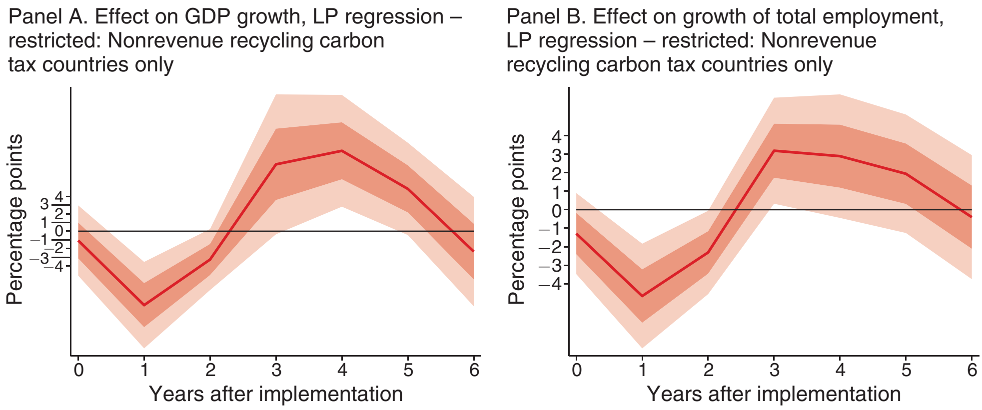

Figure 12. Effect on Growth of Total Employment

Notes: Sixty-seven percent and 95 percent confidence bands. Includes four lags of all regresssors.

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 12 shows GDP growth impacts (panel A) 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 6 for total employment is −0.7 percentage points but imprecisely estimated. 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 fall faster in the nonrevenue-recycling countries relative to the revenue-recycling countries: emissions are 10.9 percent lower in the nonrevenue-recycling countries by year 6 while they are 3.8 percent lower in the revenue-recycling countries (Figure 13). To the extent that GDP falls more in nonrevenue-recycling countries than in revenue-recycling countries, we would expect emissions to fall as well. However, as in the full sample, the estimates are imprecise, and we cannot reject no change in cumulative emissions.

B. *Large Carbon Tax Countries*

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. We therefore consider the subset of countries with share-weighted carbon tax rates are at least \$10 per ton in at least one year (thus, corresponding to \$30/ton covering one-third of emissions). Those countries are Denmark, Finland, France, Ireland, Norway, Sweden, and Switzerland. This seven-country sample excludes all countries without a carbon

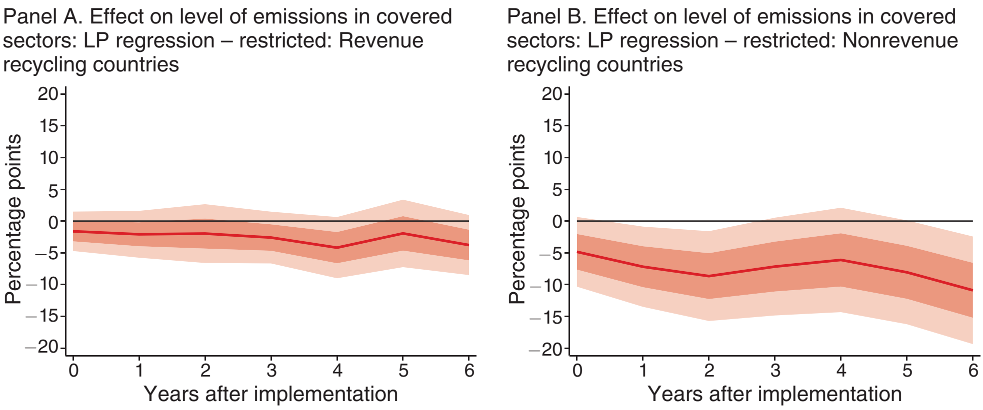

Figure 13. Effect on Level of Emissions in Covered Sectors

Notes: Sixty-seven percent and 95 percent confidence bands. Includes four lags of all regresssors.

tax, providing an empirical counterpart to the point that the countries without a carbon tax are used to improve precision, not for identification. The results for GDP growth (Figure 14, panel A) are very close to the full-sample results (Figure 3, panel B). The results for employment (not shown) are stronger than for the full sample but, again, the differences are not statistically significant. The estimated emissions effect in the seven-country subsample (Figure 14, panel B) is very similar to results for the full sample (Figure 10, panel B) on impact and for the first four years, showing four-year cumulative declines of 4.2 percent (subsample) and 4.5 percent (full sample), respectively.

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 dataset also increases 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. *Nonlinear Effects*

In principle, the effect of a carbon tax could be nonlinear in the tax rate and/or in the share of emissions covered by the tax. We are able to explore such possibilities because our data have considerable variation in both the carbon tax rate and coverage. It is also possible that imposing a carbon tax could have different impacts depending on whether the economy is especially strong (a boom) or weak (a bust). We can test for that as well by interacting the tax rate with a lag of GDP growth.

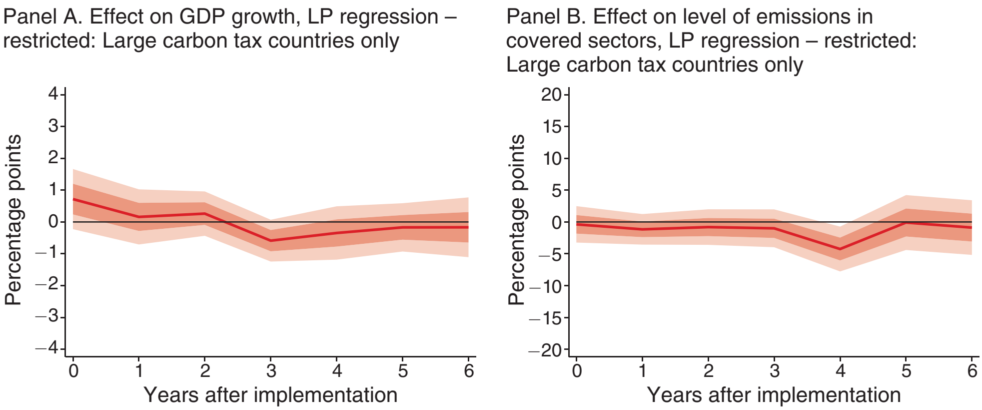

Figure 14. Effect on GDP Growth

Notes: Sixty-seven percent and 95 percent confidence bands. Includes four lags of all regresssors.

We therefore used local projections to estimate three nonlinear specifications. Our first approach includes the square of the share-weighted tax rate, $(\tau_{it})^2$ and its lags, so that the marginal effect on growth depends linearly on the level of the share-weighted tax. Our second approach includes the share-weighted tax rate interacted with the share, $\tau_{it} s_{it}$, and its lags, so that the marginal effect depends linearly on the share (s_{it}). With some exceptions, including the nonlinear terms does not substantially increase the standard errors of the estimated dynamic effects. The dynamic effects including the nonlinearities are typically close economically and statistically (within a standard error) to those for the linear specifications. Thus, the results show little evidence that the marginal effect of the tax depends either on the tax rate or on the coverage share, within the range of our data.

Finally, we test for differential impacts of the carbon tax by interacting the tax rate with a lag of the GDP growth rate and evaluated IRFs at different quantiles of the growth rate. We find negligible differences when comparing the tax impact interacted with the tenth percentile of GDP growth (an economic "bust") and when interacted with the ninetieth percentile of GDP growth (an economic "boom"). Results and additional discussion for all three nonlinear specifications are provided in the Appendix.

E. *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, Pollitt, and Newbery (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 reestimated our regressions using their data, and selected results are shown in the Appendix.[16] 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 Dolphin, Pollitt, and Newbery (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.

VI. Conclusion

Placing a price on carbon pollution is a key element of any cost-effective portfolio of policies 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. Our results are robust to controlling for how carbon tax revenue is used, whether we limit the analysis to countries with large tax rates or to the Scandinavian countries that were early adopters of carbon taxes as part of a Green Tax Reform, allowing for marginal effects to depend on the level of the tax or the covered share, or other cuts of the data.

We find evidence of modest emissions reductions arising from the tax. It is worth noting, however, that most countries exclude from the tax base emissions for sectors covered by the ETS. Sectors covered by the ETS (electric generation, energy intensive manufacturing) are the sectors with the lowest marginal abatement costs among fossil fuel users. Carbon taxes thus are left to cover transportation and the building sector in large part, two sectors with higher than average marginal abatement costs. This suggests that a carbon tax applied broadly would likely have a larger impact on emissions at any given tax rate than the European taxes focused on narrow, high cost sectors.

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

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