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Climate Policies and External Adjustment

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Rudolfs Bems
International Monetary Fund
Centre for Economic Policy Research London

Luciana Juvenal
International Monetary Fund

Weifeng Larry Liu
Centre for Applied Macroeconomic Analysis, ANU
The Australian Research Council Centre of Excellence in Population Ageing Research

Warwick J. McKibbin
Centre for Applied Macroeconomic Analysis, ANU
The Australian Research Council Centre of Excellence in Population Ageing Research
The Peterson Institute for International Economics
Centre for Economic Policy Research London

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Keywords

global climate policies, carbon taxes, net-zero emissions, current account balances, international capital flows, dynamic general equilibrium modelling, G-Cubed

JEL Classification

F41, F42, H23, Q54

Address for correspondence:

(E) cama.admin@anu.edu.au

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Rudolfs Bems
International Monetary Fund and
Centre for Economic Policy Research London

Luciana Juvenal
International Monetary Fund

Weifeng Larry Liu
The Australian National University and
The Australian Research Council Centre of Excellence in Population Ageing Research

Warwick J. McKibbin
The Australian National University,
The Australian Research Council Centre of Excellence in Population Ageing Research,
The Peterson Institute for International Economics and
Centre for Economic Policy Research London

[*] Authors' contacts: Bems (rbems@imf.org), Juvenal (ljuvenal@imf.org), Liu (larry.wf.liu@anu.edu.au), McKibbin (warwick.mckibbin@anu.edu.au). Liu and McKibbin gratefully acknowledge the financial support from the Australian Research Council Centre of Excellence in Population Ageing Research (CEPAR) (CE170100005). We thank numerous colleagues for helpful comments and suggestions. Xiaohan Shao provided excellent research assistance. The views expressed here are those of the authors and should not be attributed to the International Monetary Fund, its Executive Board, or its management.

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1. Introduction

As global economic disruption from climate change has become more apparent, there has been increasing interest in understanding the effects of climate mitigation policies on the macroeconomy. Given the net-zero target by 2050,[1] studies have focused on the impact of mitigation policies on economic activity, employment, and international trade, as well as their distributional effects (see Chateau, et al., 2022a; Jaumotte et al., 2021; Kotlikoff et al., 2021; and OECD 2022). Other recent topics of interest are the implications of mitigation policies for global commodity markets and financial markets, as well as monetary policy (see Bolton and Kacperczyk, 2021; IEA, 2021; and McKibbin et al., 2021). The literature also discusses mitigation policy choices and design, given the recommended limits on temperature increases and the need to avoid catastrophic consequences of climate change (Jaumotte and Schwerhoff, 2021; Parry et al., 2021).

Less attention has been given to the effects on current account balances and international capital flows—the external adjustment. The green transition will require a significant economic transformation, involving internal and external adjustments. Past episodes of energy transitions, such as oil discoveries, have led to sizeable current account adjustments in the affected economies (Arzeki et al., 2017). A global green transition would not impact current account balances if countries and mitigation policies were identical. However, significant structural differences across countries—such as the degree of fossil fuel dependence in domestic energy and durable goods production and income generation through exports and the role of renewables in energy generation—can induce and magnify current account responses. Differences in the content and pace of implementation of mitigation policies are another source of cross-country asymmetries that could trigger current account adjustments.

This paper addresses the gap in the literature by examining the effect of mitigation policies on the external sector using a model-based approach. We study a scenario of net-zero emissions by 2050 in the G-Cubed global macroeconomic model (McKibbin and Wilcoxen,

[1] So far, 97 parties, representing 101 countries and 80.7% of global GHG emissions, have communicated a net-zero target by around the mid-century, including the largest emitters, such as China, the United States, European Union, India and Japan (see Net-zero Target Status | Explore Net-Zero Targets | Climate Watch Data).

2013; Liu et al., 2020). The scenario's package of mitigation policies consists of (i) a carbon tax with a compensatory transfer to households, (ii) a green subsidy to renewables, and (iii) green infrastructure investment. The paper narrows the focus of analysis to cover the external sector impact over the next decade, which is a relevant horizon for macroeconomic policymakers. Coverage of the largest economies and aggregated regions that together constitute the global economy allows the scenario to account for the global general equilibrium effects of climate policies, with implications for capital flows and global interest rates.

The paper finds that, while attaining the objective of addressing climate change, combinations of climate mitigation policies could sizably impact current account balances by changing short- and medium-term investment and saving decisions.

First, a credible and globally coordinated carbon tax decreases the current account [2] in greener advanced economies and increases it in more fossil-fuel-dependent developing countries. On the investment side, the tax permanently reduces the return on carbon-intensive investments. In response, investment falls globally but more in fossil-fuel-dependent economies, resulting in significant cross-country differences in the investment response. With adjustment costs in investment, the expansion in non-fossil fuel energy sectors takes longer to ramp up, causing an initial fall in economy-wide investment. On the saving side, the global decline in investment reduces the global interest rate, which decreases savings across countries relatively uniformly. As a result, current account movements are driven by the investment response, ultimately determined by country characteristics such as the initial intensity of carbon emissions and net fossil fuel exports.

Second, globally coordinated supply-side policies—a green subsidy for renewables and infrastructure investment—boost investment and saving and increase the global interest rate. Compared with the carbon tax, these policies have a more limited impact on the external sector, either because of the slow pace of sectoral expansion for renewables (in the absence of government support) or the imposed identical size of the boost to green infrastructure,

[2] We define the current account such that a decrease in the current account is a move towards current account deficit while an increase is a move towards surplus.

which leads to comparable investment and saving responses within countries, leaving the current account broadly unchanged.

Third, for the package of mitigation policies, the carbon tax dominates the external sector impact, while the other policies have much smaller effects. A coordinated policy package that reduces global emissions shifts capital flows toward the greener advanced economies in the global economy, with the carbon tax policy primarily driving the cross-border capital flows. Following an initial rise led by the green infrastructure investment, the global interest rate falls over time as the persistently increasing carbon tax reduces investment globally, shifting economic activity towards more labor-intensive sectors.

Finally, the current account impact of climate change mitigation policies depends crucially on the degree of policy synchronization across regions. A partial implementation of mitigation policies can reverse or magnify external sector effects relative to the globally coordinated implementation, depending on the type of policy and the country implementing it. For example, a unilateral carbon tax in Europe increases the current account surplus in that region (instead of decreasing the current account under coordinated implementation) because the tax reduces domestic investment and shifts capital abroad. By contrast, a unilateral green subsidy in Europe magnifies the external sector response in that region by further reducing the current account balance as capital flows into the subsidized renewable energy sectors.

This paper can be linked to several strands of literature. First, our model is closely related to the studies that use computable general equilibrium (CGE) models to estimate the macroeconomic and trade impacts of climate policy. In open-economy CGE models, a balanced current account is typically imposed, with either a savings-driven or investment-driven closure (Burfisher 2017). This modeling assumption prevents the possibility of investigating current account movements. The G-Cubed model shares key features of CGE models, with countries and sectoral disaggregation in production and detailed energy sectors. It differs from CGE models by incorporating key features of dynamic general equilibrium (DGE) models, with forward-looking agents, real and nominal rigidities, and fiscal and monetary policies. Forward-looking agents make intertemporal decisions in an environment where savings need not equal investment, with an endogenously determined current account.

Second, the paper is related to the broader literature on the interaction between international trade (and trade policy) and environmental pollution (and environmental policy). There is a well-established literature examining the impacts of international trade on the environment and closely related, the impacts of trade policy on the environment (e.g., Copeland et al. 2022; Copeland and Taylor 2003; Grossman and Krueger 1995; Gallagher 2010; Jakob 2022). Early studies along this line focus on local environmental pollution but attention has been increasingly shifted to climate change given its emergence as a global crisis. On the other hand, many studies examine the impacts of climate policies on international trade typically in CGE models, as mentioned above. More recently, there are some discussions on the impacts of climate change on international trade through the channels of extreme weather shocks, comparative advantage, and low-carbon technologies (Brenton and Chemutai 2021). This paper falls into the literature on the impacts of climate policy on international trade but deviates from the literature by considering trade imbalances.

Finally, the subject of this paper can be linked to past work on global trends in saving-investment and current account balances, and, in particular, studies of global balances and the global saving glut (Bernanke 2005; Obstfeld and Rogoff 2005). In recent decades, the US has experienced persistent current account deficits while other countries (e.g., China, Japan and Germany) have run large surpluses. Capital outflows have also arisen from oil exporters as they convert their enormous oil revenues into foreign assets. The persistent imbalances have stimulated extensive academic and policy debates, especially after the global financial crisis (Gourinchas and Rey 2014). The imbalances have raised concerns about long-term financial stability and resilience (IMF 2019) and have also been a driver of trade disputes. Climate change mitigation policies and the green transition could potentially induce comparable large changes in global saving and investment that could impact global current account balances and accompanying capital flows.

The rest of the paper is organized as follows. To assist in understanding the results of the quantitative macro model, Section 2 starts with a simple theoretical model that provides analytical insights for the current account implications of climate policies. Section 3 introduces the large-scale quantitative model (G-Cubed). Section 4 provides simulation results for the climate change mitigation scenario, with a focus on the external sector responses. We start with results for individual mitigation policies, followed by a discussion of the full mitigation package. Also covered are the implications of mitigation policies that are not synchronized across countries. Section 5 concludes.

2. A Primer on Current Account Implications of Climate Policies

In this section, we develop a simple theoretical model that provides analytical insights that assist in understanding the quantitive results from the large-scale G-Cubed model, focusing on carbon taxes as the main climate change mitigation policy.

2.1 A Theoretical Model

Consider a global economy of two symmetric countries (Home and Foreign). There are two time periods $t = 1,2$. Agents have perfect foresight. Each country has two sectors: one is a non-tradable sector and its output Y_t^N comes from endowments being constant at $\bar{Y}^N$; the other is a tradable sector and its output Y_t^T is produced according to the following production function

$$Y_t^T = A_t F(K_t) = A_t K_t^{\alpha}, \tag{1}$$

where A_t is total factor productivity, K_t is capital stock, $0 < \alpha < 1$ is the elasticity of output to capital. The capital stock accumulates through investment,

$$K_{t+1} = K_t + I_t, \tag{2}$$

where, without loss of generality, the depreciation rate is set to zero and initial capital K_1 is given.

We assume the non-tradable sector does not generate carbon emissions, and the tradable sector produces carbon emissions. For simplicity, emissions are associated with output without introducing energy as a production factor. The tradable goods are homogeneous across countries, and their price is normalized to one. The domestic price of non-tradable goods is p_t. Assume the initial foreign asset position B_1 is zero.

A representative household makes a consumption plan to maximize its lifetime utility as

$$U = ln(C_1) + \beta ln(C_2), \tag{3}$$

where $0 < \beta < 1$ is the subjective discount factor and C_t denotes the aggregate consumption in period t which is a Cobb-Douglas function of tradable consumption C_t^T and non-tradable consumption C_t^N as

$$C_t = (C_t^T)^{\theta}(C_t^N)^{1-\theta}. \tag{4}$$

Households are subject to the budget constraint in period t as

$$C_t^T + p_t C_t^N + I_t + B_{t+1} = Y_t^T + p_t Y_t^N + (1 + r_t)B_t. \tag{5}$$

In equilibrium, the non-tradable goods market clears such that

$$Y_t^N = C_t^N. \tag{6}$$

The tradable goods market clears such that

$$C_t^T + I_t + B_{t+1} = Y_t^T + (1 + r_t)B_t, \tag{7}$$

which indicates the current account balance as

$$CA_t = Y_t^T + r_t B_t - C_t^T - I_t. \tag{8}$$

The global financial market clears such that

$$CA_t + CA_t^* = 0, \tag{9}$$

where * represents the foreign economy. This condition determines the world interest rate.

Our analysis focuses on the impacts of carbon taxes on saving, investment, the interest rate, and the exchange rate in period 1. The investment function with respect to the interest rate in period 1 is characterized as (see all derivations in the Appendix)

$$I_1(r_2) = \left(\frac{\alpha A_2}{r_2}\right)^{\frac{1}{1-\alpha}} - K_1. \tag{10}$$

On the other hand, the saving function with respect to the interest rate in period 1 is given by

$$S_1(r_2) = \frac{1}{1+\beta}\left(\beta Y_1^T + \frac{r_2}{1+r_2} I_1 - \frac{Y_2^T}{1+r_2} - \frac{K_1}{1+r_2}\right). \tag{11}$$

Proposition 1. The investment function $I_1(r_2)$ decreases in the interest rate r_2, and the saving function $S_1(r_2)$ increases in the interest rate r_2.

The monotonicity of investment is straightforward. The monotonicity of saving, which is opposite to the monotonicity of consumption, depends on three effects: (1) an income effect: consumption changes because the price of consumption changes when the interest rate increases; (2) a substitution effect: consumption changes because the relative price of consumption across periods changes when the interest rate changes; and (3) a wealth effect: consumption changes because the lifetime income changes through two channels: one is the discount channel and the other is production resource movement across periods (see Obstfeld and Rogoff, 1996). The assumption of a log utility function implies that the substitution and income effects offset each other. To understand the wealth effect, we break down the effect into five components, as shown in the following equation.

$$\frac{dS_1}{dr_2} = \frac{1}{1+\beta}\left(\underbrace{\frac{r_2}{1+r_2}\frac{dI_1}{dr_2}}_{1} - \underbrace{\frac{1}{1+r_2}\frac{dY_2^T}{dr_2}}_{2} + \underbrace{\frac{I_1}{(1+r_2)^2}}_{3} + \underbrace{\frac{K_1}{(1+r_2)^2}}_{4} + \underbrace{\frac{Y_2^T}{(1+r_2)^2}}_{5}\right). \tag{12}$$

Optimal investment implies that $\frac{dY_2^T}{dK_2} = r_2$, so the first two terms are equal. That is, the impact of the interest rate on investment I_1 (component 1) is exactly offset by the impact on output Y_2^T (component 2). More specifically, when the interest rate increases, investment I_1 decreases, so consumption would increase and saving would decrease. On the other hand, as investment I_1 decreases, future output Y_2^T would decrease, so consumption would decrease and saving would increase. The two channels exactly offset each other, making the wealth effect dependent on the discount channel. Components 3 and 4 represent the impact of the interest rate on the discounted value of capital in the future, the latter of which partly comes from the initial capital K_1 and partly from investment I_1. Component 5 represents the impact of the interest rate on the discounted value of future output. When the interest rate increases, the discounted future wealth decreases, so consumption would decrease and saving would increase. Therefore, the overall wealth effect is positive.

2.2 Carbon Tax and External Sector Adjustment

A simple way of mimicking a carbon tax is to consider a negative productivity shock. As our carbon tax scenario in the quantitative model is designed with progressive tax rates over time, we assume in the theoretical model that productivity A_1 remains unchanged and A_2 declines in the Home economy. The following proposition shows how the future productivity level affects both the investment function and the saving function.

Proposition 2. The investment function $I_1(r_2)$ increases in productivity A_2, and the saving function $S_1(r_2)$ decreases in A_2.

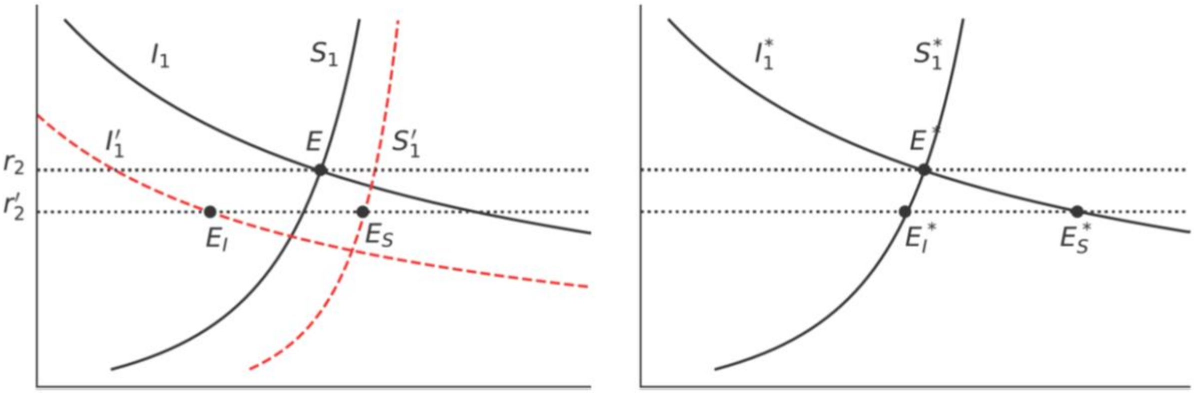
The impact of future productivity on current saving can be broken down into three components, as shown in the following equation:

$$\frac{dS_1}{dA_2}\Big|_{\bar{r}_2} = \frac{1}{1+\beta}\left(\underbrace{\frac{r_2}{1+r_2}\frac{dI_1}{dA_2}}_{1} - \underbrace{\frac{A_2 dF(K_2)/dK_2}{1+r_2}\frac{dK_2}{dA_2}}_{2} - \underbrace{\frac{F(K_2)}{1+r_2}}_{3}\right). \tag{13}$$

Optimal investment implies that $\frac{A_2 dF(K_2)}{dK_2} = r_2$, so the first two terms are equal. It follows that the impact of productivity A_2 on investment I_1 (component 1) is exactly offset by the impact on future output through capital stock (component 2). More specifically, when productivity A_2 improves, investment I_1 increases, so consumption would decrease and saving would increase. On the other hand, as investment I_1 increases, future output would increase, so current consumption would increase and saving would decrease. The two channels exactly offset each other. The third component represents the direct impact of productivity A_2 on output (given capital stock unchanged). It follows that when productivity A_2 increases, current consumption would increase because the lifetime income increases, therefore current saving would decrease.

We next apply Proposition 2 to the case of a carbon tax-induced negative future productivity. Figure 1 presents the Metzler diagram with the Home economy on the left and the Foreign economy on the right. Since $I_1(r_2)$ increases in A_2 and $S_1(r_2)$ decreases in A_2, $I_1(r_2)$ shifts to the left while $S_1(r_2)$ shifts to the right in response to the negative productivity shock, $\Delta A_2 < 0$. In equilibrium, the global interest rate unambiguoisly falls and capital unambiguoisly flows from the Home economy to the Foreign economy, as the Home country runs a current account surplus. However, as the figure makes clear, in general, the equilibrium S and I responses will depend on model specification, through the impact on the slope of the S and I curves and their sensitivity to the productivity shock. We leave the quantification of the equilibrium S and I resposnes to the full-fledged model.

Figure 1: Negative productivity shock, $\Delta A_2 < 0$, in Metzler diagram



Note: This figure is based on $\alpha = 0.3, \beta = 0.9, K_1 = 1, A_1 = A_2 = 1$ and $\Delta A_2 = -0.3$.

The rest of this section investigates the impact of productivity shocks in the Home economy on the prices in both the Home and Foreign economies and hence on the real exchange rate. The following proposition presents the impacts of productivity shocks on the prices.

Proposition 3. The domestic non-tradable price p_1 increases in productivity A_2. The foreign non-tradable price p_1^* also increases in productivity A_2 .

The productivity affects the non-tradable price p_1 through two channels: a productivity channel and an interest rate channel. First, if the productivity falls, the lifetime tradable output decreases directly, so households would reduce consumption for both tradable and non-trdable goods. Given the tradable output decreases but the non-tradable output remains constant, the non-tradable good becomes cheaper. Second, if productivity A_2 falls, the interest rate r_2 declines, and the lifetime tradable output still falls, so the non-tradable good becomes less expensive.

In the Foreign economy, the productivity in the Home economy affects the non-tradable price p_1^* only through the interest rate channel. As the two economies share the same interest rate, the impacts of productivity change through the interest rate channel are the same in the two economies. That is, the foreign non-tradable price falls if productivity A_2 falls.

Define the real exchange rate for the Home economy as $e_t = p_t/p_t^*$. The following proposition presents the impacts of carbon-tax-driven productivity shocks on the exchange rate.

Proposition 4. The real exchange rate e_1 in the Home economy depreciates in response to a carbon-tax-driven negative productivity shock in the future period (ΔA_2).

The productivity affects the exchange rate through two channels: a productivity channel and an interest rate channel. But the marginal effect of productivity change on the exchange rate is only determined by the effect on the domestic price p_1 through the productivity channel because the effects on the domestic price p_1 and the foreign price p_1^* through the interest rate channel are canceled out given the initial symmetry across countries.

In sum, this section has shown that climate change mitigation policies, proxied here with a carbon-tax-motivated productivity decline, can induce an external sector adjustment. A country with a larger (smaller) future carbon tax will run a current account surplus (deficit) and its exchange rate will depreciate (appreciate). The carbon tax will also decrease the global interest rate. At the same time, we also show that a full-fledged quantitative global general equilibrium is required to fully quantify the impacts. The simple framework of this section does not robustly pin down the impact of the carbon tax on the equilibrium investment and saving response. A quantitative model can also account for other important factors omitted from this section, for example, the green transition's-induced shift away from relatively capital-intensive energy sectors and cross-country heterogeneity in carbon intensity of economic activity.

3. A Quantitative Model

This section presents the quantitative G-Cubed model, its baseline, and the climate mitigation scenario featured in the October 2020 WEO, emphasizing aspects particularly relevant for studying the current account impact.

3.1 The G-Cubed Model

The G-Cubed model used in this paper partitions the world economy into 10 countries and regions, separating major economies and fossil-fuel-producing countries and regions (Table 1). The model includes 20 sectors, with rich sectoral detail on energy sectors and power generation, including three key fossil fuel sectors—oil, gas, and coal—and renewables-based electricity generation sectors (Table 2).

Table 1: Regions in the G-Cubed Model

Region Code	Region Description
AUS	Australia
CHN	China
EUW	Europe
IND	India
JPN	Japan
OPC	Selected Oil-Exporting Developing Countries
OEC	Rest of the OECD
ROW	Rest of the World
RUS	Russian Federation
USA	United States

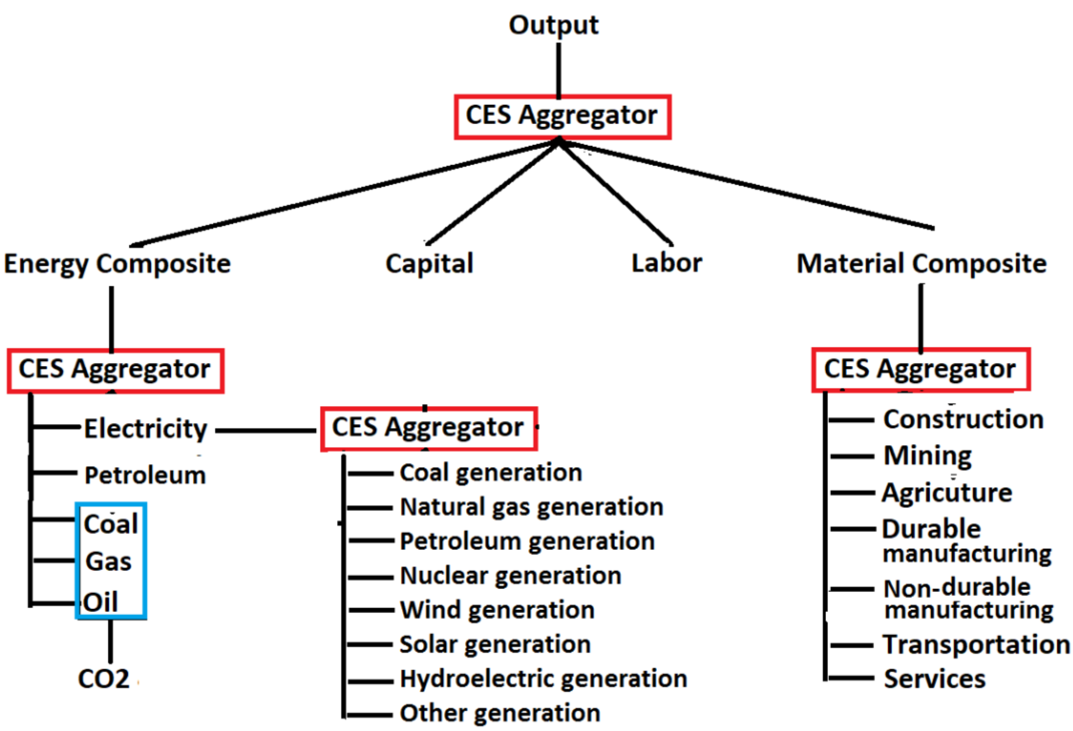
Notes: The coverage of each region in the above table is presented below: (a) Europe: Germany, France, Italy, Spain, The Netherlands, Belgium, Bulgaria, Croatia, Czech Republic, Estonia, Cyprus, Lithuania, Latvia, Hungary, Malta, Poland, Romania, Slovenia, Slovakia, Luxemburg, Ireland, Greece, Austria, Portugal, Finland, United Kingdom, Norway, Sweden, Switzerland, Denmark; (b) Rest of the OECD: Canada, New Zealand, Iceland, Liechtenstein; (c) Oil-Exporting Developing Countries: Ecuador, Nigeria, Angola, Congo, Iran, Venezuela, Algeria, Libya, Bahrain, Iraq, Israel, Jordan, Kuwait, Lebanon, West Bank and Gaza, Oman, Qatar, Saudi Arabia, Syria, United Arab Emirates, Yemen; (d) Rest of the World: All countries not included in other groups.

The structure of the core model is set out in McKibbin and Wilcoxen (1999, 2013), as well as Liu et al. (2020). An illustration of the production structure is contained in Figure 2. CO2 emissions are measured through the burning of fossil fuels in energy generation.

Table 2: Sectors in the G-Cubed Model

Number	Sector Name	Note
1	Electricity delivery	Energy Sectors Other than Generation
2	Gas extraction and utilities	
3	Petroleum refining	
4	Coal mining	
5	Crude oil extraction	
6	Construction	Goods and Services
7	Other mining	
8	Agriculture and forestry	
9	Durable goods	
10	Nondurable goods	
11	Transportation	
12	Services	
13	Coal generation	Electricity Generation Sectors
14	Natural gas generation	
15	Petroleum generation	
16	Nuclear generation	
17	Wind generation	
18	Solar generation	
19	Hydroelectric generation	
20	Other generation	

Figure 2: Production Structure in the G-Cubed Model

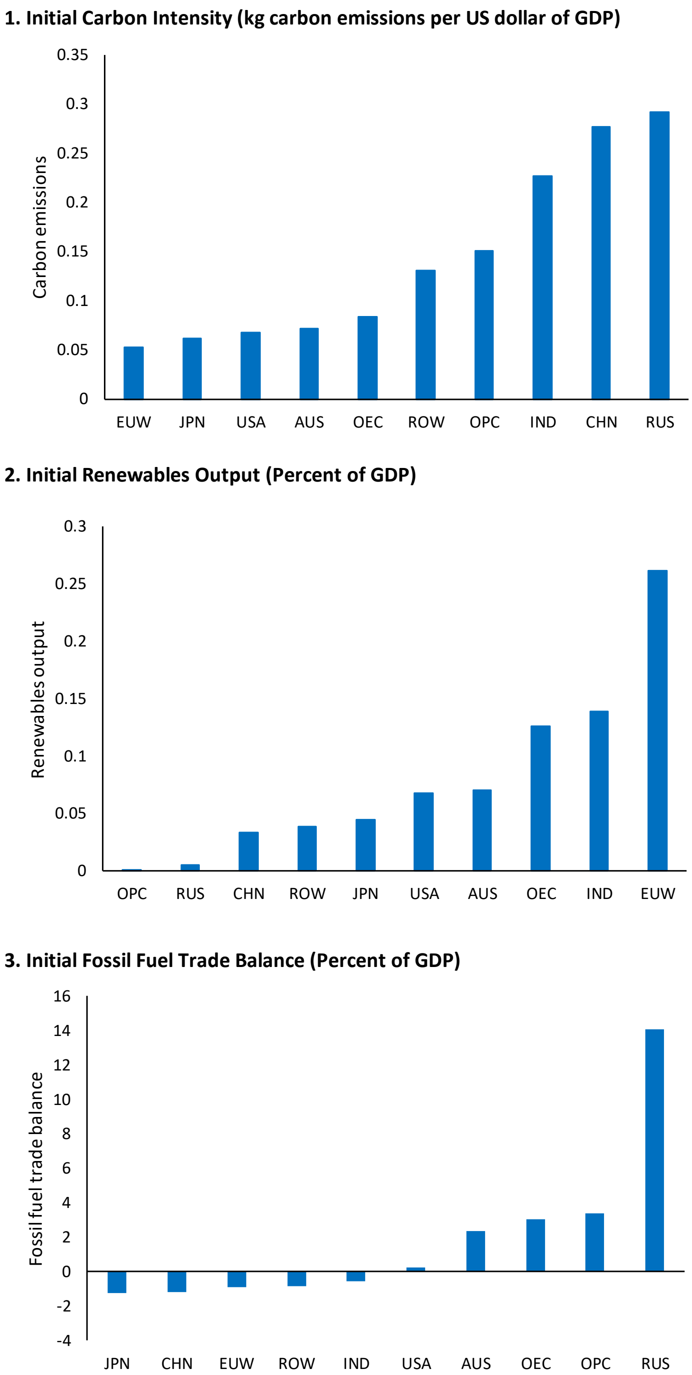


The model's sectoral detail captures key asymmetries central to the analysis of the current account. First, regions differ in the carbon intensity of economic activity (Figure 3, panel 1). Carbon intensity is higher in fast-growing emerging economies such as China and India, as their fossil energy structure relies more heavily on coal. These economies also rely more on carbon-intensive industries. Less carbon-intensive advanced economies rely relatively more on gas and oil for energy generation. Second, regions differ in the importance of renewable energy for electricity generation (Figure 3, panel 2). This sector is dominated by Europe, which accounts for 62 percent of global renewable energy (including solar, wind, and other renewables). The renewables sector magnifies differences in carbon intensities across countries and regions. While renewables account for about 20 percent of energy generation in Europe and the OEC, they represent less than 5 percent in all fossil fuel exporters. Third, regions and countries differ in energy trade (Figure 3, panel 3). Russia and the OPC group are the main fossil fuel exporters, while other countries, such as Japan, are fossil fuel importers, especially of oil and gas.

The G-Cubed model incorporates standard features of large macro models, including several that are worth highlighting: (i) intertemporal general equilibrium with standard optimization; (ii) rigidities, such as limits on the pace of investment (quadratic adjustment costs), that prevent economies from moving quickly from one equilibrium to another; (iii) cross-border capital and trade flows and bilateral cross-border input linkages; (iv) heterogeneous households and firms—besides conventional forward-looking agents, a fraction of households consume their current income, and a fraction of firms make backward-looking investment decisions; (v) monetary and fiscal policy rules. The model has been applied to study a wide range of macroeconomic policy questions.

Importantly, the model incorporates a full-fledged external sector. Intertemporal decisions of households and firms determine both saving and investment in response to the change in government policies. The gap between aggregate saving and investment determines the current account. A key variable that affects national saving, investment, and current accounts is the real interest rate, which directly affects both saving and investment decisions as well as human wealth through a discounting channel.[3] Flexible exchange rates and open capital accounts are assumed for the 10 countries and regions.

Figure 3: Structural Asymmetries



[3] Note that the precautionary saving motive is absent for the model. Given uncertainties associated with climate change and the green transition, precautionary considerations could provide an additional motive for saving.

3.2 The Baseline Scenario

The baseline relies on projections of population, projections of sectoral productivity growth rates by sector and by country, and projections of energy efficiency improvements based partly on historical experience and expected future developments. The key inputs into the baseline are the initial dynamics from 2018 to 2019 (the evolution of each economy from 2018 to 2019) and subsequent projections from 2019 onwards for sectoral productivity growth rates by sector and by country. We solve the model from 2018 adjusting various constants in the model so that the model solution for 2018 replicates the database for 2018 (the latest data we have). Sectoral output growth from 2018 onwards is driven by labor force growth and labor productivity growth.

For labor force, we use the working-age population projections from the UN Population Prospects 2019 to calculate the economy-wide labor growth rates for each region. For labor productivity, we use a catch-up model to generate labor productivity growth rates (defined in terms of labor-augmenting technological progress). We assume that the United States is the world frontier in productivity in each sector, where the productivity increases at a constant rate of 1.4 percent every year for all sectors (the average for US productivity growth) except renewable sectors which we assume grow more quickly at an additional rate of 5 percent (6.4 percent in total). For all other economies, the sectoral productivity projections follow the Barro approach estimating that the average catchup rate of individual countries to the worldwide productivity frontier is 2% per year. We use the Groningen Growth and Development database to estimate the initial productivity level in each sector of each region in the model, and then take the ratio of the initial productivity to the equivalent sector in the US. Given this initial gap, we use the Barro catchup model to generate long-term projections of the productivity growth rate of each sector within each country. Where we expect that regions will catch up more quickly to the frontier due to economic reforms or more slowly to the frontier due to institutional rigidities, we vary the catchup rate over time. The calibration of the catchup rate attempts to replicate recent growth experiences of each country and region in the model.

In addition, we assume that autonomous energy efficiency in every sector increases at a constant rate of 1 percent every year for all economies except China and India where we assume an additional rate of 2 percent (3 percent in total) assuming the two largest developing economies gain energy efficiency faster due to technological catchup.

The baseline scenario abstracts from the 2020 pandemic-related fall in output and emissions, assuming that the subsequent rebound brings output and emissions levels in 2021 close to their 2018 level—the latest year for which the model has been calibrated. While this is a simplification, we expect it to be of minor significance for the results especially in the medium and long run. Black and Parry (2020), for example, finds that the required emission reductions for meeting temperature stabilization goals are essentially unchanged by the Covid-19 crisis. But the Covid-19 crisis could lead to long-term behavioral changes that would raise or lower emissions—such as reduced use of public transportation and greater reliance on individual vehicles or greater use of digital communication, leading to reduced commuting and less travel. In line with this, the baseline assumes (somewhat above) trend increases in energy efficiency.

The baseline projects global carbon emissions to continue rising at an average annual pace of 1.7 percent and reach 57.5 gigatons by 2050. Improvements in energy efficiency and some penetration of renewables—reflecting an implicit assumption of continuation of current policies and some autonomous increases (for example, reflecting consumer preferences)—cannot offset the forces of population and economic growth that are driving emissions. Projections of economic growth over the next 30 years determine the expected growth of future emissions, and therefore the scale of effort needed to keep temperature increases to 1.5–2°C. Global growth progressively declines from 3.7 percent in 2021 to 2.1 percent in 2050, reflecting a tapering off of growth in emerging market economies as they catch up toward the income levels of advanced economies. Whereas advanced economies have historically contributed the lion's share of emissions, China and India, as large and fast-growing emerging market economies, are significant emitters and are expected to continue to account for growing shares of carbon emissions. Their per capita emissions, however, still remain relatively small when compared with those of advanced economies.

3.3 Climate Change Mitigation Scenario

The climate change mitigation scenario brings global net carbon emissions to zero by 2050 with the help of a policy package comprising carbon taxes, accompanied by compensatory transfers to households, and green supply policies—infrastructure investment and a subsidy to renewables.

For the carbon tax, carbon prices are calibrated to achieve an 80 percent reduction in emissions from the energy sector in each region by 2050 relative to 2018, after accounting for emission reductions from the infrastructure investment and the green subsidy.[4] The carbon tax consists of an initial tax rate followed by an annual increase of 7 percent. A quarter of the resulting carbon tax revenues are transferred back to households to help protect the purchasing power of the poorest households from the increase in energy prices. The remaining three-quarters of the revenue is recycled to reduce government debt.

The green subsidy consists of a subsidy to output of renewables—solar and wind electricity sectors—financed by government debt. Specifically, output of renewables is provided a price subsidy of 80 percent.

The low-carbon infrastructure investment consists of an initial green public infrastructure investment of 1 percent of GDP gradually declines to zero over 10 years. Public investment is assumed to occur in the renewables and other low-carbon energy sectors, transport infrastructure, and services.[5] In line with the analysis in Calderón, Moral-Benito, and Servén (2015), it is assumed that for every 10 percent increase in the aggregate stock of infrastructure capital, productivity in private sector output rises by 0.8 percent. The new infrastructure, once in place, is sustained by spending an additional 0.2 percent of GDP to offset depreciation, which locks in the productivity gains of the sectors that benefit from the green infrastructure.

The three mitigation policies play distinct roles in reducing emissions and supporting economic growth. The carbon tax by 2050 accounts for 80 percent of emission reductions, but negatively impacts economic growth. Meanwhile, the green supply-side policies provide

[4] The remaining 20 percent of carbon emission reductions would come from factors not captured by the model, such as natural emission sinks and carbon removal technologies. An exception is made for the OPC region, where emissions are kept at the initial level because of an outsized negative economic impact from the global decline in demand for fossil fuels.

[5] The latter aims to capture the higher energy efficiency of buildings.

limited contributions to the emission reductions but ensure that the green transition is growth neutral at the global level.[6]

The mitigation policy package affects carbon emissions and the macroeconomy through two main channels. First, the carbon tax increases the relative price of fossil fuel energy, encouraging energy efficiency and discouraging energy usage. This is the scenario's main channel for reducing carbon emissions, with important implications. As economies reduce energy usage, economic activity shifts from capital-intensive high-carbon sectors to more labor-intensive low-carbon sectors. Hence, the impact of decarbonization is more negative for investment than it is for output and employment. Less energy-intensive aggregate economic activity also limits the size of carbon tax revenues that can be raised. Second, both the carbon tax and the green supply policies increase the price of fossil fuel energy relative to renewables-based energy, contributing to the growth and investment in the renewables sector. However, this shift in energy composition is a slow-moving process because of limits to the pace of sectoral expansion, with a potential role for targeted policies to facilitate the growth of the sector. Importantly, the credibility and anticipation of the mitigation policies, implemented over the next three decades, are crucial for generating the outcomes of the climate change mitigation scenario. Credible carbon tax policy can trigger large changes in immediate economic outcomes, including investment responses and dynamic effects, even if the initial size of the tax is small.

Two additional considerations are worth noting. First, the global economic transformation entailed by the mitigation scenario is gradual and orderly, avoiding abrupt adjustments in fossil fuel prices, which increase persistently over the scenario's horizon. There are also no technological breakthroughs, including technology leapfrogging, assumed that would facilitate the green transition, beyond the spillovers from the green infrastructure investment. Second, the results presented in this paper abstract from long-term climate damages. A model extension incorporating climate damages suggests a very limited economic and external sector impact for the global economy over the next decade (Fernando, Liu, and McKibbin 2021).

[6] The scenario is also designed to be employment-neutral and public-debt-neutral for the global economy however the distribution across countries is not growth neutral.

4. Results

To investigate the external sector impact of the net-zero emissions by 2050 scenario, this section analyzes the three mitigation policies individually, followed by an analysis of the full policy package. The section also examines partial implementation of climate mitigation policies and explores implications of climate change mitigation policies for the global real interest rate.

4.1 Carbon Tax

The carbon tax policy resembles a negative productivity shock that varies by sector and country, depending on the current and anticipated path of carbon dependence. Greener countries are the least affected, while fossil fuel extraction activities are permanently reduced. The economic impact of the policy is back-loaded, with tax levels gradually increasing until 2050 to achieve the emission targets.

The internal investment-saving balance approach is adopted to gauge the external sector response to the tax, distinguishing between (i) global intertemporal implications and (ii) cross-country variation in response to the tax. To focus on the responses over the first decade, the results are reported as average deviations from the baseline growth path for the first 10 years of the simulation.

The carbon tax decreases aggregate investment globally as the anticipated return on fossil-fuel-linked investment is permanently reduced.[7] The global interest rate falls, shifting income towards consumption and reducing global saving until the global investment-saving balance is restored.[8] The economic magnitude of the adjustment is sizable, with investment and saving declining by 2 percent of global GDP over the first decade, reflecting the high capital intensity of fossil-fuel-dependent economic activity. Meanwhile, the global interest rate declines by 0.25 percentage point (or 25 basis points).

The results reveal a large variation in the investment response across countries. The carbon taxes play the key role in reducing emissions to net-zero by 2050, which implies that fossil-

[7] This overall decline in investment relies importantly on the slow investment response in the expansion of renewables due to adjustment costs.

[8] Public sector surpluses stemming from carbon tax revenues are more than offset by private dissaving, resulting in decreased aggregate saving.

fuel-related investment must be mostly removed. Thus, the decline of investment relative to the baseline depends on the share of fossil-fuel-related investment in total investment or, equivalently, the share of fossil-fuel-related output in total output. Figure 4 reports results for all 10 countries and regions, ordered by the size of the investment response. The contraction in investment is most pronounced in the fossil-fuel-producing countries and regions (Russia, OEC, ROW, OPC), while relatively greener advanced economies and regions (Japan, EUW) are affected the least (Figure 4, panel 1). China and India are more negatively affected than advanced economies because of their carbon-intensive manufacturing activities.[9] Saving declines in all countries but more evenly across countries compared to investment (Figure 4, panel 2). On the one hand, saving would decrease when investment decreases and hence total wealth decreases. The more fossil-intensive, the more saving tends to decrease. On the other hand, the decline of investment would decrease the real interest rate, and thus saving would increase. The more investment declines, the more the real interest rate would decrease, and thus the more saving would increase. The overall effect is dominated by the wealth effect.[10] The effects of fossil fuel heterogeneity on saving in the two channels go in opposite directions, leaving relatively homogenous responses across countries.

The response of the current account is driven by heterogeneity in the investment response across countries (Figure 4, panel 3). The current account decreases where investment contracts the least and increases in countries where the carbon tax decreases investment the most, as capital is relocated towards greener economies. The dominant role of aggregate investment in driving external sector responses is captured by a strong negative cross-country correlation (–0.94) between investment and current account responses and an absence of correlation between the current account and aggregate saving (0.01). A stylized two-country graphic illustration of these economic forces is presented in Section 3.

The real exchange rate (RER) acts as a shock absorber for the most affected countries and regions. In response to the carbon tax, the RER depreciates in countries with the most negative economic impact—with the largest declines in investment and capital outflows

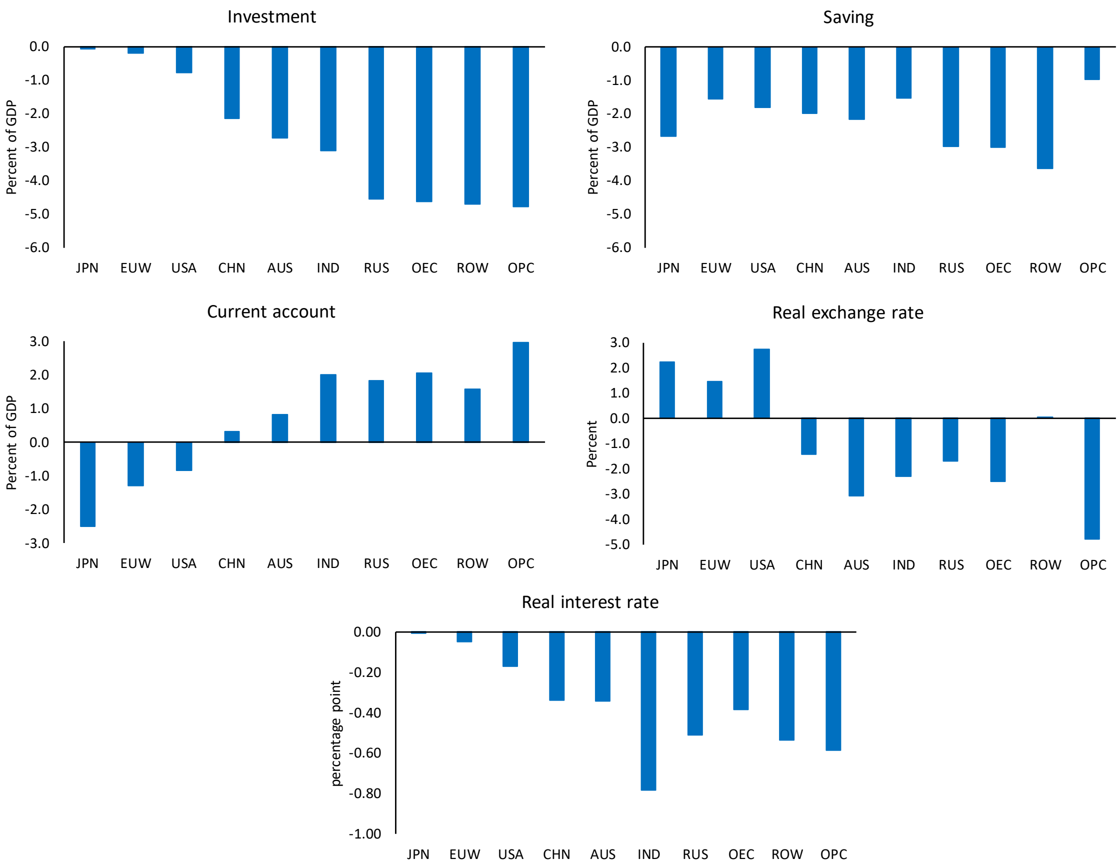
[9] Using a different computable general equilibrium model–based climate change mitigation scenario, OECD (2022) reports a similar higher cost of decarbonization, in terms of the investment response, for China and India.

[10] The overall saving is also impacted by the intertemporal consumption smoothing motive, as income declines in response to the persistently increasing carbon tax. More of the income is saved in the initial decade in economies/regions where the income decline is anticipated to be the steepest. However, the variation in this saved income share plays a limited role quantitatively.

(Figure 4, panel 4). For such economies, the RER facilitates the external sector adjustment through the expenditure switching channel, as the demand at home shifts from imported to domestic goods and services, and exports are boosted. Conversely, countries that are the least affected by the carbon tax exhibit capital inflows and current account deficits relative to the baseline. The strong link between the current account and the RER adjustment is captured by a –0.86 cross-country correlation for responses.

The heterogeneity in real interest rate responses is governed by the change in investment relative to saving within each economy (Figure 4, panel 5). The countries with a large fall in investment relative to savings will experience a larger fall in the real interest rate, and the real exchange rate will depreciate instantly and gradually appreciate over time to make the relative interest rates consistent with the interest rate parity condition. Consequently, the responses in the real interest rates are highly correlated with the responses in investment across countries.

Figure 4. Impact of a coordinated carbon tax (Deviations from baseline, average over first decade)



The external sector impact of the carbon tax is large in economic terms. The absolute value of the 10-year average current account response ranges from 0.3 to 3 percent of GDP. The absolute value of the RER adjustments, relative to the baseline path, ranges from 0 to 4.8 percent, with an outsized response in initial years.

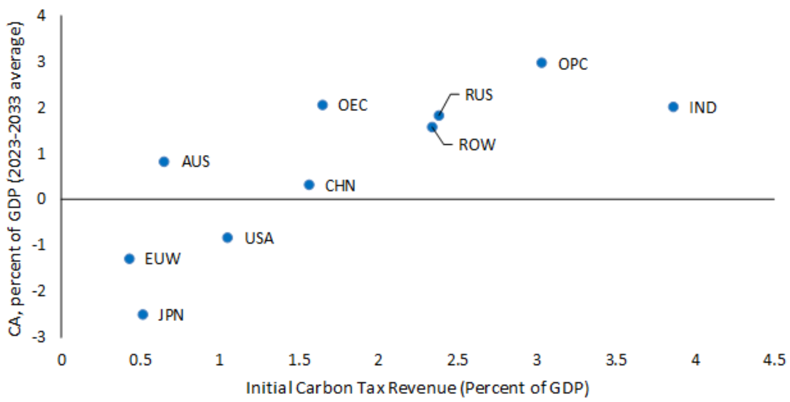
Country-specific determinants of carbon emissions drive the cross-country differences in the external sector response. One key characteristic discussed earlier is initial carbon intensity (see Figure 3, panel 1). In addition, long-run growth of carbon emissions will be higher in countries with higher projected labor force and productivity growth rates and in sectors with a more limited scope for reducing reliance on carbon-intensive inputs. Each of these carbon-emission-inducing factors necessitates a higher carbon tax to reach the 2050 emission targets. Cross-country differences in the role of these factors can be summarized with the collected carbon tax revenues, which exhibit a strong positive correlation with the change in the current account. In countries or regions where the revenues collected from the tax (and projected carbon emissions) are the highest, the current account increases the most (Figure 5, panel 1), suggesting a form of twin surpluses. Conversely, countries and regions with relatively low carbon tax revenues exhibit current account decreases.

A country's status as a net fossil fuel exporter is an important additional determinant of the current account response. Net fossil-fuel-exporting countries face a reduced demand for fossil fuel from abroad, which further depresses investment and increases the current account (Figure 5, panel 2). This channel operates and exerts an economically significant impact on the external sector even if the fossil-fuel-exporting country does not impose a carbon tax.[11] More generally, the nature of this cross-border demand spillover could differ drastically across net resource-exporting countries. While net exporters of fossil fuels are negatively affected, the demand for metals critical for green energy transition could surge. However, the G-Cubed model does not incorporate sufficient detail on mineral resources to explore such additional considerations.

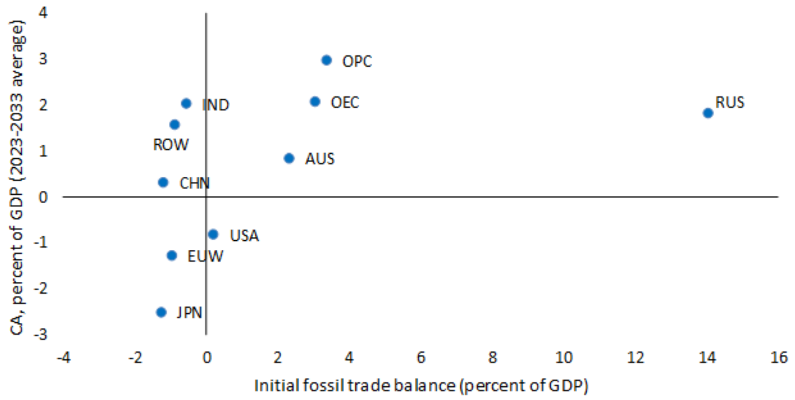
[11] See panel 2 of Figure 11 for a simulation of this external sector spillover effect on net fossil fuel exporters from a carbon tax imposed in Europe only.

Figure 5. Country Characteristics and External Sector Impact of the Carbon Tax

1. Initial Carbon Tax Revenue and Current Account Deviation from Baseline



2. Initial Fossil Fuel Trade Balance and Current Account Deviation from Baseline



4.2 Green Subsidy

The green output-based subsidy to the renewables sector—solar and wind energy generation—is reminiscent of a positive sector-specific productivity shock. The subsidy complements the carbon tax in stimulating a shift in energy generation from fossil fuels to renewables.

For the global economy, the green subsidy triggers an intertemporal adjustment familiar from the discussion of the carbon tax, but operating in reverse. The subsidy boosts investment in renewable activities, which leads to an increase in the global interest rate and saving until the global investment-saving balance is restored. Despite the large subsidy, the magnitude of the response is limited when compared with the carbon tax. Investment (and saving) increase globally by 0.1 percent of GDP, while the interest rate rises by 0.11 percentage point. The muted response is explained by the small initial size of the renewables sector—at a mere 0.1 percent of the global output—and by the limits on the pace of investment.[12]

There are stark differences in the investment response across countries and regions (Figure 6, panel 1). Europe, with its abundant renewable energy generation, has the strongest investment boom because limits to the pace of investment provide an advantage to regions with capital for renewables already in place (Figure 3, panel 2). At the other end of the spectrum, for fossil-fuel-producing countries and regions with small renewables sectors (RUS, OPC), the increased relative price of fossil-fuel-based energy reduces demand for fossil fuels, decreasing investment in the sector. While the renewables sector is attracting investment and growing rapidly, the sector's small size limits its macroeconomic impact. Saving increases in all regions in tandem with the rise in the global interest rate (Figure 6, panel 2).

Changes in the current account are driven mainly by the heterogeneity in the investment response across countries and regions. There is an outsized decrease in Europe, reflecting the investment boom, while current accounts increase the most in fossil-fuel-dependent countries. (Figure 6, panel 3).[13] The cross-country correlation between investment and current account responses is –0.91. As in the case of the carbon tax, the RER response facilitates the current account adjustment, with the largest appreciation in Europe and depreciations for fossil fuel exporters (Figure 6, panel 4). Reflecting investment responses, current account and RER adjustments are a fraction of those generated by the carbon tax.

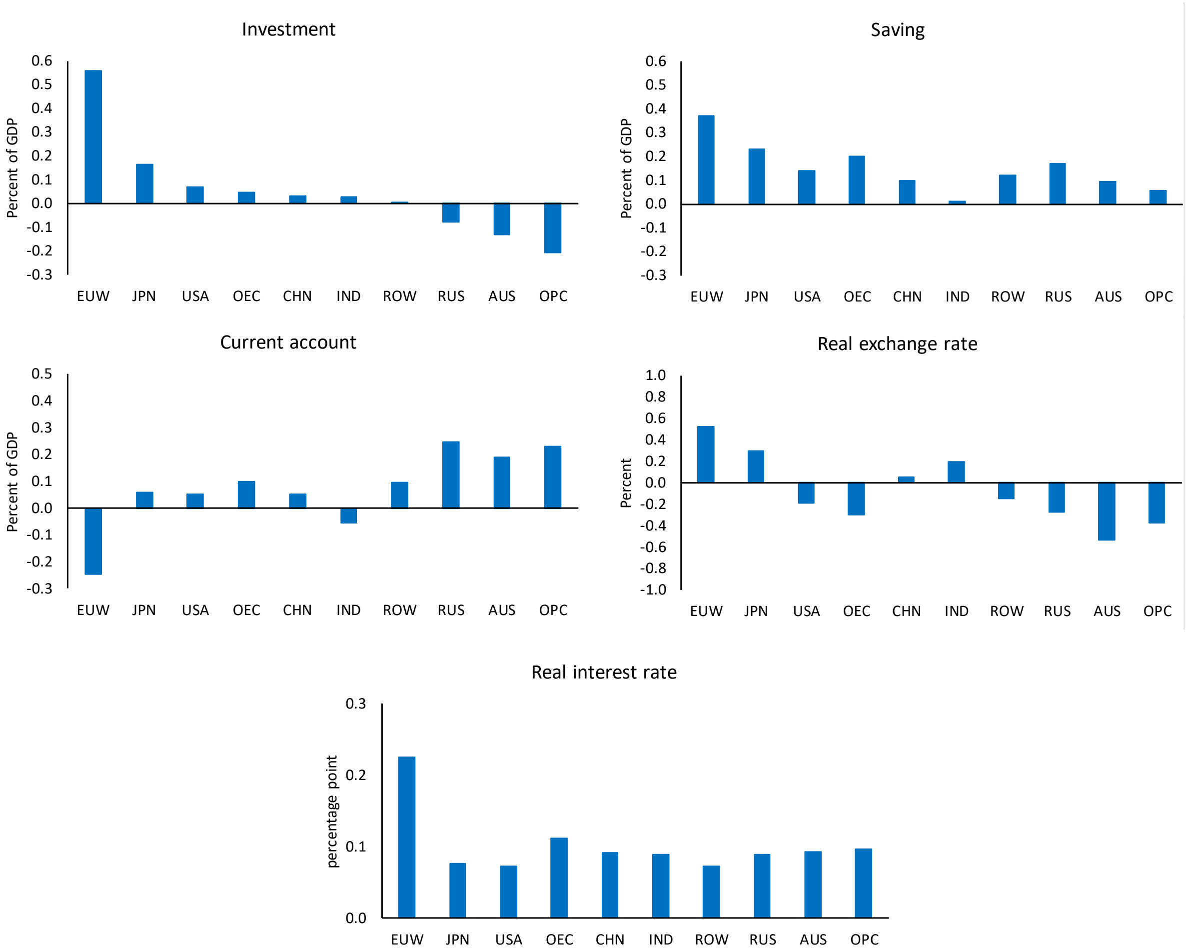
The external sector impact of the subsidy is ultimately driven by the cross-country variation in the initial size of the renewables sector. Given the constrained pace of sectoral expansion, in countries/regions where the initial size of the renewables sector is the smallest (RUS, OPC), the average size of the output-based green subsidy over the first decade remains below 0.04 percent of GDP and the current account increases the most (Figure 7). Meanwhile, Europe

[12] The model includes quadratic investment adjustment costs. As a result, countries that have smaller initial capital stocks in renewable activities experience a higher cost of adjustment per unit of capital investment because their marginal costs rise faster, constraining the pace of sectoral expansion.

[13] The stylized two-country graphic illustration of the model's forces in Figure 1 can be modified to capture the investment-saving and the current account impacts of the green subsidy. The key change is that a green subsidy shifts the investment curve outward, rather than inward, and the shift is larger for the green region.

provides the largest subsidy—at 0.3 percent of its GDP and 57 percent of the global green subsidy—and exhibits the largest decrease in the current account.

Figure 6. Impacts of green subsidy (Deviations from baseline, average over first decade)

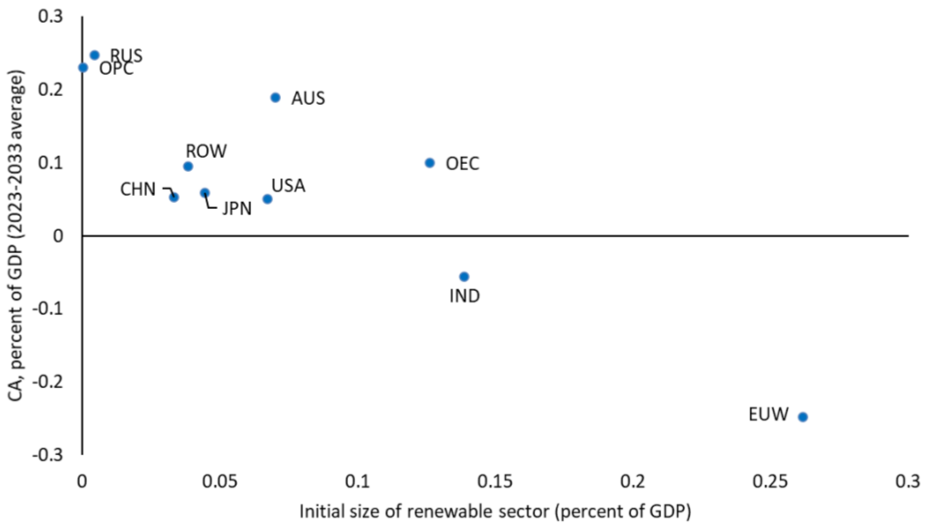


4.3 Infrastructure Investment

The green public infrastructure component of the mitigation policy package amounts to a sizable and front-loaded fiscal expansion that aims to counter the negative growth impact of the carbon tax. An additional economic boost stems from the assumed private sector productivity spillover, induced by the increased public infrastructure capital stock (Calderón, Moral-Benito, and Servén 2015).[14] Importantly, the aggregate size of both components of the infrastructure investment policy—temporary fiscal expansion and private sector productivity spillover—is assumed to be identical across countries

[14] For details on the modeling of the private sector productivity spillover see Jaumotte, Liu, and McKibbin (2021).

Figure 7. Initial size of renewables sector and CA deviation from baseline



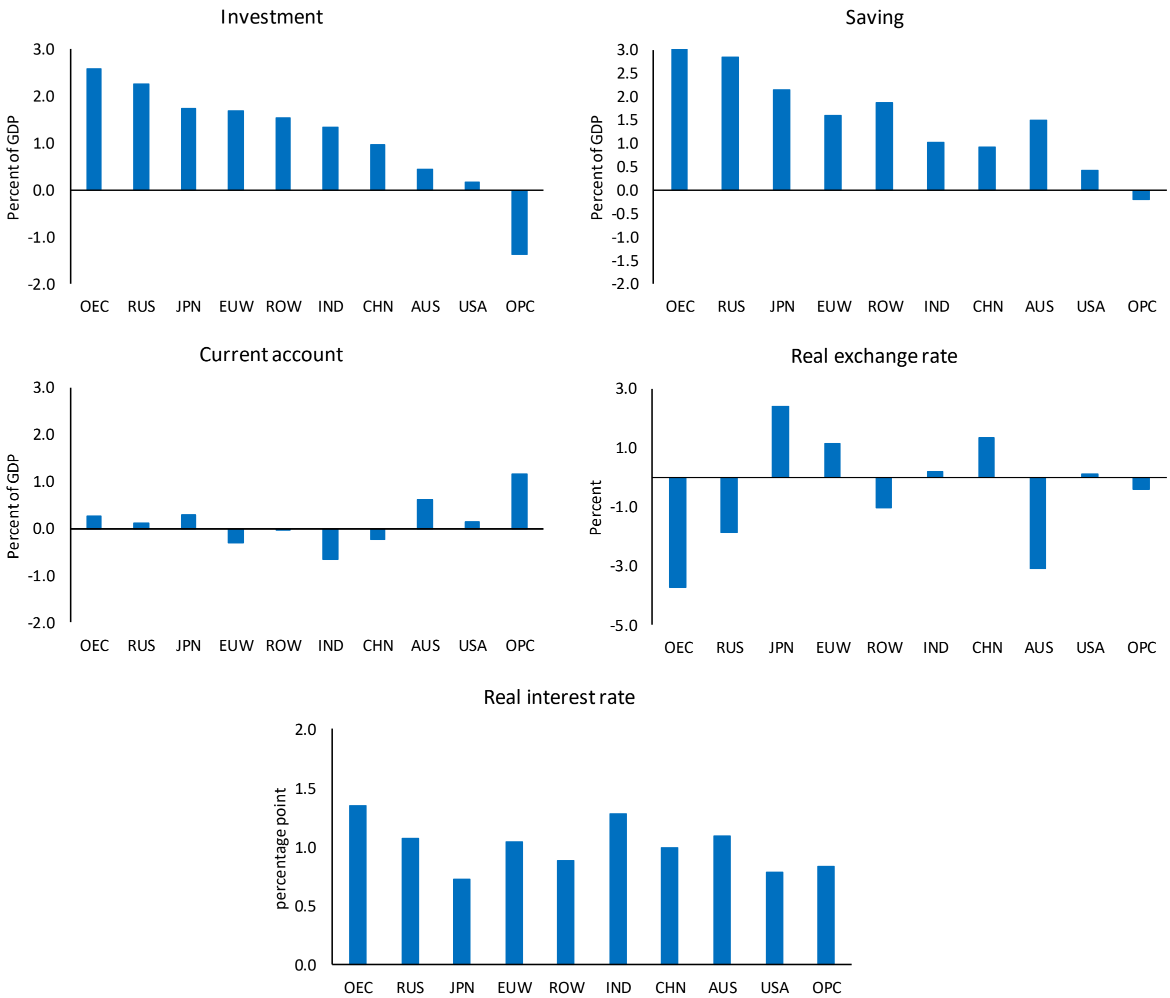
The symmetric and coordinated nature of the infrastructure investment policy limits its impact on the external sector (Figure 8).[15] This finding should come as no surprise, as what matters for the current account response is the fiscal policy action (and productivity gains) relative to the rest of the world and country-specific characteristics, such as the degree of openness. Intuitively, when policy-induced shifts in the investment curve are identical across countries, the resulting increase in investment and saving broadly offsets, increasing the interest rate but leaving the current account unchanged.

Investment increases in all countries except OPC because of the productivity growth in the low-carbon sectors. OPC suffers because its low-carbon output is nearly zero, and the global renewable energy boost reduces oil demand. Savings increase because output increases in the first decade, and households have a desire to smooth consumption over time, given that public investment phases out after the first decade. OPC and Australia experience strong current account surpluses because capital flows out of these economies, given that the global renewable energy boost reduces demand for fossil fuels. China and India experience current account deficits because the declining demand for fossil fuels reduces fossil fuel prices, which benefits manufacturing producers. However, these current account findings need to be interpreted with caution. First, they depend on the assumed symmetric size of the

[15] Figure 9 reports the impact of the infrastructure investment policy on the external sector, comparing it with the other mitigation policies.

infrastructure investment across countries. Second, the external sector results could be sensitive to the assumed symmetry in productivity spillovers and their sectoral distribution.

Figure 8. Impacts of infrastructure investment. Deviations from baseline (average over first decade)



4.4 Mitigation Policy Package

The mitigation policy package is designed to be growth-neutral and public-debt-neutral by 2050 at the global level. Its external sector impact is equal to the sum of the three individual mitigation policies—carbon tax, green subsidy, and infrastructure investment (Figure 9). Several takeaways are worth highlighting.

First, despite the policy package delivering positive output growth globally during the initial decade, aggregate investment falls in all but the least carbon-intensive economies (Figure 9, panel 1). The public infrastructure boost offsets approximately half of the carbon-tax-induced decline in investment globally. The remaining negative impact on investment is mainly due to the higher capital intensity of fossil-fuel-producing sectors, the role of which declines significantly in the global economy as carbon emissions are reduced, shifting economic activity towards more labor-intensive sectors.

Second, the carbon tax dominates the current account impact, while the other policies have much smaller effects, as discussed earlier. For the model's median region, the carbon tax accounts for 91 percent of the total current account response to the mitigation policy package (Figure 9, panel 3). The carbon tax is also the main driver of the RER response, accounting for 46 percent of the overall adjustment. In the greener advanced countries/regions (JPN, EUW), the sizable current account and RER adjustments that occur as investment increases while saving remains broadly unchanged generate a Dutch-disease-type effect, with export activity shrinking as a share of GDP.

Third, the prospects for the country-specific and global real interest rates are closely linked to the dynamics of aggregate investment (Figure 9, panel 5). Carbon taxes reduce investment, gradually decreasing the interest rate over the three decades of globally coordinated climate change mitigation efforts. In contrast, the front-loaded green infrastructure policy raises the global interest rate in the short term, but its impact is transitory, dissipating as the infrastructure boom moderates after the first decade. Given its limited size, the green subsidy has a muted impact on the global interest rate. Overall, following an initial infrastructure-investment-induced rise, the mitigation policy package leads to a gradual decline in the global interest rate (Figure 10).

Finally, individual country responses to the mitigation policy package and its components exhibit a sizable country-specific component. Despite strong correlations, the investment behavior cannot fully explain current account and RER responses. This is to be expected given the significant variation in the size of policy shocks across countries and in country characteristics. For example, countries vary in the degree of openness (that is, the share of output that is exported and the share of final demand that is imported), bilateral exposures, sectoral structure of economic activity, and labor force trends.

Figure 9. Impacts of aggregate policy package. Deviations from baseline (average over first decade)

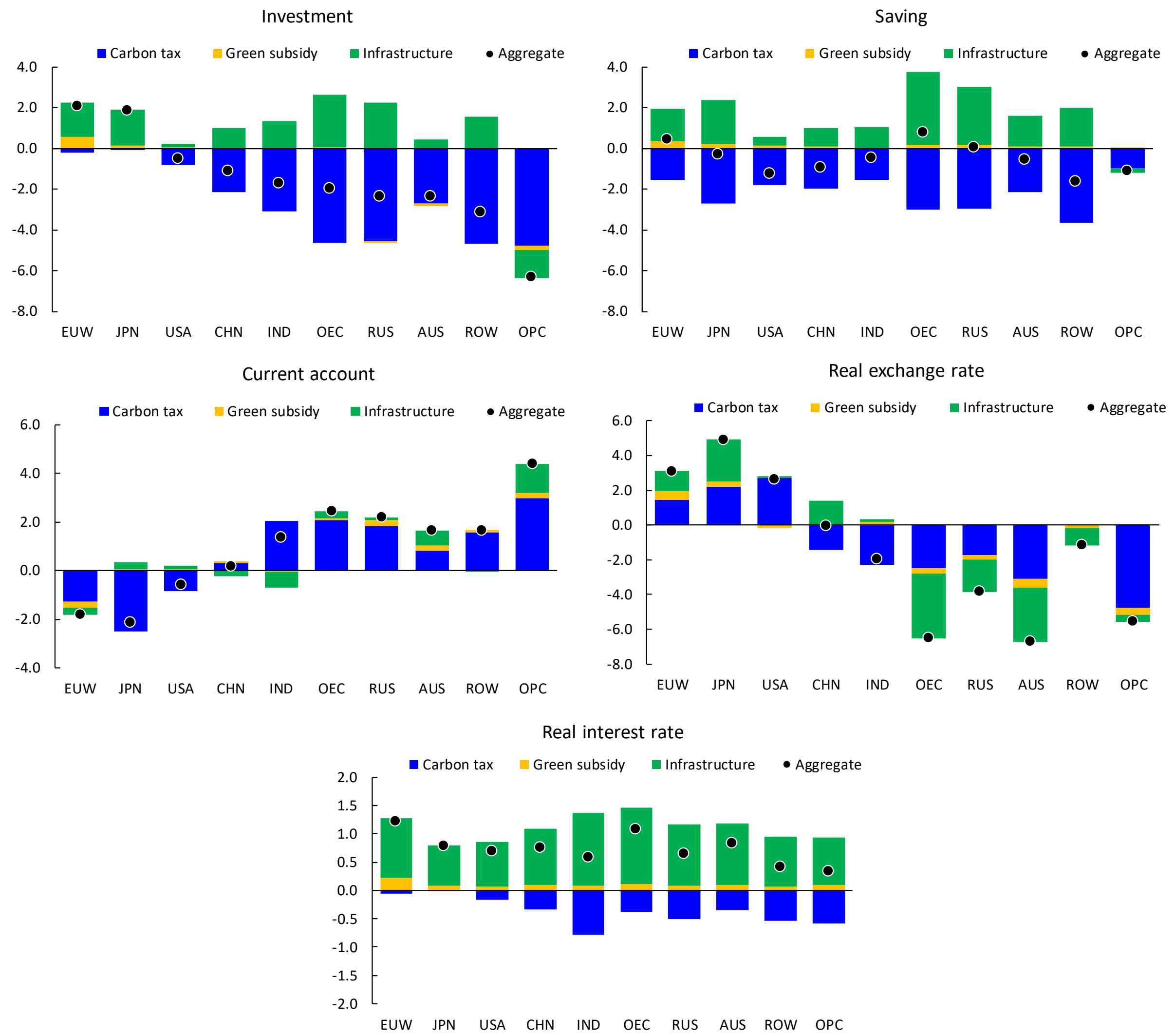
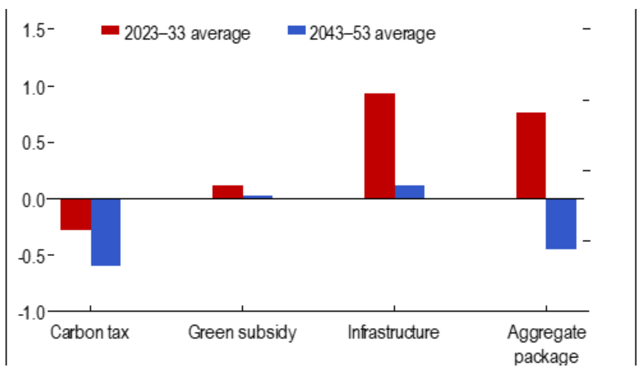


Figure 10: Mitigation Policies and Global Interest Rates: First Decade versus 2050



4.5 Role of Policy Synchronization

A partial or asynchronous implementation of mitigation policies adds a policy asymmetry that can alter external sector outcomes. The analysis thus far has examined globally coordinated implementation of mitigation policies, with all countries reaching the emission reduction targets. However, the progress and medium-term commitments toward climate change mitigation vary considerably across countries.[16] To explore the implications of the uneven progress, this section examines an alternative partial implementation scenario, focusing on a case in which only one region—Europe—implements the carbon tax and the green subsidy.[17]

For the global economy, implementing the carbon tax in Europe leads to the familiar intertemporal adjustment in the investment-saving balance: a fall in investment and saving, accompanied by a reduction in the global interest rate. With only Europe implementing the tax, the size of the adjustment is significantly smaller than under coordinated implementation, with a mere 0.2 percent of GDP drop in investment (and saving) globally and a 0.02 percentage point decrease in the interest rate over the first decade.

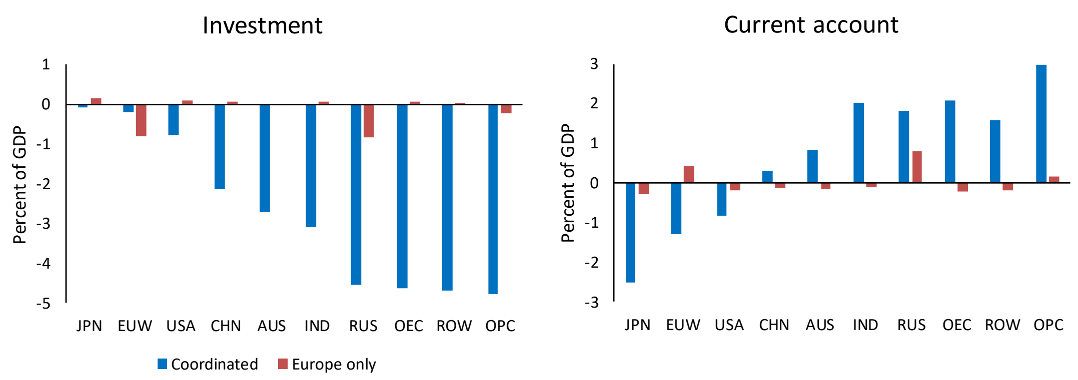
The muted global impact hides large differences in investment and current account responses across countries (Figure 11, panels 1 and 2). As the carbon tax reduces the anticipated return on investment in Europe, investment and saving fall in that region (Figure 11, panel 1). For fossil fuel exporters, there is a sizable negative economic impact. Spillovers from reduced demand for fossil fuels in Europe depress investment upstream in Europe's fossil-fuel-supplying countries—Russia and, to a lesser extent, other fossil-fuel-exporting developing economies (such as those in the OPC group). For the other regions, in the absence of a carbon tax, investment increases marginally, while saving declines, as in Europe. Reflecting the investment responses, capital flows out of Europe and its fossil fuel suppliers and into the regions/countries that do not impose the carbon tax, as revealed by current account surpluses in Europe and fossil-fuel-producing countries/regions and deficits in other countries/regions (Figure 11, panel 2).

[16] See, e.g., the IMF Climate Change Dashboard at https://climatedata.imf.org/.

[17] While Europe, as the green transition front-runner, is an instructive scenario specification, broadly similar findings were obtained with other partial-implementation scenarios (for example, the case of mitigation policies implemented only by advanced economies).

Relative to coordinated implementation, a unilateral carbon tax in Europe reveals a sizable negative competitiveness impact for that region. The fall in investment in Europe is magnified because the carbon tax (and the anticipated decline in the return on investment) is accommodated by a smaller decline in the global interest rate than would occur with coordinated implementation (Figure 11, panel 1). Furthermore, the current account response is reversed, as the outsized fall in investment increases the current account in Europe (Figure 11, panel 2). Instead of drawing capital inflows, the imposed permanent carbon tax turns Europe into a source of capital outflows as investment shifts toward regions with a higher return on investment.[18]

Figure 11. Carbon tax: Impact of partially implemented mitigation policies on the external sector

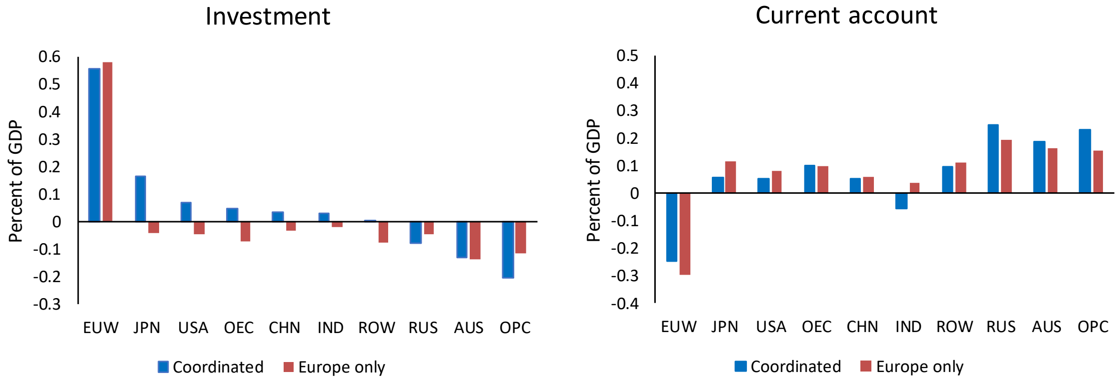


By contrast, the green subsidy, when implemented in Europe only, further boosts economic activity in the region. Not surprisingly, given Europe's outsized role in the global green subsidy, results for this scenario resemble those of the coordinated implementation scenario (Figure 12). The key difference between the two scenarios is that a subsidy only in Europe raises the global interest rate by less. As a result, investment in Europe is boosted, further decreasing the region's current account. For other countries/regions, external sector outcomes reflect a trade-off between the green subsidy and a more muted increase in the global interest rate. Where the subsidy under coordinated implementation is small (Russia, OPC), the interest rate effect dominates, increasing investment and reducing the current

[18] Recent literature explores border carbon adjustments as a policy tool to reduce the negative competitiveness effect from a unilateral carbon tax. While not examined in this chapter, such an adjustment would be implemented by countries with stricter climate policies on the imported carbon content from regions with more limited climate change mitigation efforts. The bulk of the impact of border carbon adjustments can be achieved by focusing on energy-intensive and trade-exposed sectors (Chateau, Jaumotte, and Schwerhoff 2022a).

account balance. Where the subsidy is more sizable (United States, Japan), the absence of the subsidy dominates, reducing investment and increasing the current account.

Figure 12. Green subsidy: Impact of partially implemented mitigation policies on the external sector



Overall, partial implementation of mitigation policies can have sizable and varied impacts on the external sector, either putting countries at a competitive disadvantage or magnifying the economic boost from a mitigation policy. However, a critical shortcoming of partial implementation is the failure to deliver the necessary global carbon emission reductions. To succeed in averting climate change, both advanced and developing countries must cooperate in achieving the climate mitigation targets, including through burden-sharing arrangements such as income-differentiated carbon price floors or sectoral carbon pricing (Parry, Black, and Roaf 2021; Chateau, Jaumotte, and Schwerhoff 2022a).

5. Conclusion

While ensuring that climate targets are met, various climate mitigation policies could imply substantially different current account adjustments. In the G-Cubed model, a globally coordinated carbon tax disproportionately reduces investment in more carbon-intensive economies as the return on investment in carbon-intensive activities falls permanently. The heterogeneous investment responses, in turn, sizably decrease current accounts in the greener advanced economies and increase current accounts in the more carbon-intensive and fossil-fuel-dependent countries. Ultimately, country characteristics such as initial carbon intensity, net fossil fuel exporter status, as well as projected labor force and productivity growth rates, drive the current account response in the model. In contrast to the carbon tax, supply-side policies—green subsidies and infrastructure investment—have a more limited impact on the external sector, either because of their constrained size or symmetric nature, which induces comparable investment and saving responses, leaving the current account broadly unchanged.

The examined climate change mitigation policies also impact the real interest rate. When implemented as a package, these mitigation policies reduce the interest rate over the first decade, driven by the boost in infrastructure investment. Over longer horizons, as front-loaded supply-side policies are phased out, mitigation policies are dominated by the carbon tax, which reduces the real interest rate.

The impact of climate change mitigation policies on current accounts depends crucially on the degree of policy synchronization across regions. When the carbon tax is implemented in Europe alone, the European current account increases (instead of decreasing under coordinated implementation) because the tax hike reduces domestic investment and shifts capital abroad. By contrast, the green subsidy implemented in Europe alone magnifies the external sector impact: the more muted interest rate response stimulates investment, further decreasing the current account. Partial implementation scenarios highlight the importance of bilateral linkages and spillovers in determining region-specific external sector outcomes following a policy shock. A crucial shortcoming of partial implementation is its failure to adequately address climate change.

In summary, the policies to address climate change have differential effects on external balances across countries. A general equilibrium analysis that takes into account important real world asymmetries across countries can assist in unravelling the nature and the scale of the expected adjustment in external balances.

Appendix

The optimality condition for investment in the tradable sector is

$$\alpha A_2 K_2^{\alpha-1} = r_2 \tag{A1}$$

Thus,

$$K_2 = \left(\frac{\alpha A_2}{r_2}\right)^{\frac{1}{1-\alpha}} \tag{A2}$$

$$I_1 = K_2 - K_1 \tag{A3}$$

The above conditions result in the investment function as

$$I_1 = \left(\frac{\alpha A_2}{r_2}\right)^{\frac{1}{1-\alpha}} - K_1 \tag{A4}$$

It follows that I_1 decreases in r_2 since

$$\frac{dI_1}{dr_2} = \left(\frac{\alpha A_2}{r_2}\right)^{\frac{1}{1-\alpha}} = -\frac{1}{1-\alpha}(\alpha A_2)^{\frac{1}{1-\alpha}}(r_2)^{-\frac{2-\alpha}{1-\alpha}} < 0 \tag{A5}$$

The two-period horizon implies

$$I_2 = -K_2 \tag{A6}$$

It also follows that

$$Y_2^T = A_2\left(\frac{\alpha A_2}{r_2}\right)^{\frac{\alpha}{1-\alpha}} \tag{A7}$$

The optimality condition for aggregate consumption is

$$C_2 = \beta(1+r_2)C_1\left(\frac{p_1}{p_2}\right)^{1-\theta} \tag{A8}$$

and the optimal consumption bundle must satisfy

$$\frac{C_t^N}{C_t^T} = \frac{1-\theta}{\theta}\frac{1}{p_t} \tag{A9}$$

The above two conditions imply the Euler equation in terms of tradable goods as

$$C_2^T = \beta(1+r_2)C_1^T \tag{A10}$$

Combining the Euler equation and the intertemporal budget constraint for tradable goods yields

$$\beta(1+r_2)C_1^T = (1+r_2)(Y_1^T - C_1^T - I_1) + Y_2^T - I_2 \tag{A11}$$

The saving is

$$S_t = Y_t^T + r_t B_t - C_t^T \tag{A12}$$

Combining the above two equations yields

$$\beta(1+r_2)(Y_1^T - S_1) = (1+r_2)(S_1 - I_1) + Y_2^T - I_2 \tag{A13}$$

Thus,

$$S_1 = \frac{1}{(1+\beta)(1+r_2)}(\beta(1+r_2)Y_1^T + (1+r_2)I_1 - Y_2^T + I_2)$$

$$= \frac{1}{(1+\beta)(1+r_2)}(\beta(1+r_2)Y_1^T + (1+r_2)I_1 - Y_2^T - K_2)$$

$$= \frac{1}{1+\beta}\left(\beta Y_1^T + I_1 - \frac{Y_2^T}{1+r_2} - \frac{K_1+I_1}{1+r_2}\right)$$

$$= \frac{1}{1+\beta}\left(\beta Y_1^T + \frac{r_2}{1+r_2}I_1 - \frac{Y_2^T}{1+r_2} - \frac{K_1}{1+r_2}\right) \tag{A14}$$

Therefore,

$$\frac{dS_1}{dr_2} = \frac{1}{1+\beta}\left(\frac{r_2}{1+r_2}\frac{dI_1}{dr_2} + \frac{I_1}{(1+r_2)^2} + \frac{Y_2^T}{(1+r_2)^2} - \frac{1}{1+r_2}\frac{dY_2^T}{dr_2} + \frac{K_1}{(1+r_2)^2}\right)$$

$$= \frac{1}{1+\beta}\left(\frac{r_2}{1+r_2}\frac{dI_1}{dr_2} + \frac{I_1+K_1}{(1+r_2)^2} + \frac{Y_2^T}{(1+r_2)^2} - \frac{1}{1+r_2}\frac{dY_2^T}{dr_2}\right)$$

$$= \frac{1}{1+\beta}\left(\frac{r_2}{1+r_2}\frac{dI_1}{dr_2} + \frac{K_2}{(1+r_2)^2} + \frac{Y_2^T}{(1+r_2)^2} - \frac{1}{1+r_2}\frac{dY_2^T}{dK_2}\frac{dK_2}{dr_2}\right)$$

$$= \frac{1}{1+\beta}\left(\frac{r_2}{1+r_2}\frac{dI_1}{dr_2} + \frac{K_2}{(1+r_2)^2} + \frac{Y_2^T}{(1+r_2)^2} - \frac{r_2}{1+r_2}\frac{dK_2}{dr_2}\right)$$

$$= \frac{1}{1+\beta}\frac{K_2+Y_2^T}{(1+r_2)^2} > 0 \tag{A15}$$

The impact of A_2 on $I_1(r_2)$ is derived as

$$\frac{dI_1}{dA_2}|_{\bar{r}_2} = \left(\frac{\alpha}{\delta+r_2}\right)^{\frac{1}{1-\alpha}}\frac{1}{1-\alpha}A_2^{\frac{\alpha}{1-\alpha}} > 0 \tag{A16}$$

The impact of A_2 on $S_1(r_2)$ is derived as

$$\frac{dS_1}{dA_2}|_{\bar{r}_2} = \frac{1}{1+\beta}\left(\frac{r_2}{1+r_2}\frac{dI_1}{dA_2} - \frac{1}{1+r_2}\frac{dY_2^T}{dA_2}\right)$$

$$= \frac{1}{1+\beta}\left(\frac{r_2}{1+r_2}\frac{dI_1}{dA_2} - \frac{r_2}{1+r_2}\frac{dK_2}{dA_2} - \frac{1}{1+r_2}\left(\frac{\alpha A_2}{r_2}\right)^{\frac{\alpha}{1-\alpha}}\right)$$

$$= -\frac{1}{1+\beta}\frac{1}{1+r_2}\left(\frac{\alpha A_2}{r_2}\right)^{\frac{\alpha}{1-\alpha}} < 0 \tag{A17}$$

Immediately,

$$\frac{dC_1^T}{dA_2}|_{\bar{r}_2} > 0 \tag{A18}$$

The interest rate r_2 is determined by

$$F \equiv Y_1^T - C_1^T - I_1 + Y_1^{T*} - C_1^{T*} - I_1^* = 0 \tag{A19}$$

It follows from the implicit function theorem that

$$\frac{dr_2}{dA_2} = -\frac{\partial F/\partial A_2}{\partial F/\partial r_2} = -\frac{\partial C_1^T/\partial A_2 + \partial I_1/\partial A_2}{\partial C_1^T/\partial r_2 + \partial I_1/\partial r_2 + \partial C_1^{T*}/\partial r_2 + \partial I_1^*/\partial r_2} > 0 \tag{A20}$$

To determine the non-tradable price, replacing C_1^T with C_1^N in equation (A11) based on the optimal consumption bundle ratio yields

$$(1+\beta)(1+r_2)\frac{\theta}{1-\theta}p_1 C_1^N = (1+r_2)(Y_1^T - I_1) + Y_2^T - I_2 \tag{A21}$$

Imposing the non-tradable-market clearing condition yields

$$(1+\beta)(1+r_2)\frac{\theta}{1-\theta}p_1 \bar{Y}^N = (1+r_2)(Y_1^T - I_1) + Y_2^T + K_2 \tag{A22}$$

Thus,

$$p_1 = \frac{1-\theta}{\theta}\frac{1}{1+\beta}\frac{1}{\bar{Y}^N}\left(Y_1^T - I_1 + \frac{Y_2^T + K_2}{1+r_2}\right)$$

$$= \frac{1-\theta}{\theta}\frac{1}{1+\beta}\frac{1}{\bar{Y}^N}\left(Y_1^T - \left(\frac{\alpha A_2}{r_2}\right)^{\frac{1}{1-\alpha}} + K_1 + \frac{A_2}{1+r_2}\left(\frac{\alpha A_2}{r_2}\right)^{\frac{\alpha}{1-\alpha}} + \frac{1}{1+r_2}\left(\frac{\alpha A_2}{r_2}\right)^{\frac{1}{1-\alpha}}\right)$$

$$= \frac{1-\theta}{\theta}\frac{1}{1+\beta}\frac{1}{\bar{Y}^N}\left(Y_1^T - \frac{\delta+r_2}{1+r_2}\left(\frac{\alpha A_2}{r_2}\right)^{\frac{1}{1-\alpha}} + K_1 + \frac{A_2}{1+r_2}\left(\frac{\alpha A_2}{r_2}\right)^{\frac{\alpha}{1-\alpha}}\right)$$

$$= \frac{1-\theta}{\theta}\frac{1}{1+\beta}\frac{1}{\bar{Y}^N}\left(Y_1^T + \frac{1-\alpha}{\alpha}\frac{r_2}{1+r_2}\left(\frac{\alpha A_2}{r_2}\right)^{\frac{1}{1-\alpha}} + K_1\right) \tag{A23}$$

A_2 affects p_1 through two channels: (1) a productivity channel given A_2 affects Y_2^T directly; (2) an interest rate channel given A_2 increases the interest rate r_2.

Similarly, for the Foreign economy,

$$p_1^* = \frac{1-\theta}{\theta}\frac{1}{1+\beta}\frac{1}{\bar{Y}^N}\left(Y_1^{T*} - I_1^* + \frac{Y_2^{T*}+K_2^*}{1+r_2}\right) \tag{A24}$$

A_2 affects p_1^* only through the interest rate channel. Thus, the effect of productivity change in period 2 on the exchange rate is

$$\frac{de_1}{dA_2} = \frac{1}{p_1^{*2}}\left(\frac{dp_1}{dA_2}p_1^* - \frac{dp_1^*}{dA_2}p_1\right) = \frac{1}{p_1}\left(\frac{dp_1}{dA_2} - \frac{dp_1^*}{dA_2}\right)$$

$$= \frac{1}{p_1}\left(\frac{\partial p_1}{\partial A_2} + \frac{\partial p_1}{\partial r_2}\frac{dr_2}{dA_2} - \frac{dp_1^*}{dr_2}\frac{dr_2}{dA_2}\right) = \frac{1}{p_1}\frac{dp_1}{dA_2} > 0 \tag{A25}$$

It follows that the exchange rate appreciates if the productivity in the future period improves.

References

Arezki, R., V. A. Ramey, and L. Sheng. 2017. "News Shocks in Open Economies: Evidence from Giant Oil Discoveries." Quarterly Journal of Economics 133 (1): 3–155.

Black, S., D. Minnett, I. Parry, J. Roaf, and Z. Karlygash. 2022. "The Carbon Price Equivalence of Climate Mitigation Policies." Unpublished, International Monetary Fund, Washington, DC.

Boer, L., A. Pescatori, and M. Stuermer. 2021. "Energy Transition Metals." IMF Working Paper 2021/243, International Monetary Fund, Washington, DC.

Bolton, P. and M. Kacperczyk. 2021. Do investors care about carbon risk?, *Journal of Financial Economics,* 142 (2): 517-549.

Copeland, B. R., and M. S. Taylor. 2003. Trade and the Environment: Theory and Evidence.

Copeland, B. R., J. S. Shapiro, and M. S. Taylor. 2022. Globalization and the Environment. Chapter 2, Handbook of International Economics, Volume 5.

Burfisher, M. E. 2021. *Introduction to Computable General Equilibrium Models (2nd ed.)*. Cambridge University Press.

Calderón, C., E. Moral-Benito, and L. Servén. 2015. "Is Infrastructure Capital Productive? A Dynamic Heterogeneous Approach." Journal of Applied Econometrics 30:177–98.

Chateau, J., F. Jaumotte, and G. Schwerhoff. 2022a. "Economic and Environmental Benefits from International Cooperation on Climate Policies." IMF Research Department Paper 2022/007, International Monetary Fund, Washington, DC.

Chateau, J., F. Jaumotte, and G. Schwerhoff. 2022b. "Climate Policy Options: A Comparison of Economic Performance." IMF WP/22/242, International Monetary Fund, Washington, DC.

Copeland, B. R., and M. S. Taylor. 1994. North-South trade and the environment. The Quarterly Journal of Economics 109 (3), 755–787.

Fernando, R., W. Liu, and W. J. McKibbin. 2021. "Global Economic Impacts of Climate Shocks, Climate Policy and Changes in Climate Risk Assessment." CEPR Discussion Paper 16154, Centre for Economic Policy Research, London.

Gallagher, K. (ed. 2010). Handbook on Trade and the Environment. Edward Elgar Publishing.

Grossman, G. M., and A. B. Krueger, 1993. Environmental impacts of a North American free trade agreement. In: The Mexico-U.S. Free Trade Agreement. M.I.T. Press.

International Energy Agency (IEA). 2021. Net Zero by 2050. Paris. https://www.iea.org/reports/net-zero-by-2050.

International Monetary Fund (2019). Global Imbalances. https://www.imf.org/external/np/g20/pdf/2019/060519b.pdf.

Jaumotte, F., W. Liu, and W. J. McKibbin. 2021. "Mitigating Climate Change: Growth-friendly Policies to Achieve Net Zero Emissions by 2050." IMF Working Paper 2021/195, International Monetary Fund, Washington, DC.

Jaumotte, Florence, and G. Schwerhoff. 2021. “Reaching Net Zero Emissions.” IMFBlog, International Monetary Fund, July 22. https://blogs.imf.org/2021/07/22/reaching-net-zero-emissions/.

Liu, W., W. J. McKibbin, A. Morris, and P. J. Wilcoxen.. 2020. “Global Economic and Environmental Outcomes of the Paris Agreement.” *Energy Economics* 90:1–17.

McKibbin, W. J., and P. J. Wilcoxen. 1999. “The Theoretical and Empirical Structure of the G-Cubed Model.” *Economic Modelling* 16 (1): 123–48.

McKibbin, W. J., and P. J. Wilcoxen. 2013. “A Global Approach to Energy and the Environment: The G-Cubed Model.” In *Handbook of Computable General Equilibrium Modelling*, edited by Peter B. Dixon and Dale W. Jorgenson. North Holland: Elsevier.

McKibbin, W., M. Konradt, and B. W. di Mauro. 2021. “Climate Policies and Monetary Policies in the Euro Area.” Paper presented at the European Central Bank 2021 Sintra Forum, May 12.

Michael J. (ed. 2022). Handbook on Trade Policy and Climate Change. Mercator Research Institute on Global Commons and Climate Change (MCC) and Ecologic Institute, Berlin, Germany.

Obstfeld, M. and K. Rogoff. 1996. *Foundations of International Macroeconomics*. MIT Press.

Organisation for Economic Co-operation and Development (OECD). 2022. “Delivering Climate Mitigation under Diverse National Policy Approaches.” Paris.

Parry, I., S. Black, and J. Roaf. 2021. “Proposal for an International Carbon Price Floor among Large Emitters.” IMF Staff Climate Note 2021/001, International Monetary Fund, Washington, DC.

Brenton, P., and V. Chemutai. 2021. The trade and climate change nexus: the urgency and opportunities for developing countries. Washington, DC: World Bank.

Van der Mensbrugghe, D. 2019. The environmental impact and sustainability applied general equilibrium (ENVISAGE) model. *The World Bank, January*, 334934-1193838209522.

Van der Mensbrugghe, D., 2020. The Mitigation, Adapation and New Technologies Applied General Equilibrium (MANAGE) Model, Version 2.0. Center for Global Trade Analysis, Purdue University