Regime-Dependent Environmental Tax Multipliers

Evidence from 75 Countries

Christian Schoder
Abstract

This paper reviews the main transmission channels of an environmental tax reform shifting the tax burden from labor to carbon emission. The analysis uses a simple open-economy macro model and estimates dynamic environmental tax as well as personal income tax multiplier effects on output and employment for a panel of 75 high- and low-income countries from 1994 to 2018. Tax policy changes are identified by cyclically adjusting the tax revenues. The estimated environmental tax multiplier effects on output range from 1 on impact to 1.8 at the peak. Personal income tax multipliers are slightly higher, ranging from 1.4 to 2.3. While income taxes reduce employment, environmental taxes do not. Environmental tax multipliers are highly regime dependent: they are close to zero or statistically insignificant unless taxes are increased when output contracts, fuel prices are high, the environmental tax levels are high, or the carbon intensity of output is low. Commodity trade-exposed countries face higher tax multipliers. This analysis concludes that, compared with income taxes, environmental taxes can be a less contractionary source of revenues to support the post-COVID-19 fiscal consolidation efforts, especially in countries that are at the beginning of their decarbonization efforts.
Regime-Dependent Environmental Tax multipliers: Evidence from 75 Countries

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1 Introduction

The global economic recession following the outbreak of the Corona Virus Disease 2019 (COVID-19) has forced policy makers to focus on protecting people against impacts and supporting the economic system. Costly fiscal expansion to stabilize output and employment during the pandemic and shrinking tax revenues have raised concerns about sovereign debt sustainability. At the same time, the climate crisis constitutes a major policy challenge. According to surveys by the World Economic Forum (2020), environmental concerns rank at the top among long-term global risks. The previous five years have been measured as the warmest on record.

To realign environmental goals with sustainable growth and fiscal consolidation, Estevão (2020), IMF (2020), and OECD (2020) have advocated environmental tax reforms shifting the tax burden from labor to carbon emission as elements of COVID-19 recovery programs. World Bank Group President David Malpass states that “with oil prices lower, this is a good moment for countries to work toward reducing and reforming their fossil fuel subsidies”.1 In a joint blog post, Vitor Gaspar (IMF), Navid Hanif (UN), Ceyla Pazarbasioglu (WBG), and Pascal Saint-Amans (OECD) argue that the aftermath of a crisis provides opportunities to implement green tax reforms.2

Environmental taxes cover a broad set of tax instruments in the areas of energy, transportation, pollution, and natural resources. At the core of environmental taxes, however, are taxes on fuels and carbon emissions. The appeal of environmental tax reforms to policy makers crucially depends on their macroeconomic implications. The previous empirical literature has found that environmental taxes have either insignificant or even positive effects on output and employment. Metcalf and Stock (2020) estimate the dynamic output and employment effects of carbon tax rates for a panel of 31 European countries, employing the World Bank’s Carbon Pricing Dashboard. They find them to be small and insignificant. Bernard, Islam, and Kichian (2018) estimate the output effects of the carbon tax introduced in the Canadian province of British Columbia and find them to be small. These studies estimate the effect of changes in tax rates rather than tax revenues which makes the computation of tax multiplier effects and, hence, the comparison with other tax instruments difficult. The assessment of the net output and employment effects of an environmental tax reform potentially involving an increase in environmental taxes and a reduction in personal income taxes requires the estimation of multipliers. Finally, the previous empirical literature has focused on European countries or Canadian provinces. Complementing empirical analyses, simulation-based studies reviewed by Heine and Black (2019) suggest that environmental tax reforms may well expand output and employment. Based on a Computable General Equilibrium model, Barrios, Pycroft, and Saveyn (2013) predict environmental tax reforms to be welfare enhancing in EU member states.

The present paper seeks to complement the previous literature by discussing the transmission channels of environmental and labor taxes and estimating the respective tax multiplier effects. Before the empirical analysis, the paper sketches out a simple open-economy energy-macro model to address the core parameters which drive both environmental and labor tax multipliers. This model is based on the Energy Dynamic Stochastic Disequilibrium (E-DSDE) model proposed by Schoder (2021). Its core assumption is a large pool of underutilized labor which can be swiftly utilized in case of fluctuations in aggregate demand. The energy sector uses carbon as an input to production.

Using a panel of 75 high- and low-income countries with observations from 1994 to 2018, the empirical section seeks to identify dynamic output and employment multipliers of environmental taxes such as energy taxes (EGT) mainly comprising fuel taxes and compare them to those of personal income taxes (PIT). For an assessment in the context of the post-COVID recovery, I study econometrically how the multipliers depend on the business cycle, the state of the energy sector, and exposure to trade.3 I differentiate between regimes

3Recent studies find evidence for the regime dependence of fiscal multipliers (Jordà and Taylor 2016; Callegari, Melina, and Batini 2012; Baum, Ribeiro, and Weber 2012; Gunter et al. 2018; Gechert and Rannenberg 2018). Jordà and Taylor (2016) estimate the output loss of a 1% of GDP fiscal consolidation pooling expenditure cuts and tax increases and find a 5-years GDP loss of 4% during contractions and of only 1% during expansions. Callegari, Melina, and Batini (2012) estimate fiscal multipliers for the US, Japan, and Europe and find them to stronger during contractions. Baum, Ribeiro, and Weber (2012) obtain similar
of negative and positive output gaps, economic contraction and expansion, low and high fuel prices, and low and high tax levels, low and high carbon-intensive GDP, and low and high trade exposure. The study exploits the OECD Policy Instruments for the Environment (PINE) database which gathers detailed information on environmental taxes (EVT) and EGT as a sub-category since 1994. Data on PIT and excise tax (EXT) revenues, the latter of which is used for robustness checks, are taken from the UNO WIDER database.\textsuperscript{4}

The problem of identifying the exogenous, discrete policy variation in the respective tax revenues is addressed by applying a cyclical adjustment to the tax revenues, which is a common identification strategy in the literature.\textsuperscript{5} The underlying assumption is that the feedback effect of output on tax revenues is controlled by a constant, country-specific output-gap elasticity. To obtain the cumulative multipliers of a permanent tax change, I use the local projection method proposed by Jordà (2005) and Jordà, Schularick, and Taylor (2015) and employed by Dabla-Norris and Lima (2018) to estimate dynamic multipliers for a country panel.

The theoretical analysis reveals that the multiplier effects of an upstream carbon or energy tax as proposed by Metcalf and Weisbach (2009) critically depend on various elasticities of substitution along the value chain. In particular, the ability of the energy and production sectors to reduce carbon and energy intensities, respectively, as well as the response of labor demand to an increase in energy prices drive the size of upstream tax multiplier effects on output and employment: the more flexible the production structure, the lower the multiplier effects and the stronger the expansion in employment. In contrast to that, PIT directly affect aggregate demand and reduce the labor input to production. Hence, the underlying model predicts PIT multipliers to be stronger than those of energy taxes, assuming substitution elasticities that are in line with the literature. Due to the complex nature of supply chains, the model predicts EGT multipliers to be more heterogenous across countries than PIT multipliers. Commodity trade exposed countries engaging in a very price-competitive environment should expect higher tax multipliers in general.

The empirical analysis confirms the theoretical predictions: First, EGT multiplier effects on output are slightly weaker than PIT multipliers. Averaged over the entire sample, the estimated EGT multiplier on output is around 1 on impact and reaches 1.8 at the peak two years after. The estimated PIT multiplier is 1.4 on impact and peaks at 2.3 after three years which is in line with the literature (Dabla-Norris and Lima 2018). Three to four years after impact, cumulative EGT multipliers are still significant whereas environmentally related multipliers have converged to zero. Only PIT multipliers are statistically significant at all horizons. PIT multipliers are driven by a permanent drop in consumption which is not the case for EGT. These baseline results are in line with the view expressed in Heine and Black (2019): environmental tax reform shifting the tax burden from labor to fossil energy may be expansionary. It could therefore contribute to countries’ recoveries from the current COVID-19 crisis.

Second, PIT have more adverse employment effects than EGT. While raising PIT by 1% of GDP reduces employment from 0.2%-points on impact to 0.7%-points at the peak after three years, energy taxes do not seem to have a statistically significant effect on employment at all. This is consistent with Metcalf and Stock (2020) who do not find significant employment effects of carbon taxes as well as with our model’s prediction: Facing higher labor costs, firms may substitute labor for energy and capital. Facing higher energy costs, however, they may substitute energy for capital and/or labor.

Third, investigating how the multipliers depend on the business cycle reveals that EGT have no negative output effects when implemented during years of economic expansion or when GDP is above its potential. The results for the US, Germany, France, Japan, and Canada comparing periods of positive and negative output gaps. As another form of non-linearity, Gunter et al. (2018) study how value-added tax multipliers depend on the initial level of taxation and find that lower taxes are associated with lower multipliers than higher taxes. Gechert and Rannenberg (2018) review 98 empirical studies and conclude that expenditure multipliers are stronger during downturns while tax multipliers are not.


Only during contractions, EGT multipliers seem to be strong. When the output gap is negative, EGT multipliers are also found to be strong. Yet, this result is not robust to excluding extreme changes in the tax-GDP ratio. For PIT, I find similar multipliers to those of the baseline, independent from the state of the business cycle, which is consistent with Gechert and Rannenberg (2018) who do not find overall tax multipliers to be state dependent. Overall, these results reinforce the view that, in a recovery, a revenue-side consolidation of public finances is best achieved by increases in environmental taxes rather than income taxes. The optimal timing is when the economy is on a robust path of recovery.

Fourth, the state of the energy sector matters for the size of environmentally related tax multipliers. They depend on pre-tax real fuel prices. EGT multipliers are negative and significant when fuel prices are above the median but not when they are below the median. PIT multipliers, however, do not depend on fuel prices. These results support the idea of restructuring tax collection in times of economic recovery when fuel prices are low. Note that the World Bank fuel price forecasts suggest that they are predicted to remain low for much of the decade when countries are expected to consolidate their budgets. EGT multipliers also seem to moderately depend on the level of the tax (as a share of GDP). They tend to be stronger and more significant when EGT are above the median. When EGT are lower than the median, a tax increase has no significant effect on output. For PIT, I do not find a significant dependence of the multiplier on the PIT level. Moreover, environmentally related tax multipliers depend on the carbon intensity of GDP. EGT multipliers are lower when, upon implementation, the carbon intensity of GDP is higher. These results suggest that countries at the beginning of a decarbonization effort can expect lower multipliers.

Fifth, environmentally related tax multipliers depend on the share of commodity exports in GDP. For EGT but not for PIT, multipliers are significantly stronger in the regime of high commodity exports than in the regime of low commodity exports. This result suggests that countries relying on commodity exports should expect higher environmentally related tax multipliers than those trading more differentiated goods.

Thorough robustness checks are conducted suggesting that the baseline findings are robust to various changes to the sample and specification: I additionally consider environmental taxes (EGT) including energy, transport, pollution, and resource taxes as well as excise taxes (EXT) as alternatives to EGT. The results are in line with the findings for EGT. Controlling for gasoline prices does not affect the results. Including the real interest rate as a control reduces the sample size considerably but does not alter the baseline results except for slightly reducing the environmentally related tax multipliers. Controlling for public debt does not change the baseline results. Excluding control variables from the regression model entirely does not change the results, either. Changing the lag structure of the specifications from one to two makes the PIT multiplier stronger and the EGT/EVT multipliers slightly weaker, thereby increasing the differences between income and environmental tax multipliers. Including the 1st and 99th percentiles of changes in the tax-GDP ratio in the sample for the baseline estimation causes the environmentally related tax multipliers to slightly increase, but they are still weaker than the PIT multipliers. Excluding the 1st and 99th percentiles of changes in the tax-GDP ratio for the regime-dependent estimation reproduces the main results but the confidence bands increase due to the lower degrees of freedom. One exception are the differences in the multipliers of the negative-output gap and positive-output gap regimes which collapse. Excluding countries with double-digit multipliers to work with a more homogeneous sample does not affect the results. Restricting the sample to sub-samples (high- and middle-income countries, high-income countries, middle-income countries) does not change the results considerably. For high-income countries, the difference between the low and high fuel price regimes with considerably stronger multipliers in the latter case, even for PIT, becomes more significant. In middle-income countries, environmentally related tax multipliers are weak and partly positive. Overall, the core results seem to apply to countries independent of their income level. Finally, the output gap elasticities for PIT is reduced by 0.2 and increased by the same amount for the environmental taxes. This makes the identification less favorable for an environmental tax reform. The change in the cyclical adjustment, reduces the PIT multipliers and increases the environmentally related tax multipliers. Nevertheless, in most specifications, the former remains stronger than the latter.

Compared to previous multiplier work, there are important caveats of the present study which are related to data availability. While almost all tax multiplier studies exploit quarterly data, we have available only annual data. Moreover, there is no data on tax rates or exogenous policy changes available that would allow us to follow the narrative approach proposed by Romer and Romer (2010). Riera-Crichton, Vegh, and Vuletin
(2016) found this approach to be superior over the cyclical adjustment approach followed in the present paper. Once the OECD PINE database is extended by including historical data on environmentally related tax policy changes, the multiplier estimation can be revisited following the narrative approach. Another consequence of imperfect data availability is the necessity to assume multiplier homogeneity across countries even though there are good reasons to believe that multipliers vary strongly between countries. We can relax the assumption of homogeneity only by considering different regimes and checking robustness for high income countries. Estimating the output and employment effects of the implied fuel tax rates provided by the World Bank’s Carbon Pricing Assessment Tool (CPAT), which we use for the cyclical adjustment of the tax revenue series, is not an option as we do not have data on the respective tax bases and country pooling would be impossible. Despite these caveats, our results are powerful as they are robust to considerable changes in the sample and specifications. Moreover, the PIT results are in line with the literature lending credibility to the results on the environmentally related taxes as well.

The remainder of the paper proceeds as follows: Section 2 lines out the open-economy macro framework used to assess the driving forces of environmental and labor tax multipliers. Details on the model and its calibration are reported in Appendices A and B, respectively. Section 3 briefly discusses the econometric method, data, and identification strategy. Section 4 presents the results of the baseline specification employing the full sample. Regime-dependent multipliers are estimated in Section 5. Section 6 discusses the robustness checks conducted and section 7 concludes. Appendix C reports the results of the robustness checks in detail.

2 Carbon and labor taxes in a simple energy macro framework

This section reviews the core drivers of carbon and labor tax multipliers based on a simple open-economy macro framework which is a simplified two-country version of the Energy Dynamic Stochastic Disequilibrium (E-DSDE) model proposed by Schoder (2021) to simulate the macroeconomic implications of an upstream carbon tax in economies with persistent unemployment or a high share of informality. The core feature of the model is dis-equilibrium unemployment originating from the assumption that the rate of nominal wage inflation is exogenous as in Benigno and Fornaro (2018). With idle labor, the economy can swiftly respond to demand shocks by adjusting employment. Schoder (2020) provides a detailed review of the macroeconomics of DSDE models. The model features an energy sector which uses carbon as an input. Appendix A reports the model equations which are all derived from first principles. Appendix B reports the baseline calibration of the model.

2.1 The model setup

The model features two types of households: optimizing households and rule-of-thumb households. The former provide a part of the overall labor supply, and they own all the firms. Hence, they receive labor and capital income (from equity and bonds). They smooth consumption and saving optimally over time. Rule-of-thumb households provide the other part of labor supply and accommodate the firms’ labor demand at a given real wage. They consume their entire income and, hence, do not accumulate assets.

The production sector is decomposed into multiple layers along the value chain as illustrated in Figure 1. Retail firms combine domestic and foreign wholesale goods and form the final good which is used for consumption and capital investment. The trade elasticity controls how strongly imports respond to changes in the real exchange rate: that is, the ratio of foreign and domestic wholesale prices. This trade elasticity is one of the parameters which will turn out crucial for the size of the multipliers. Retailers operate under perfect competition and do not make profits.

Wholesale firms combine domestic core and energy goods into wholesale goods which they sell to the retailers at home and abroad. Note that I assume the domestic and foreign economy to be symmetric: the production structure is the same abroad. Only wholesale goods are traded. Competition is assumed to be perfect. Crucial for the transmission of a carbon tax increase is the elasticity of substitution between core and energy goods which may be complements or substitutes to each other.

A continuum of firms produces differentiated core goods which are then aggregated to a homogeneous core good by a perfectly competitive firm. Due to input substitution between the differentiated goods core firms
have market power allowing them to set the price with a markup over marginal costs. The production structure of differentiated core goods has two levels: Firms use capital-energy goods and labor to produce the core good. They hire labor for which they pay a wage to the households and a labor tax to the government. Capital-energy is generated from capital and energy inputs. Capital is firm-specific and controlled by capital investment. Core firms purchase energy from the energy firms. Quadratic price and capital adjustment costs allow the model to replicate the empirically observed hump-shaped form of macroeconomic adjustment. Note that the crucial parameter in the core goods sector is the elasticity of substitution between capital and energy.

The modeling of the energy firm sector is at the core of the E-DSDE model. I assume that firms produce energy using only capital and carbon as inputs. For the sake of simplicity, carbon can be exploited at a fixed cost per carbon unit. Again, capital is firm-specific and subject to the same quadratic adjustment costs as before. I assume, however, that energy firms operate under perfect competition. The energy production technology allows for substitution between capital and carbon. A few implications of this modeling device are worth to note: First, the elasticity of substitution determines if capital and carbon are substitutes or complements. An elasticity of above (below) unity implies capital and carbon to be substitutes (complements). In that case a rising carbon price would (increase) reduce capital investment in the energy sector, ceteris paribus. Second, the marginal returns of carbon in energy production are decreasing as carbon increases. Conversely, carbon reduction is less costly in terms of energy output loss when the level of carbon is high compared to when it is low. It is easier to reduce carbon at the beginning of the decarbonization effort than when carbon is already low. Third, since the marginal exploitation cost of carbon is assumed to be fixed, the profit maximizing energy firm will increase the carbon input until the marginal product is equal to that cost plus the carbon tax rate.

While there are various ways to model a carbon tax, the approach proposed by Schoder (2021) has important advantages: Even though derived from first principles, it is very simple and tractable. The energy sector is embedded in a macro framework which performs well empirically despite the absence of typical Dynamic Stochastic General Equilibrium (DSGE) features such as habit formation, variable capital utilization, or constrained monetary policy (Schoder 2017). The transmissions of a carbon and labor taxes are governed by substitution elasticities at various points of the value chain. Niu et al. (2018) provide an alternative theoretical framework based on full-employment DSGE model. They introduce a carbon tax in the core goods sector. Instead of taking carbon as an input to energy production, they assume a carbon emission function of energy use and the share of fossil energy. Nevertheless, their results are very similar to those of the present study as discussed below.

While the labor supply is constant, households accommodate any labor demand expressed by the firms. Instead of assuming that the nominal wage adjusts to clear the labor market which would constitute a general equilibrium, the disequilibrium model considered here takes the nominal wage as a policy variable (equivalent to the interest rate) which responds to the labor market through a Phillips curve relationship: the rate

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6An alternative interpretation is that capital is the only input and the carbon intensity of capital controls the capital productivity. Under this interpretation, carbon intensity is a control variable of the energy firm.
of nominal wage inflation increases with employment. The employment elasticity of wage inflation varies strongly between countries and is a crucial parameter determining to what extent tax-induced changes in employment affect the price inflation of core goods and, hence, the multipliers.

Regarding policy, the model assumes that the interest rate responds to core inflation (excluding energy goods) by more than one-to-one in line with the Taylor principle. Government spending is constant. Carbon and labor taxes constitute all tax revenues. The government budget is balanced at the initial steady state only.

### 2.2 Simulating the macroeconomic effects of carbon and labor tax increases

The model outlined above allows to trace the transmission channels of carbon and labor taxes and identify core parameters which affect the size of the multipliers. The baseline calibration either matches estimated values in related models or ensures that the model’s steady state is broadly in line with real-world economies. Details on the model and its calibration are provided in Appendix A and B, respectively.

Figure 2 compares the macroeconomic effects of a permanent increase in the carbon tax rate generating (on impact) an additional tax revenue of 1% of GDP and a permanent increase in the labor tax rate of the same magnitude. The percentage steady-state deviations of output over time define the dynamic multipliers estimated in the empirical section below. Under the baseline calibration, the labor tax multiplier effect on output is considerably stronger than the carbon tax multiplier as reported in panel (a) of Figure 2. Both consumption and investment perform considerably worse in response to a labor tax increase than to a carbon tax increase. The trade balance deteriorates more for the carbon tax. What drives these results?

The large labor tax multiplier is driven by the decline in employment arising from the erosion of the households’ disposable income, the substitution of labor with energy-capital and the negative aggregate demand feedback on sales which further reduces employment. With labor taxes directly cutting into the disposable income of households and a lower relative labor demand and employment, aggregate consumption decreases strongly. This is even though the real wage decreases less than after a carbon tax increase. In economies with large pools of idle labor (such that the nominal wage share does not respond strongly to changes in labor market conditions) and a high share of hand-to-mouth consumers (spending their income on consumption), consumption is predicted to be the main driver of the labor tax multiplier. Figure 3 shows the responses of GDP and its components to a labor tax shock under deviations from the baseline calibration. An increase in the labor market feedback on wage inflation (turquoise line) reflecting economies with tighter labor markets and smaller informal sectors will dampen the negative labor tax multiplier as the drops in the real wage and disposable income are limited.
Figure 3: The macroeconomic effects of a labor tax increase by 1% of GDP for the baseline (green), when the employment elasticity of wage inflation increases by 0.1 (turquoise), and when selected elasticities of substitution increase by 0.2: between domestic and foreign goods (red), core goods and energy (blue), capital and energy (yellow), and capital and carbon (purple).

In addition to consumption, investment declines. Even though firms use more energy-capital in production relative to labor, the decline in aggregate demand dominates the investment decision.

Regarding price effects, core prices rise considerably in response to a labor tax increase as firms face higher labor costs. Energy prices hardly change. With increasing inflation, the trade balance deteriorates. I assume a domestic-foreign goods substitution elasticity of 0.7. This is quite high and may well characterize a low-income country with commodity-based trade for which price competitiveness is crucial. As shown in Figure 3, a higher sensitivity of imports towards the real exchange rate increases the carbon tax multipliers (red line). This confirms the common empirical finding that trade-exposed countries and especially those which trade in commodities exhibit larger multipliers (Ilzetzki, Mendoza, and Végh 2013). Finally, note that the other elasticities of substitution along the value chain do not affect the labor tax multipliers, as shown in Figure 3.

While the labor tax directly cuts into aggregate demand, the upstream carbon tax mainly affects relative prices (and hence production structures) and inflation. It immediately triggers a relative input substitution of carbon with capital in energy production. A capital-carbon elasticity of 0.6 assumed in the baseline calibration implies these inputs to be complements. Hence, capital investment in the energy sector declines when carbon gets more expensive. As shown in Figure 4 which illustrates the sensitivity of the carbon tax multiplier towards changes in relevant substitution elasticities, a higher capital-carbon elasticity (purple line) is sufficient to mitigate the decline in investment or even reverse it as in Niu et al. (2018) who predict an
expansion of investment following a carbon tax increase. Yet, with capital and carbon being complements, firms over-proportionally increase the energy price rather than expanding the capital stock when the cost of carbon increases as shown in Figure 2.

When energy prices increase, core firms will substitute energy for both capital and, especially, labor which can be hired more easily than capital can be expanded. This creates an employment boom the extend of which depends on the elasticity of substitution between capital and energy. The baseline assumes unity which is in line with Fiorito and van den Bergh (2016). As shown in Figure 4, the extend by which capital investment declines depends strongly on the ability of core firms to substitute between energy and the other factors of production: A higher elasticity increases the response of investment to a carbon tax (yellow line). Note, how sensitive the results are to changes in the capital-energy elasticity compared to changes in the other elasticities. In a nutshell, the better a country manages to increase energy efficiency in production, the lower the carbon tax multiplier will be.

Facilitating the improvement of the energy efficiency of the consumption basket further lowers the multiplier as retailers find it easier to replace more expensive energy goods by core goods. For the core goods-energy substitution, I assume a baseline elasticity of 0.3 implying them to be strong complements which is consistent with the findings of An and Kang (2011) and Medina and Soto (2005). Increasing this elasticity reduces the carbon tax multipliers as illustrated in Figure 4 (blue line).
Under baseline calibration, inflation increases strongly after a carbon tax increase. This affects the terms of trade and the trade balance deteriorates as shown in Figure 2. In addition, Figure 4 suggests that a more elastic substitution between domestic and foreign goods will lead to stronger carbon tax multiplier effects (turquoise line). Hence, trade-exposed countries relying on commodity exports can expect to face higher carbon tax multipliers than others. This is because the domestic-foreign good substitution elasticity is higher for commodities than for differentiated goods.

Note that for the sake of simplicity the model assumes enough unemployed labor to be available to accommodate demand. In the baseline calibration, the rate of wage inflation is constant. With large tax policy shocks or in countries with tight labor markets, the model may overstate the positive employment effects if the nominal wage responds to labor market tightening. As simulated in Figure 4, wage inflation will then translate into core inflation which triggers the monetary authority to increase interest rates. The carbon tax multiplier will be stronger compared to the baseline (red line).

Overall, the carbon tax multiplier may vary more strongly between countries than the labor tax multiplier. This is because the latter directly affects a core demand component and substitution effects in the value chain are only of secondary importance. An upstream carbon tax, however, leads to a series of production adjustments along the entire value chain. The result depends on many crucial elasticities of substitution which may vary considerably between countries. It can therefore be expected that environmentally related tax multiplier estimators have a higher variance than personal income tax multiplier estimators.

Finally, we compare the baseline multipliers to those derived from a calibration which is more suitable to characterize an economic recovery following a recession. Typically, the early phase of a recovery when output is below potential features severe liquidity constraints, bond spreads reflecting high financial market risk, and lower profitability (Rannenberg, Schoer, and Strasky 2015; Gechter, Hallett, and Rannenberg 2016). In line with that, we increase the share of rule-of-thumb households by 20%-points and the equity risk premium by 2%-points and decrease the core firms’ price mark-up by 10%-points. The multipliers of this below-trend-growth calibration is contrasted to the baseline in Figure 5. In a recovery, the carbon tax multiplier is lower than during normal times. The opposite holds for the labor tax. With a higher share of rule-of-thumb households, the contractionary effect of labor taxes on consumption become even more severe. In contrast to that, the positive employment effects of a carbon tax are reinforced during times of below-trend output.

3 Estimation method and data

The empirical section estimates the multiplier effects of personal income taxes (PIT) and energy taxes (EGT) on output and employment for a large panel of high and low-income countries. To check the robustness of the results for EGT, I also consider the broader category of environmental taxes (EVT) as well as excise taxes (EXT) a large part of which constitutes fuel taxes. Given the theoretical model outlined above, one appealing approach could be to apply Bayesian techniques to estimate the model parameters and empirical impulse-response functions (IRFs) to obtain the dynamic multiplier effects of interest. While this is a common
strategy in the literature (Gechert, Hallett, and Ramnenberg 2015), we delegate the model-based empirical analysis to future research and rather use the model above to provide the rationale for the regression-based empirical findings below. The advantage of a regression-based analysis is its independence from the theoretical priors incorporated in an economic model. Regression-based analysis allows the data to speak as freely as possible.

3.1 Local projection

To obtain dynamic multiplier estimates, I employ the local projection method proposed by Jordà (2005) and extended to panel data by Jordà, Schularick, and Taylor (2015) and Jordà, Schularick, and Taylor (2020). As in Dabla-Norris and Lima (2018), I estimate for every horizon

\[ y_{i,t+h} - y_{i,t-1} = \alpha_{i,h} + \delta_{i,h} + \Delta s_{i,t} \beta_{h} + \Delta x_{i,t} \gamma_{h} + \varepsilon_{h,i,t+h} \]  

(1)

where \( y_{i,t} \) is the dependent variable for which I consider the log of real per-capita GDP, consumption, investment, and net exports as well as per-capita employment in percent. To estimate cumulative multipliers, the change of these variables relative to \( t - 1 \) for each horizon constitutes the dependent variable. \( s_{i,t} \) is the identified shock variable which, for each tax instrument considered, is the cyclically adjusted tax revenue-GDP ratio in percent. \( \beta_{h} \) has the interpretation of a cumulative multiplier: that is, \( \beta_{h} \) tells us by how many percent (age-points) output (employment) increases in \( t + h \) relative to \( t - 1 \) if tax revenues increase by 1% of GDP. \( x_{i,t} \) is a vector of control variables. It includes the log of real per-capita government spending to account for the fiscal space effect of taxes on public spending: Tax increases generate revenues which could be used to increase government spending. Since the additional revenues may be used to lower other taxes, I also control for the tax-reform effect by including EGT in the specification for PIT and PIT in the specification for EVG (as well as EVG and EXT). Then, the estimated multipliers can be interpreted in isolation of possible changes in other taxes. The control variables also include the log of the GDP price deflator to account for inflation as well as the lagged dependent variable. As robustness checks, I also consider specifications that include diesel and gasoline prices as well as the short-term interest rate. I assume a lag structure of 1 but check the robustness to changing the number of lags. Increasing the lag structure to 2 or 3 does not make a considerable difference. \( \alpha_{i,h} \) and \( \delta_{i,h} \) are country and time fixed effects, respectively. The former are introduced to account for country-specific intercepts and the latter to account for common trends. \( \varepsilon_{h,i,t+h} \) is the error term. Because of serial correlation in the error terms, I follow Driscoll and Kraay (1998) and Jordà (2005) using heteroskedasticity and auto-correlation robust variance-covariance estimators.

The local projection method can easily be extended allowing dynamic multipliers to depend on regimes (Auerbach and Gorodnichenko 2012). For instance, it can be used to compare multipliers of regime 1 and regime 2. For each of the regimes considered I define a dummy variable \( z_{i,t} \) and estimate the regime-dependent parameters of

\[ y_{i,t+h} - y_{i,t-1} = \alpha_{i,h} + \delta_{i,h} + (1 - z_{i,t}) \left( \Delta s_{i,t} \beta_{h}^{(1)} + \Delta x_{i,t} \gamma_{h}^{(1)} \right) + z_{i,t} \left( \Delta s_{i,t} \beta_{h}^{(2)} + \Delta x_{i,t} \gamma_{h}^{(2)} \right) + \varepsilon_{h,i,t+h} \]  

(2)

Note that a regime is defined based on the characteristics of group \( i \) in period \( t \). Hence, the interpretation of \( \beta_{h}^{(1)} \) is the multiplier effect \( h \) periods later if the economy was in regime 1 in period 0 when the policy change was implemented.

3.2 Identification

To address the simultaneous equation bias in the estimates of the tax multipliers which may arise from the feedback of output into tax revenues, the empirical literature follows one of two approaches. To solve this problem of identifying discrete tax policy changes, the narrative approach identifies discretionary policy changes on a case-by-case basis by studying official policy records (Romer and Romer 2010). Since the data

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7The main reason why, in the context of this analysis, I prefer local projection over a traditional Structural Vector-Autoregression (SVAR) approach is that the former’s IRFs are more robust in case of miss-specification (Jordà 2005). Moreover, local projection is a much simpler method than SVARs while the respective IRFs are similar especially at short horizons (Plagborg-Moller and Wolf 2020).
set used here does not include historical data on environmental tax policy changes, I delegate the application of this identification strategy to future research. Alternatively, the cyclical adjustment approach assumes that there is a given country and tax specific constant output gap elasticity which can be used to remove the cyclical element from the tax revenues (Giavazzi and Pagano 1990; Alesina and Perotti 1997; Blanchard and Giavazzi 2002; Alesina and Ardagna 2010; Favero and Giavazzi 2012; Perotti 2012).

The present study follows the cyclical adjustment approach. In particular, the tax revenue-GDP ratios $T/Y$ are cyclically adjusted as

$$\frac{T^*}{Y^*} = \frac{T}{Y} \left(\frac{Y^*}{Y}\right)^{\eta_{YT} - 1}$$

where $Y^*$ is trend GDP obtained from the HP filter of log GDP and $\eta_{YT}$ is the output gap elasticity of the tax revenues.

Price, Dang, and Botev (2015) provide elasticities for PIT for most of the countries in the sample. They first compute the tax revenue-tax base elasticity $\eta_{BT}$, then the tax base-output gap elasticity $\eta_{YB}$, and compute the tax revenue-output gap elasticity by multiplying the former two elasticities: $\eta_{YT} = \eta_{BT}\eta_{YB}$. For the computation of the revenue-base elasticity $\eta_{BT}$, they apply statutory tax rates to data on the distribution of the components of the PIT base: wages and salaries, self-employed income, and capital income. To compute the tax base-output gap elasticity, they decompose GDP into wages, salaries and capital income, self-employed income, as well as operating surplus to approximate the respective tax bases and estimate the elasticities for each of these three components using error-correction models regressing the tax base on the output gap. Since elasticities of the income components have to sum up to one, the final elasticities are normalized accordingly. Dudine and J alles (2017) provide additional output gap elasticities for PIT. Overall, 48 countries of my sample are covered. For the remaining countries, I took the average of 1.77 as the best approximation.

Output gap elasticities for energy taxes or the broader category of environmental taxes have not been estimated before. Since reliable data on tax rates are not available historically, applying the method proposed by Price, Dang, and Botev (2015) is not feasible. Instead, I directly regress the tax revenues on GDP in logs. To avoid a simultaneous equation bias, up to 4 lags of GDP serve as instruments for contemporaneous GDP. To reduce volatility, the final elasticities are then computed as the averages over the coefficients of the 4 specifications. The average elasticity of EGT is 0.39 and therefore considerably lower than the one for PIT. Hence, energy taxes are, on average, less cyclical than personal income taxes. I use two more tax instruments for robustness checks: The average EVT output gap elasticity is 0.83. For EXT, I obtain 1.01. This is very much in line with the definition of EXT as a proportional tax over a large base. Note that Price, Dang, and Botev (2015) assume an EXT output gap elasticity of 1 for each country.\(^8\)

To create the data set, I exploit various sources: The OECD Policy Instruments for the Environment (PINE) data set provides revenue data for four environmental tax categories (energy, transport, pollution, and resources). Because they have the best coverage, we use EGT for the baseline estimations and EVT to check the robustness of the results. From the United Nations University World Institute for Development Economics Research (UNU-WIDER), I take data on PIT and EXT revenues. Data on GDP, consumption, investment, trade balance, employment, GDP deflator, government spending, population, and interest rates are taken from the World Bank’s World Development Indicators database. I also use data on diesel and gasoline supply prices from a data set compiled to inform the World Bank’s Carbon Pricing Assessment Tool (CPAT). To remove outliers in the baseline estimation, I exclude the 1st and 99th percentiles of the changes in the tax revenue-GDP ratios. The sample includes 75 countries from 1994 to 2018. Note that the panel is strongly unbalanced but every country has at least 10 observations. The countries covered are reported in Table 1.

\(^8\)Appendix C reports details on the robustness of the results with respect to different assumptions regarding output gap elasticities.
Table 1: The countries covered in the sample.

<table>
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<tr>
<th>Argentina</th>
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<td>Portugal</td>
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<td>Congo, Dem. Rep.</td>
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<td>Malta</td>
<td>Romania</td>
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<td>Croatia</td>
<td>Iceland</td>
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<td>Venezuela, RB</td>
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Figure 6 plots, for each tax instrument, the annual medians, the 33rd and 67th percentiles, and the 10th and 90th percentiles of the cyclical adjusted tax revenue-GDP ratios. It provides insights into the cross-sectional variation of each tax instrument in every year of the sample. The PIT varies strongly between countries with the median tax revenue-GDP ratio averaging around 5% but with 90% of be cross-sectional observations between around 0% and 13%. The country variation of energy taxes relative to GDP is much smaller. 90% of the observations are between 0% and 3%. Note that at the median none of the tax categories has a trend. This is also true for a sub-sample of countries that have observations in every year of the sample. Hence, energy taxes as a share of GDP did not increase over time on average.

Figure 7 shows box plots for each country’s tax revenue-GDP ratios ordered according to the overall tax revenues. They indicate not only the scale of each country’s taxation of household income and carbon emissions but also how it varied over the sample’s time dimension. Red indicates PIT and blue EGT. For the sake of comparison, all y-axes have equal range from 0% to 15%. Note that Denmark’s PIT revenue-GDP ratio is around 25% with a small variation over time and hence it is not in the plot. One striking insight from this descriptive plot is that the PIT burden varies strongly across countries. Most OECD countries accrue at least 5% of GDP from income taxes whereas developing countries tend to have a low effective PIT revenue. The latter may be related to a low collection efficiency as well as a high share of informal employment. Energy taxes hardly accrue more than 2.5% of GDP in any of the countries considered. It is worth noting that EGT revenues as a share of GPD are only moderately higher in high income countries than in low income countries.

4 Baseline Results

This section reports the estimation results for the personal income tax (PIT) and energy tax (EGT) multiplier effects on output, consumption, investment, the trade balance (as a share of GDP), and employment (as a share of the population) pooled over all countries and years of the sample. Results for EVT and EXT are reported in Appendix C. For both PIT and EGT, Figure 8 shows the respective IRFs of a tax increase. I plot the percentage changes of the dependent variable in periods $h = 0, 1, 2, 3, 4$ relative to period -1 after an impulse in period 0: an increase of the cyclically adjusted tax revenues by 1% of GDP.9

The estimated PIT multiplier effects on output range from 1.4 on impact to 2.3 at the peak after three years.

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9Note that in all specifications I include the following control variables: government spending to control for the fiscal space effect of taxes on spending as well as for revenue recycling; inflation which may affect both taxes and GDP; PIT revenues (for the EGT estimations) and EGT revenues (for the PIT estimations) to control for broad tax reform packages and to isolate the effect of the specific tax under consideration.
As indicated by the confidence intervals, PIT multipliers are significant at every horizon. The estimates are slightly higher than what the model above has predicted. Yet, it is broadly in line with Mertens and Ravn (2013) who find PIT multipliers of between 2 and 2.5 and slightly stronger than Dabla-Norris and Lima (2018) who estimate tax rate effects which translate into PIT rate multipliers of between 1.3 and 1.5. The estimates for the EGT multipliers are smaller than those for PIT: 1 on impact and 1.8 at the peak after two years. After four years, the EGT multiplier converges to zero. Regarding statistical significance, only the peak multiplier after two years is statistically significant at the 10% level. Note that these estimates are in line with Metcalf and Stock (2020) who do not find a statistically significant effect of carbon tax rates on GDP for a panel of OECD countries. Their estimates are very close to zero. This is because they do not control for government spending or PIT changes in their regression model and their estimates may well capture to effect of a full environmental tax reform rather than an isolated carbon tax increase. Note further that the EGT multiplier estimators exhibit a higher variance than the PIT multiplier estimators which is consistent with the theoretical model’s prediction that the multiplier heterogeneity across countries is higher for EGT than for PIT.

As expected, increasing energy taxes have contractionary effects on output when holding other taxes constant. The respective multipliers, however, are slightly smaller than PIT multipliers, especially at horizons of two to four years ahead. The results are in line with our theoretical considerations: Income taxes cut directly into aggregate demand and increase the relative price of labor inducing firms to substitute labor for capital. Therefore, they are found to be more harmful for output than energy taxes. Shifting the tax burden from labor to carbon emission will have positive net output effects, as suggested by the results.

The multiplier effects on consumption, investment, and the trade balance provide more in-depth insights into the driving forces of the output multipliers. As predicted by the theoretical model, PIT have a permanent, negative effect on consumption as they directly cut into the household sector’s disposable income. In contrast to that, EGT have no negative effect on consumption. Regarding investment effects, note that the model’s baseline prediction of investment contractions in response to a PIT increase is also found empirically. Yet, the estimates are not statistically significant. No conclusive evidence can be found for the EGT effects on investment and the standard error of the estimator is very large. This is highly consistent with the observations that the investment response is very sensitive to substitution elasticities in production which vary strongly between countries. The trade balance is found to deteriorate in response to increases in both PIT and EGT. Again, this is consistent with the model discussed above.

Regarding EGT and PIT multiplier effects on employment, Figure 8 shows the following: An increase of PIT by 1% of GDP lowers the employment-population ratio by 0.2% on impact by 0.7% after three years. The estimates are statistically significant. For EGT, I do not find significant employment effects or conclusive results. This is very much in line with Metcalf and Stock (2020) who find no significant employment effects of carbon taxes. In contrast to the substitution-induced employment expansion predicted by the model above,
Figure 7: Box plots for PIT (red) and EGT (blue) tax revenues as percentage shares of GDP (y-axis). Each box plot indicates the distribution of a country’s tax revenues across time. The vertical line inside the box is the median (2nd quartile). The box indicates the 1st and 3rd quartiles. The whiskers show the minimum and maximum, respectively, excluding outliers.
the data suggests that EGT multiplier effects on employment are around zero.

Finally, note that the macroeconomic responses to PIT shocks appear steadier than those to EGT shocks. This may be related to the fact that income taxes immediately affect aggregate spending and lead to immediate and straight-forward substitution effects. Energy taxes, however, may trigger various responses in energy efficiency, capital input, and labor input, all of which have different implementation lags.

5 Regime dependent multipliers

This section explores regime dependencies of the tax multipliers. How dynamic multipliers depend on the state of the business cycle is crucial for the assessment of tax effects during the post-COVID recovery. Moreover, I study how multipliers depend on the state of the energy sector including fuel prices, the level of taxes, and carbon intensity. Finally, I distinguish between high- and low-trade regimes. Since the multiplier effects for employment broadly mirror those of output, I only report the latter. The regime-dependent dynamic multiplier illustrates the response of the dependent variable if the policy impulse occurred in that very regime. A regime-change after the policy impulse is irrelevant for the regime-dependent multipliers.\footnote{Recall that regimes are captured by a dummy which takes the value one for every country-year which meets the criteria for that regime. The dummies are then interacted with the regressors as outlined in section 3. Note that regimes are formed only based on country-year characteristics at the time of the policy impulse (period 0) while the dynamic multipliers capture future values of the dependent variable relative to the previous one.}

5.1 Multipliers and the state of the business cycle

Recent studies have found evidence for regime-dependent fiscal multipliers (Jordà and Taylor 2016; Callegari, Melina, and Batini 2012; Baum, Ribeiro, and Weber 2012; Gechert and Rannenberg 2018). Jordà and Taylor (2016) have estimated a cumulative five-year fiscal consolidation multiplier of 4 when implemented in a contraction and of only 1 when implemented in an expansion. They do not differentiate between expenditure cuts and tax hikes, or between tax instruments. Moreover, Callegari, Melina, and Batini (2012) have estimated fiscal multipliers for the US, Japan, and Europe and find them to be stronger during contractions. Baum, Ribeiro, and Weber (2012) obtain similar results for the US, Germany, France, Japan, and Canada comparing periods of positive and negative output gaps. In a meta-analysis of 98 empirical studies, Gechert and Rannenberg (2018) find that expenditure multipliers are stronger during downturns while tax multipliers are not.

As argued in the theoretical section, there are good reasons for tax multipliers to depend on the state of the business cycle. During an economic contraction or early recovery, credit constraints on households are more severe and borrowing to maintain previous consumption levels becomes more difficult. The share of liquidity constrained households increases. The same holds for credit constraints on firms which are less likely to be able to substitute lower internal finance by higher external borrowing. In this economic environment current wages and profits become the main driver of consumption and investment spending. An increase in labor taxes cuts into both wages and profits thereby directly reducing aggregate demand. The effects of a carbon tax are less clear-cut. Consumers may reduce the energy intensity of their consumption basket while firms may substitute energy for other inputs to production.

I define the states of the business cycle along two dimensions: positive and negative output gap and positive and negative growth.\footnote{Different from the baseline estimations above, the regime-dependent estimations include the 1st and 99th percentiles of the change in the tax revenue-GDP ratios to increase the degrees of freedom.} Figures 9 and 10 plot the dynamic multiplier effects on GDP for the output gap regimes and the output growth regimes, respectively. The results for PIT suggest that the dynamic multipliers are independent from the state of the output gap or output growth. The PIT multipliers are similar in all output related regimes and in line with the baseline results. The differences in the estimated multipliers are statistically insignificant at every horizon. This finding suggests that the regime-dependence of fiscal consolidation multipliers identified by Jordà and Taylor (2016) is not driven by PIT. In contrast to PIT, EGT multipliers are strongly regime dependent. Asterisks and points on the x-axis labels indicate for every horizon the level of significance of testing the hypothesis that the multipliers are the same in both regimes. At every horizon, the difference is significant at least at the 5% significance level. Tax increases implemented when
Figure 8: Cumulative annual macroeconomic responses in percent to a permanent increase in the respective tax revenues by 1 percent of GDP. The dark (light) shaded areas are the 70% (90%) confidence bands.
output is above its potential or when output is expanding will not reduce GDP. The corresponding multipliers are estimated to be zero. Only when the output gap is negative (in the recession and early recovery) or when output contracts, an increase of EGT will considerably reduce GDP: The negative output-gap EGT multipliers are 2.3 on impact and peak at 3.8 after two years. The EGT multipliers for the contraction regime are 2.7 on impact and 5.5 at the peak one year later. Note that the standard errors of the negative output gap and contraction regimes are large which makes the true multipliers uncertain. Nevertheless, they are significantly different from zero. These results for EGT also hold for EVT and EXT as shown in Appendix C.

The implications for the post-COVID recovery are straight-forward: Environmental taxes are only harmful when implemented during the economic contraction and the very early recovery. Once GDP is on a solid path of recovery, environmental taxes are found not to be contractionary at all. The post-COVID recovery therefore marks a suitable time to implement environmental tax reforms.

5.2 Multipliers and the state of the energy sector

Since most fossil fuel or carbon taxes are levied on the quantity of energy used rather than on its price, firms or consumers are indifferent between paying a higher pre-tax price for energy or a higher tax. Hence, energy tax multipliers should be expected to be weaker when fossil fuel prices are low. This is confirmed by the data:
The low and high fuel price regimes are demarcated by the median pre-tax real gasoline price of 0.55 USD per liter. The results are plotted in Figure 11. As expected, the left panel suggests that PIT multipliers do not depend on fuel prices. The differences in the multipliers are not statistically significant. In contrast to that, EGT multipliers depend on the fuel-price regime, and the differences are statistically significant at least at the 10% level except on impact. When implementing the tax increase during a year of low fuel prices, the subsequent dynamic multipliers tend to be positive. When fuel prices are high during the tax change, the following EGT multipliers are between 1.8 and 3.8. PIT estimates are in line with the baseline results. Overall, these results suggest that environmental taxes may be an appealing source of domestic resource mobilization during the post-COVID recovery when, as shown in Figure 12, pre-tax fuel prices have substantially decreased from their long-term average levels and are projected to remain low for much of this decade (World Bank 2021).

Another regime-dependence of interest is how multipliers differ between country-years of high and low taxes. The tax regimes are defined separately for each tax category using the respective median tax revenue-GDP ratios of 4.59% for PIT and 1.44% for EGT as the regime demarcations. The results are plotted in Figure 13. Overall, there is no evidence that PIT multipliers are non-linear in the size of the tax. For both low and high tax regimes, I find similar PIT multipliers and the differences are not statistically significant. EGT multipliers are estimated to be higher (lower) when the tax-GDP ratio is above (below) average. The difference, however, is statistically significant only one year after the policy change. Note that the differences are significant for EVT and EXT (see Appendix C).

Finally, I check if the multipliers depend on the carbon intensity of GDP. Figure 14 reports the dynamic multipliers for low- and high-carbon regimes demarcated by a carbon emission of 0.32kg per real GDP in USD. The PIT multipliers do not depend on the carbon intensity of GDP. The differences in the regime-specific multipliers are insignificant. In contrast to that, raising EGT where/when the carbon intensity of GDP is high does not reduce GDP. Only when the carbon intensity of GDP is already low, multipliers are strong. The differences in the regime-specific EGT multipliers are statistically significant except on impact. This suggests that countries at the beginning of the decarbonization effort should expected smaller multipliers of environmental taxes than countries with lower carbon emissions.

5.3 Multipliers and the state of the external sector

Trade-exposed countries with a large share of commodity exports are expected to exhibit higher income and energy tax multipliers than others as these taxes increase inflation and reduce price competitiveness. Homogeneous commodities are more sensitive to changes in the terms of trade than more differentiated

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12Using the diesel price instead does not alter the results.

Figure 13: Dynamic tax multipliers for output under the low-tax regime (dashed line) and under the high-tax regime (dot-dashed line). The shaded areas are the 90% confidence bands. Significance codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1.

Figure 14: Dynamic tax multipliers for output under the low-carbon-intensity regime (dashed line) and under the high-carbon-intensity regime (dot-dashed line). The shaded areas are the 90% confidence bands. Significance codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1.

manufactured goods. Accordingly, I distinguish regimes of high and low commodity exports as a share of GDP.\textsuperscript{13} The sample median marking the threshold is 23.2%. Figure 14 displays the resulting IRFs confirming the theoretical predictions. The PIT multipliers are similar to the baseline results in both regimes.

\textsuperscript{13}The data on commodity exports are taken from UN Comtrade.
Figure 15: Dynamic tax multipliers for output under the low-commodity-export regime (dashed line) and under the high-commodity-export regime (dot-dashed line). The shaded areas are the 90% confidence bands. Significance codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1.

The differences are not significant. In contrast to that, EGT multipliers are commodity trade dependent. When/where commodity exports are low as a share of GDP, EGT multipliers are close to zero and statistically insignificant. Otherwise, they are estimated around 2 reaching 2.6 at the peak and significant on impact and one year after. The differences in the two sets of multipliers are also statistically significant in the first two horizons.

6 Robustness

As reported in Appendix C, the core findings are robust to various changes to the baseline sample and specifications: First, I estimate multipliers for environmental taxes (EVT) and excise taxes (EXT) as alternatives and approximations to EGT, respectively. Note that EVT is a broader category than EGT including taxes and fees for transportation, pollution, and natural resources. EXT may be seen as a decent approximation of EGT as a major part of excises is fuel taxes. Hence, there is a strong overlap between EGT and EXT. The estimated EVT multiplier is 0.5 on impact and 1.1 at the peak one year after. With the baseline specification, the EVT estimates are not statistically significant. The EXT multipliers are 1.3 on impact and 1.4 at the peak after one year. The estimates for the first two horizons are significant. Note that the results for EVT and EXT are robust to changes to the sample and specification. Only the sizes of the multipliers vary as well as the significance levels. Overall, the results are very similar to the EGT multipliers. Note that while the size of the multipliers differs between the environmentally related tax instruments, their shape is very similar with the multipliers converging to zero after a few years. All regime-dependencies of the EGT multipliers are confirmed for EVT and EXT (Appendix C.1).

Second, I additionally control for gasoline prices (Appendix C.2). This is because energy taxes, to some extent, might capture the output effect of energy prices. While the number of observations is slightly reduced, the output and employment multipliers of the environmentally related tax instruments are not considerably different from the baseline. The estimated standard errors increase somewhat at longer horizons which may be due to the lower degrees of freedom. Regarding regime dependence, the environmentally related tax multipliers on output are still stronger in contractions than in expansions. Also, the multipliers on output are stronger during low fuel prices than high fuel prices. The baseline evidence that the tax level makes a difference is weak. Note that controlling for diesel prices instead of gasoline prices does not change the results. For the sake of parsimony and to keep the degrees of freedom high, I dropped fuel prices in the baseline.

Third, controlling for the real interest considerably reduces the sample size because of data constraints (Appendix C.3). The average output multipliers are now smaller than in the baseline. The estimates of the PIT

\[14\text{In the US, for instance, more than 60}\%\text{ of the excise taxes are accrued from transportation including aviation.}\]
multipliers still exceed those of the environmentally related tax multipliers. Only the PIT multipliers remain statistically significant. The differences in the regime-dependent multipliers become small and statistically insignificant.

Fourth, the estimated multipliers may capture the effect of public debt (which decreases when taxes increase) on GDP. To control for this channel, I add the debt-GDP ratio as a regressor (Appendix C.4). The changes in the results are minor and the baseline findings can be confirmed.

Fifth, I exclude all control variables except the lagged dependent variable to check the sensitivity of the results. The PIT and EGT multipliers on output are slightly reduced, and the EXT multiplier is slightly increased. The results for the regime dependencies regarding the state of the business cycle and energy sector are similar to the baseline. Overall, the results do not change considerably (Appendix C.5).

Sixth, the number of lags increases from 1 to 2 (Appendix C.6). Averaged over the business cycle, the PIT multipliers now become even stronger with values between 1.8 and 2.8 on output. The EGT and EVT multipliers on output slightly decrease with values from 0.9 to 1.8 and 1 to 1.8, respectively. The results regarding the regime dependence of environmentally related taxes hold.

Seventh, I check the robustness of including and excluding the 1st and 99th percentiles of the change in the tax revenue-GDP ratios, respectively. In the baseline, these extreme values are excluded. To increase the degrees of freedom, they are included in the regime-dependent estimations. The robustness check conducted in Appendix C.7 reverses this: Outliers are included in the baseline and excluded in the regime-dependent estimations. In the baseline estimations, the environmentally related tax multipliers slightly increase but are still weaker than the PIT multipliers. The main insights of the regime-dependent analysis remain valid, but the confidence bands increase due to the lower degrees of freedom. Only the differences in the multipliers of the negative-output gap and positive-output gap regimes collapse.

Eighth, country-specific estimates reveal that a few countries exhibit implausibly large multipliers. Therefore, I exclude GNQ, JPN, KEN, SGP, SVN, SWE, TUN, and USA to obtain a more homogeneous sample. The results are almost identical to the baseline (Appendix C.8).

Ninth, I consider income-group specific sub-samples: For the sample of only high- and middle-income countries (Appendix C.9) and for the sample of only high-income countries (Appendix C.10), all results are broadly similar to the baseline. There is, however, a more significant difference between the low and high fuel price regimes with considerably stronger multipliers in the latter case, even for PIT. For the sample of only middle-income countries (Appendix C.11), the environmentally related multipliers become very weak and partly positive. Note, however, that for the groups of high-income countries and middle-income countries, the degrees of freedom are very low.

Tenth, since the cyclical adjustment of the tax revenues is the main identification strategy, I check how sensitive the baseline results are to reducing the output gap elasticities for PIT by 0.2 and increasing them for the environmental taxes by the same amount. This makes the identification less favorable for an environmental tax reform. Since the cyclical adjustment mainly affects the level of the multipliers and not the shapes or regime-dependencies, Appendix C.12 reports the results for the baseline and the modifications in the specification discussed in Appendix C.2 to C.5. As expected, the change in the cyclical adjustment, reduces the PIT multipliers and increases the environmentally related tax multipliers. Nevertheless, in most specifications, the former remain stronger than the latter.¹⁵

¹⁵ Additional robustness checks which are not reported here have been conducted. Experimenting with alternative assumptions regarding fixed effects has shown that a pooled estimation or assuming fixed country effects only leads to severely upward biased results at larger horizons. Including a time trend does not fix the problem. Hence, I rejected these approaches and settled for two-way fixed effects in the baseline. Moreover, I have experimented with Two-Stage Least Squares estimation using PIT and diesel as well as gasoline excise tax rates as instrumental variables for the PIT and EGT revenue-GDP ratios, respectively. The results, however, were neither meaningful nor robust and suffered severely from the low quality of the respective instruments. As PIT tax rates I used the statutory top rates which rarely vary over time. Hence, their predictive power for variations in tax revenues are limited, not exceeding an R-Squared of 10% in our sample. The resulting standard errors in the second stage estimation are very large. The diesel and gasoline excise tax rates we obtained from the World Bank's Carbon Pricing Assessment Tool (CPAT v1.0) which are estimated as the difference between the fuel supply cost and retail price after subtracting the VAT. Unfortunately, the predictive power of the instruments is also low explaining only about 10% of the variation in EGT. Hence, the instruments are weak and the resulting standard errors in the second stage estimation are large.
7 Conclusions

The aim of this study is to inform the policy debate in the aftermath of the COVID-19 pandemic on what macroeconomic implications environmental tax reforms shifting the tax burden from labor to carbon emission can be expected to have for output and employment. For that purpose, I estimate output, consumption, investment, trade, and employment multipliers of different environmentally related taxes and compare them to personal income tax multipliers. The environmentally related taxes considered are energy taxes, environmental taxes, and excise taxes. The estimation of regime-dependent multipliers allows to study multipliers in the context of the post-COVID-19 recovery. To review the main determinants of tax multipliers, the theoretical section tracks the transmission channels of both an upstream carbon tax and a labor tax within an open-economy macro framework. The main insight is that carbon tax multipliers depend crucially on the input substitution elasticities which control to what extent the production sectors can replace carbon intensive energy by other production factors. In contrast to that, labor taxes have very adverse aggregate demand effects as they directly cut into disposable income and reduce labor demand. Carbon taxes mainly affect the value chain, while labor taxes drive aggregate demand. Under an empirically sound calibration, carbon tax multipliers are predicted to be smaller than the labor tax multipliers. Carbon tax multipliers are predicted to be more volatile than labor tax multipliers. Trade exposed countries can expect higher multipliers in general if their exports are very price sensitive which may characterize commodity traders. Overall, the empirical analysis confirms these theoretical predictions.

The empirical analysis exploits a panel of 75 high- and low-income countries with observations between 1994 and 2018. To study multipliers specifically in the context of the post-COVID-19 recovery, I thoroughly assess how they depend on the states of the business cycle, energy sector, and external sector. The paper considers various regimes along the dimensions of output gap, GDP growth, fuel prices, tax levels, carbon intensities, and commodity trade. Regarding the econometric methodology, the problem of identifying the exogenous variation of the respective tax policy is addressed by applying a cyclical adjustment to the tax revenues. To obtain the cumulative multipliers of a permanent tax change, I use the local projection method developed to estimate impulse-response functions.

The econometric analysis yields the following main results which are robust to various changes to the sample and specifications: First, on average over the entire sample, environmentally related tax multipliers are slightly weaker than personal income tax multipliers. This result can be explained by strong negative effects of income taxes on consumption which are not found for environmentally related taxes. The investment response to tax increases is highly volatile since input substitution elasticities differ considerably across countries. The trade balance is found to deteriorate in response to tax increases. Compared to output multipliers, employment multipliers are less statistically and economically significant. While environmentally related taxes do not seem to have statistically significant effects on employment at all, an increase of PIT slightly reduces employment. Overall, the baseline results are in line with the view that an environmental tax reform shifting the tax burden from labor to fossil energy may be expansionary.

Second, investigating how multipliers depend on the state of the business cycle sheds light on the optimal timing of an environmental tax reform. The results of the regime-dependent multiplier estimation clearly suggest that environmentally related tax multipliers are around zero and statistically insignificant when the tax increase is implemented when output is above its potential or when output is expanding. Hence, especially in the later stage of the recovery, environmentally related tax multipliers should be expected to be zero, on average. Only when implemented during contractions, environmentally related tax multipliers seem to be strong.\footnote{The result that multipliers are strong when output is below its potential is not robust to excluding outliers. Hence, a small number of observations may drive this result.} For PIT, however, I find similar multipliers to those of the baseline and no statistically significant evidence for business-cycle dependent multipliers. These results reinforce the view that, from the revenue side, public finances are best consolidated by increases in energy taxes rather than personal income taxes.

Third, environmental tax multipliers may depend on the state of the energy sector. Comparing low and high fuel price regimes reveals that environmentally related tax multipliers are only negative and significant when country-year-specific fuel prices are above the median value at the time of the policy change. When fuel prices are low, these taxes do not seem to adversely affect GDP. PIT multipliers are not found to depend on
fuel prices. Overall, these results support the idea of restructuring fuel taxation in times of economic recovery when/where fuel prices are low. Moreover, comparing low and high tax regimes reveals that environmentally related multipliers tend to be stronger in high tax regimes while no significant difference can be found for PIT. Also, environmental tax multipliers are lower when the carbon intensity of GDP is higher. This suggests that countries at the beginning of a decarbonization effort can expect lower multipliers.

Finally, I test if tax multipliers depend on the commodity export share of GDP. For both income taxes and environmentally related taxes, the multipliers are stronger in the regime of high commodity exports than in the regime of low commodity exports. Yet, the differences in the regime-specific multipliers are only small for income taxes and not statistically significant. This result suggests that countries relying on commodity exports should expect higher environmentally related tax multipliers than those trading more differentiated goods.

These results have significant policy implications for the economic recovery from the current COVID crisis. While the need for fiscal consolidation is becoming a pressing issue for many countries, fuel prices are low, and output is expanding. In such a context, the results suggest that environmentally related taxes have no impact on output or employment while labor taxes are contractionary. Especially in countries with low environmentally related taxes, a carbon-intensive output, or a low dependence on commodity exports, an environmental tax reform can be expected to contribute to three central recovery objectives: consolidate public finances, reduce carbon emission, and stimulate output and employment growth.
A simple open-economy energy macro model

This section reports the open economy model which the theoretical multiplier discussion is based on. The derivation of the model equations from first principles can be found in Schoder (2021) which is a more elaborate but closed-economy version of the present model. Since we conduct a simulation exercise, the model abstracts from stochastic shocks. Hence, agents have perfect foresight and results are deterministic. It will be convenient to let \( g \) denote the deterministic gross growth rate of the economy. We use the following notation: \( \tilde{X}_t \equiv X_t/g_t \), for any aggregated variable \( X_t \) with \( X \) denoting the steady state value. This section states only the model equations for the domestic country and international linkages. The foreign country is assumed to be symmetric.

To keep the model simple, we add the following assumptions to Schoder (2021): There is no consumption habit formation, skilled-unskilled labor distinction, variable capital utilization or government-corporate bond spread. We assume the interest rate \( R \), government spending \( G \), labor supply, and the rate of nominal wage inflation \( \Pi_L \) to be constant. We assume log utility and Cobb-Douglas production functions throughout.

A.1 Optimizing households

Optimizing households (C-households) own the firms and supply a share \( 1 - \sigma \) of the labor services \( L_t \). They receive interest income, dividends \( \tilde{D}_{Z,t} \) and \( \tilde{D}_{E,t} \), and wages \( \tilde{\omega}_t \) which they save or spend on a final consumption basket \( \tilde{C}_{C,t} \) comprising domestic \( \tilde{Y}_{d,t} \) and foreign goods \( \tilde{Y}_{f,t} \). They choose inter-temporal paths for consumption, bonds \( B_{C,t} \), intermediate firm (Z-firm) equity, and energy firm (E-firm) equity to maximize inter-temporal utility where per-period utility depends on consumption and steady-state wealth \( A_C \).

Holding risky assets generates disutility as in Krishnamurthy and Vissing-Jorgensen (2012), Fisher (2015), and Albonico et al. (2017) which provides the rationale for a risk premium \( \xi \) of equity over bonds. The households face a budget constraint: The uses of funds in real terms are consumption and new wealth. The sources of funds in real terms are the last period’s holding of assets plus the interest, dividends and capital gains reflecting changes in stock prices \( \tilde{p}_{SZ,t} \) and \( \tilde{p}_{SE,t} \). Note that the variables are deflated by the GDP deflator (with growth rate \( \Pi_{Y,t} \)) including domestic and imported goods. The first order conditions (FOCs) w.r.t. to consumption and bond holdings as well as the budget constraint imply, after consolidation,

\[
\frac{\psi}{\tilde{C}_{C,t}} - \frac{1}{A_C} = \beta \frac{R}{\Pi_{Y,t+1}} \frac{\psi}{\tilde{C}_{C,t+1}}
\]

(3)

\[
\tilde{C}_{C,t} + \tilde{A}_{C,t} = \frac{R}{\Pi_{Y,t}} \tilde{B}_{C,t-1} + \frac{R + \xi}{\Pi_{Y,t}} (\tilde{p}_{SZ,t-1} + \tilde{p}_{SE,t-1})/g + (1 - \sigma)\tilde{\omega}_t L_t
\]

(4)

\[
\tilde{p}_{SZ,t} = \Lambda_{t,t+1} g (\tilde{p}_{SZ,t+1} + \tilde{D}_{Z,t+1})
\]

(5)

\[
\tilde{p}_{SE,t} = \Lambda_{t,t+1} g (\tilde{p}_{SE,t+1} + \tilde{D}_{E,t+1})
\]

(6)

\[
\Lambda_{t,t+1} = \left( \frac{R + \xi}{\Pi_{Y,t}} \right)^{-1}
\]

(7)

Eq. (3) is a variant of the Euler equation which relates marginal utilities intertemporally and determines how the household smooths consumption optimally. Note that steady-state wealth is required to link the Euler equation at the steady state to the rest of the system and to break the classical dichotomy as explained in Schoder (2021). The natural rate of interest is no longer uniquely determined by the Euler equation but linked to the real economy through wealth. Eq. (4) is the budget constraint and eqs. (5) and (6) define stock prices as the respective firms’ expected discounted streams of future dividends. Eq (7) is the factor by which households discount future dividends.

A.2 Rule-of-thumb households

Rule-of-thumb households supply labor for which they receive a wage. They have no access to the bond market and, since we abstract from deposits, cannot smooth consumption or save, respectively. That is, the household’s utility maximization problem has a corner solution w.r.t. consumption. The FOCs imply

\[
\tilde{C}_{L,t} = \sigma \tilde{\omega}_{t} L_t
\]

(8)
which is the budget constraint controlling the households’ aggregate consumption.

A.3 Retail firms

Retail firms combine domestic and imported foreign wholesale goods, \( \bar{W}_{d,t} \) and \( \bar{W}_{f,t} \), into final good bundles using a Constant Elasticity of Substitution (CES) aggregator and operating under perfect competition. The profit maximizing domestic and foreign wholesale good inputs as well as the price index relationship are

\[
\bar{W}_{d,t} = \alpha_Y p_{W_d,t}^{1-\epsilon_Y} \left( \bar{C}_{C,t} + \bar{C}_{L,t} + \bar{I}_{Z,t} + \bar{I}_{E,t} + \bar{G} + \frac{\tau_p}{2} \left( \frac{p_{Z,t}}{p_{Z,t-1}} \Pi_{Y,t} - \Pi_L \right) \bar{Z}_t \right) \tag{9}
\]

\[
\bar{W}_{f,t} = (1 - \alpha_Y) p_{W_f,t}^{1-\epsilon_Y} \left( \bar{C}_{C,t} + \bar{C}_{L,t} + \bar{I}_{Z,t} + \bar{I}_{E,t} + \bar{G} + \frac{\tau_p}{2} \left( \frac{p_{Z,t}}{p_{Z,t-1}} \Pi_{Y,t} - \Pi_L \right) \bar{Z}_t \right) \tag{10}
\]

where \( p_{W_d,t} \) and \( p_{W_f,t} \) are the prices of domestic and foreign final goods, respectively, relative to the GDP price index. \( \epsilon_Y \) is the elasticity of substitution between domestic and foreign inputs to the aggregator. \( \alpha_Y \) captures the home bias. It is the share of domestic inputs when domestic and foreign input prices are the same. The last terms in eqs. (9) and (10) are the spending associated with the adjustment of prices in the intermediate goods sector.

A.4 Wholesale firms

Wholesale firms combine core goods \( Z_i \) and energy goods \( E_{W,t} \), neither of which are traded, using a CES aggregator generating a wholesale good serving as an input for domestic and foreign retailers, \( \bar{W}_{d,t} + \bar{W}_{d,t}' \). Profit maximization implies

\[
\bar{Z}_t = \alpha_W \left( \frac{p_{Z,t}}{p_{W,t}} \right)^{-\epsilon_W} \left( \bar{W}_{d,t} + \bar{W}_{d,t}' \right) \tag{12}
\]

\[
\bar{E}_{W,t} = (1 - \alpha_W) \left( \frac{p_{E,t}}{p_{W,t}} \right)^{-\epsilon_W} \left( \bar{W}_{d,t} + \bar{W}_{d,t}' \right) \tag{13}
\]

\[ p_{W,t} = (\alpha_W p_{Z,t}^{1-\epsilon_W} + (1 - \alpha_W) p_{E,t}^{1-\epsilon_W})^{\frac{1}{1-\epsilon_W}} \tag{14} \]

A.5 Core goods firms

A perfectly competitive core goods firm aggregates differentiated core good varieties \( Z_{i,t} \) from the intermediate goods firms \( i \in (0, 1) \). Taking as given the respective prices and the demand for core goods, the representative firm chooses the optimal selection of intermediate goods varieties to minimize costs. The resulting demand function of each variety is a constraint to the intermediate goods firm’s optimization problem (see below).

A.6 Intermediate core goods firms

Intermediate core goods firms (Z-firms) use labor and energy-capital inputs to produce a variety of the intermediate good according to a Cobb-Douglas production function and sell it to the core goods firms. They operate in monopolistic markets and, hence, have price setting power. We assume that the capital stock is firm-specific and cannot be traded on the spot market. They face price and capital adjustment costs as well as fixed costs of production. They pay payroll taxes. Energy-capital is produced using a Cobb-Douglas aggregator. Under these constraints, the representative intermediate core goods firm chooses the price for its output \( p_{Z,t} \), labor input \( L_t \), capital investment \( I_{Z,t} \), the capital stock \( K_{Z,t} \), energy input \( E_{Z,t} \), and the bonds issued to maximize the firm’s value which is the discounted inter-temporal distributed real dividends or the value of the equity shares held by the C-households. The FOC w.r.t. pricing implies

\[
\varphi_t (1 + \mu_p) - \tau_p \mu_p \left( \frac{p_{Z,t}}{p_{Z,t-1}} \Pi_{Y,t} - \Pi_L \right) \Pi_{Y,t} + \tau_p \mu_p \Lambda_{t,t+1} \left( \frac{p_{Z,t+1}}{p_{Z,t}} \Pi_{Y,t+1} - \Pi_L \right) \left( \frac{1}{p_{Z,t}} \Pi_{Y,t+1} \Pi_{Y,t+1} \Pi_{Z,t+1} \right) Z_t = 1 \tag{15}
\]
which states that the mark-up $\mu_P$ arising from the intermediate goods firms’ monopoly power and the quadratic price adjustment costs drive a wedge between the real marginal revenue 1 and the real marginal cost $\varphi_t$. The FOC w.r.t. labor demand equates the marginal cost of labor and its marginal revenue product:

$$(1 + t_W) \dot{\omega}_t = \varphi_t (1 - \alpha_Z) \left( \frac{\dot{Z}_t + \chi Z}{L_t} \right)^{\frac{1}{\bar{\gamma}}}$$  \hfill (16)$$

The FOCs w.r.t. capital investment and capital stock are

$$1 = Q_{Z,t} - Q_{Z,t} \left( \frac{\tau_t}{2} \left( \frac{\dot{I}_{Z,t}}{I_{Z,t-1}} - 1 \right)^2 + \tau_t \left( \frac{\dot{I}_{Z,t}}{I_{Z,t-1}} - 1 \right) + \Lambda_{t,t+1} Q_{Z,t-1} \right) \left( \frac{\dot{I}_{Z,t+1}}{I_{Z,t}} - 1 \right) \left( \frac{I_{Z,t+1}}{I_{Z,t}} \right)^2$$

$$Q_{Z,t} = \Lambda_{t,t+1} (\varphi_{t+1} \alpha_Z \alpha_S) \left( \frac{\dot{Z}_{t+1} + \chi Z}{S_{t+1}} \right)^{\frac{1}{\bar{\gamma}}} \left( \frac{\dot{S}_{t+1}}{K_{Z,t}} \right)^{\frac{1}{\bar{\gamma}}} + (1 - \delta) Q_{Z,t+1}$$  \hfill (17)$$

Eq. (17) translates a change in the shadow price of capital $Q_{Z,t}$ into a change in investment. Note that without capital adjustment costs $Q_{Z,t} = 1$ investment will adjust instantly to realize the desired capital stock. Eq. (18) links $Q_{Z,t}$ to the desired capital stock. Without adjustment costs, the optimal capital stock ensures the marginal return of a dollar spent on capital is equal to its cost which is depreciation. Note that the marginal return includes the reduction of labor costs associated with the increase in capital. The FOC w.r.t. energy implies

$$p_{E,t} = \varphi_t \alpha_Z (1 - \alpha_S) \left( \frac{\dot{Z}_t + \chi Z}{S_t} \right) \left( \frac{\dot{S}_t}{E_{Z,t}} \right)^{\frac{1}{\bar{\gamma}}}$$  \hfill (19)$$

which states that energy input will equate its marginal revenue including the savings in labor costs and taxes to its marginal costs which is the price. The aggregate law of motion of the capital stock normalized by trend growth is

$$\dot{K}_{Z,t} = \left( 1 - \frac{\tau_t}{2} \left( \frac{\dot{I}_{Z,t}}{I_{Z,t-1}} - 1 \right)^2 \right) \dot{I}_{Z,t} + (1 - \delta) \dot{K}_{Z,t-1} \frac{1}{g}$$  \hfill (20)$$

The aggregated production functions are

$$\dot{Z}_t = \left( \alpha_Z \dot{S}_t \right)^{\frac{s-1}{s}} + (1 - \alpha_Z) \left( \dot{L}_t \right)^{\frac{s-1}{s}} - \chi Z$$  \hfill (21)$$

$$\dot{S}_t = \left( \alpha_S (\dot{K}_{Z,t-1} \frac{1}{g}) \right)^{\frac{s-1}{s}} + (1 - \alpha_S) \left( \dot{E}_{Z,t} \right)^{\frac{s-1}{s}}$$  \hfill (22)$$

We assume firms to maintain a debt-capital ratio of $\lambda$. Then, the aggregated detrended real distributed profits are

$$\dot{D}_{E,t} = p_{Z,t} \dot{Z}_t - (1 + t_W) \dot{\omega}_t L_t - p_{E,t} \dot{E}_{Z,t} - \frac{\tau_{P,t}^2}{2} \left( \frac{p_{Z,t} \Pi_{Y,t} - \Pi_{E,t}}{p_{Z,t-1}} \right)^2 \dot{Z}_t - \dot{I}_{Z,t} + \lambda \left( \dot{K}_{Z,t} - \frac{R}{\Pi_{Y,t}} \dot{K}_{Z,t-1} \frac{1}{g} \right)$$  \hfill (23)$$

The growth rate of the real wage is linked to wage and price inflation according to

$$\frac{\dot{\omega}_t}{\dot{\omega}_{t-1}} - 1 = \Pi_L - \Pi_{Y,t}$$  \hfill (24)$$

### A.7 Energy firms

A perfectly competitive energy firm (E-firm) produces energy used as inputs by the whole sale firm and the intermediate core goods firms. Energy production requires capital and carbon which can be exploited

$$27$$
at cost $\tau_E$ and is taxed with rate $t_E$. Carbon $c_t$ is interpreted as a property of technology, in particular as a productivity of capital. Every period the firm chooses the carbon intensity of its energy production technology. A higher carbon intensity implies a higher capital productivity but also a higher exploitation cost and carbon tax burden. Since the firm is a price taker, the FOC w.r.t. energy output simply states that the price is equal to its marginal costs. Then, the FOCs w.r.t. capital investment and capital stock are

$$1 = Q_{E,t} - Q_{E,t+1}$$

$$Q_{E,t} = \Lambda_{t+1}(p_{E,t} - \alpha_{E}(\tilde{E}_{t+1}/\epsilon_{E} - (1 - \delta)Q_{E,t+1}))$$

which are equivalent to those of the Z-firms. The FOC w.r.t. to carbon intensity implies

$$\tau_E + t_E = p_{E,t}(1 - \alpha_{E})\left(\tilde{E}_t + \chi_{E}\right)^{\epsilon_E}$$

The firm chooses the carbon intensity such that the value of the marginal product from an additional unit of carbon is equal to the tax rate. The higher the tax rate, the higher is the optimal marginal product and, hence, the lower the optimal carbon intensity. The aggregate law of motion of the capital stock normalized by trend growth is

$$\tilde{K}_{E,t} = \left(1 - \frac{\tau_I}{2}\left(\frac{\tilde{I}_{E,t}}{\tilde{I}_{E,t-1}} - 1\right)^2\right)\tilde{I}_{E,t} + (1 - \delta)\tilde{K}_{E,t-1}/g$$

The aggregated production function is

$$\tilde{E}_t = \alpha_E(\tilde{K}_{E,t-1}/g)^{\epsilon_E-1} + (1 - \alpha_E)\tilde{c}_t^{\epsilon_E-1} - \chi_{E}$$

The aggregated detrended real dividends are

$$\tilde{D}_{E,t} = p_{E,t}\tilde{E}_t - t_E\tilde{c}_t - \tilde{I}_{E,t} + \lambda\left(\tilde{K}_{E,t} - \frac{R}{\Pi_{Y,t}}\tilde{K}_{E,t-1}/g\right)$$

A.8 Policy

With only payroll taxes and carbon taxes in place, the government budget constraint is

$$\tilde{G}_t + \tilde{B}_{G,t} = \tilde{I}_W\tilde{\omega}_tL_t + t_E\tilde{c}_t + \frac{R}{\Pi_{Y,t}}\tilde{B}_{G,t-1}$$

Monetary policy follows a Taylor rule and sets the policy rate in response to changes in core inflation:

$$\frac{R_t}{R} = \left(\frac{p_{Z,t}}{p_{Z,t-1}}\frac{\Pi_{Y,t}}{\Pi_{Y}}\right)^{\epsilon_R}$$

The nominal wage evolves according to a Phillips-curve relationship,

$$\frac{\Pi_{L,t}}{\Pi_L} = \left(\frac{L_t}{L}\right)^{\epsilon_L}$$
A.9 Market clearing

Clearing of the retail goods market, the energy market, and the bond markets implies

\[ \tilde{Y}_t = \tilde{Y}_{d,t} + \tilde{Y}_{d,t}^* \]  
\[ \tilde{E}_t = \tilde{E}_{Z,t} + \tilde{E}_{E,t} \]  
\[ \tilde{B}_{c,t} + \tilde{B}_{F,t} + \tilde{B}_{G,t} = 0 \]

where

\[ \tilde{B}_{F,t} = -\lambda (K_{Z,t} - K_{E,t}) \]

Note that the labor market does not clear and dis-equilibrium unemployment prevails.

A.10 International linkages

The law of one price implies that the domestic good needs to have the same price at home and abroad after adjusting for the real exchange rate \( X_t = P^*_Y / P_Y \). Hence,

\[ p_{Wd,t} = p_{Wd,t}^* X_t \]  
\[ p_{Wf,t} = p_{Wf,t}^* X_t \]

The definition of the real exchange rate implies

\[ \frac{X_t}{X_{t-1}} = \frac{\Pi_{Y,t}}{\Pi_{Y,t}} \]

assuming a constant nominal exchange rate.
B  Model calibration

A part of the model parameters is calibrated according to typical findings in the empirical literature for equivalent or closely related parameters. The remaining parameters are restricted such that the model generates a steady state which corresponds to long-run averages of macroeconomic data.

This share of non-Ricardian households is in line with Gali, Lopez-Salido, and Valles (2007) and Kaszab (2016).

Table B.1 reports the calibration of the model. The discount factor is $\beta = 0.99$ as in Smets and Wouters (2003). The annualized equity risk premium over the policy rate is $4\xi_S = 8$. The consumption demand scaling parameter $\psi$ is calibrated to ensure a steady-state GDP of unity.

The steady-state mark-up is $\mu_P = 0.2$ as in Christiano, Eichenbaum, and Rebelo (2011) and Kaszab (2016). Fixed costs in the core goods production are $\chi_Z = 0.38$ which keeps the core firms’ investment share in output at 18%. We set the fixed costs in energy production $\chi_E = 0.03$ to equalize the core and energy firms’ dividend rates. The capital depreciation rate is $\delta = 0.025$. The core and energy firms’ debt-capital ratio $\lambda = 0.3$ is restricted to ensure a corporate bonds-GDP ratio of 2.

Constant Elasticity of Substitution (CES) production technologies are characterized by an input share parameter $\alpha$ and a substitution elasticity $\epsilon$. For the retail firms combining domestic and foreign wholesale goods, we assume $\alpha_Y = 0.8$ which reflects a considerable home bias and $\epsilon_Y = 0.6$. The energy share in wholesale goods is $1 - \alpha_W = 0.1$ with an elasticity of $\epsilon_W = 0.3$ which is in line with An and Kang (2011) and Medina and Soto (2005). The energy-capital share in core goods production is $\alpha_Z = 0.33$ which restricts the

<table>
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<td>$\beta$</td>
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<td>$\xi$</td>
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<td>Wage share $\tilde{w}_L/\tilde{Y} = 0.6$</td>
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Cost scaling parameters

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<td>—</td>
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<tr>
<td>$\tau_E$</td>
<td>Carbon exploitation costs</td>
<td>0</td>
<td>—</td>
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Policy

<table>
<thead>
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<th>Steady-state parameters</th>
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<tr>
<td>$g$</td>
<td>Deterministic growth rate</td>
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<td>—</td>
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<tr>
<td>$\Pi_L$</td>
<td>Wage inflation rate</td>
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<td>—</td>
</tr>
<tr>
<td>$\bar{R}$</td>
<td>Interest rate</td>
<td>1.002</td>
<td>—</td>
</tr>
<tr>
<td>$\bar{G}$</td>
<td>Public spending</td>
<td>0.2</td>
<td>Budged is balanced $\bar{G} = \bar{T}$</td>
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</tbody>
</table>

Table B.1: Model calibration.
wage share to 0.6. The substitution elasticity is $\epsilon_Z = 1$ which is consistent with Knoblach and Stöckl (2020). The energy share in energy-capital goods is $1 - \alpha_S = 0.2$ with an elasticity of $\epsilon_S = 1$ similar to Fiorito and van den Bergh (2016). The capital share in energy production is $\alpha_E = 0.36$ which ensures an energy firm investment share in output of 2%. The elasticity of substitution between capital and carbon is $\epsilon_E = 0.6$.

The price and investment adjustment cost scaling parameters are $\tau_P = \tau_I = 20$. We assume carbon can be exploited at no cost making the carbon tax the only carbon cost for the firm. The labor and carbon tax rates $t_W = 0.17$ and $t_E = 0.17$, respectively, ensure that the respective tax revenue shares are 10% of GDP. The Taylor principle requires monetary policy to respond to core inflation by more than one-to-one. Hence, $\epsilon_R = 1.1$. The baseline assumes a constant wage inflation: that is, $\epsilon_L = 0$. The deterministic growth rate is $g = 1.005$. The gross inflation rate $\Pi_L = 1$ implies that prices are constant at the steady state. The gross nominal interest rate is $R = 1.002$. Government consumption is $\tilde{G} = 20\%$ of GDP implying a balanced budget at the steady state.
C Robustness checks

C.1 Environmental taxes (EVT) and excise taxes (EXT)

Figure C.1: Cumulative annual output response in percent to an increase in the tax revenues by 1 percent of GDP using the baseline specification. The shaded areas indicate the 90% confidence bands.
C.2 Control for gasoline prices

Figure C.2: Cumulative annual output response in percent to an increase in the tax revenues by 1 percent of GDP controlling for gasoline prices. The shaded areas indicate the 90% confidence bands.
C.3 Control for interest rates

![Graphs showing the cumulative annual output response in percent to an increase in the tax revenues by 1 percent of GDP controlling for real interest rates. The shaded areas indicate the 90% confidence bands.](image)

Figure C.3: Cumulative annual output response in percent to an increase in the tax revenues by 1 percent of GDP controlling for real interest rates. The shaded areas indicate the 90% confidence bands.
C.4 Control for public debt

Figure C.4: Cumulative annual output response in percent to an increase in the tax revenues by 1 percent of GDP controlling for real interest rates. The shaded areas indicate the 90% confidence bands.
C.5 No control variables

Figure C.5: Cumulative annual output response in percent to an increase in the tax revenues by 1 percent of GDP excluding all control variables. The shaded areas indicate the 90% confidence bands.
Figure C.6: Cumulative annual output response in percent to an increase in the tax revenues by 1 percent of GDP with 2 lags. The shaded areas indicate the 90% confidence bands.
C.7 Outliers included in baseline and excluded in regimes

Figure C.7: Cumulative annual output response in percent to an increase in the tax revenues by 1 percent of GDP including outliers in baseline and excluding outliers in the regime estimations. The shaded areas indicate the 90% confidence bands.
C.8 Outlying countries excluded

Figure C.8: Cumulative annual output response in percent to an increase in the tax revenues by 1 percent of GDP excluding outlier countries
C.9 Only high- and middle-income countries

Figure C.9: Cumulative annual output response in percent to an increase in the tax revenues by 1 percent of GDP for high- and middle-income countries. The shaded areas indicate the 90% confidence bands.
C.10 Only high-income countries

Figure C.10: Cumulative annual output response in percent to an increase in the tax revenues by 1 percent of GDP for high-income countries. The shaded areas indicate the 90% confidence bands.
C.11 Only middle-income countries

Figure C.11: Cumulative annual output response in percent to an increase in the tax revenues by 1 percent of GDP for middle-income countries. The shaded areas indicate the 90% confidence bands.
C.12 Weaker adjustment of PIT and stronger adjustment for EGT, EVT, and EXT

Figure C.12: Cumulative annual output response in percent to an increase in the tax revenues by 1 percent of GDP with, compared to the baseline, a weaker cyclical adjustment of PIT (output gap elasticities reduced by 0.2) and a stronger adjustment of EGT, EVT, and EXT (output gap elasticities raised by 0.2). The shaded areas indicate the 90% confidence bands.
References


