Environmental Policy Instruments Response to Trade Shocks

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Abstract

We develop a dynamic stochastic general equilibrium model for an open economy and evaluate three environmental policy instruments: cap-and-trade, pollution taxes, and an emissions intensity standard in the face of two types of uncertainty. We evaluate the economic responses to these policies in terms of key macroeconomic variables' volatility under uncertain economic growth and uncertain levels of import competition. Uncertain economic growth is modeled as an exogenous temporary shock to the total factor productivity. Import competition is modeled as an exogenous temporary shock to the terms of trade, motivated as a surge in Chinese imports. Our findings suggest that cap-and-trade policies are most effective in dampening macroeconomic volatility from a productivity shock. However, under the import shock, pollution taxes and intensity targets are as effective as cap-and-trade policies in reducing variance on consumption and employment. The cap-and-trade policy does limit the intensity of the import competition shock suggesting that particular policy instrument might serve as a barrier to trade.

JEL classification: Q54, E32

Key words: Environmental policy, Import competition, Business cycles, Macroeconomic dynamics, Open economy

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1 Introduction

How do environmental policy instruments respond to trade shocks? Emerging studies show that the surge of low-cost exports from China has led to downward pressure on the price of traded goods (Kamin, Marazzi, and Schindler, 2006; Amiti and Freund, 2010; Mandel, 2013). China's entry into the world economy has led to a big movement in the terms of trade and an increase in imports in much of the rest of the world. We ask how such fluctuations in the terms of trade affect the choice of environmental policy instruments. The existing literature that evaluates environmental policy instruments' merits under uncertainty employs a closed-economy framework. This limits their ability to address this question.

In this paper, we analyze the properties of environmental policy instruments under uncertainties for an economy open to international trade and capital flows. We document the economic responses to environmental regulation under uncertain economic growth and unanticipated import surges. To do so, we develop a small open economy (SOE) dynamic stochastic general equilibrium (DSGE) model that incorporates three environmental policy instruments which are certainty equivalent in emissions: cap-and-trade, pollution tax, and an emission intensity standard, which sets an allowed emissions level per unit of output. We introduce exogenous temporary productivity shocks to simulate uncertain economic growth and an exogenous temporary terms-of-trade shock to simulate an unanticipated import surge. We then compare the effects on key macroeconomic variables -welfare, pollution levels, outputs, consumption, investment, supply of labor and trade flows -in the economy across cap-and-trade, pollution tax, and emissions intensity standard policy instruments.

Since Weitzman (1974) seminal article, economists have been weighing the merits of different environmental policy instruments. More recently, environmental policy's ability to respond to the business cycle has been an important metric in evaluating the policy instrument choice. Pizer (2005), Webster, Sue Wing, and Jakobovits (2010) and Ellerman and Wing (2003) compare policies indexing emissions' levels to output (known as intensity targets) to pollution taxes, and to cap-and-trade policies.[1] Fischer and Springborn (2011) and Angelopoulos, Economides, and Philippopoulos (2013) are among the few researchers who compared the performance of emission caps, emission taxes, and indexed standards under real business cycles. Annicchiarico and Dio (2015) compares the performance of these policy instruments under nominal shocks.

The existing literature largely adopts a closed-economy framework to address these concerns. In a world with near perfect capital mobility and large international trade flows, the domestic economy is no longer fully constrained by its resources. With increased globalization the ability of environmental policy instruments to respond to international shocks is increasingly important. Using an open economy model allows us to confirm the robustness of the results in the existing closed economy models. It also allows us to evaluate how these policy instruments respond to import shocks. For example, we can evaluate how an economy would respond to a surge in Chinese imports under each policy instrument.

Our results suggest that cap-and-trade policies reduce the business cycle's intensity relative to a pollution tax or intensity target. This is consistent with the findings of Fischer and Springborn (2011); Annicchiarico and Dio (2015) in closed economy models. Allowing the regulated economy to access global product and investment markets does not affect the key findings of the existing literature. More interestingly for a terms of trade shock all three policy instruments have a similar impact on key economic variables like consumption and employment. The cap-and-trade policy is most effective in reducing the surge in imports. In this way cap-and-trade policies can act as an unintended trade barrier, reducing the severity of import competition during times when it is most intense.[2]

[1]See Peterson (2008) and Hepburn (2006) for reviews of this literature.

[2]Of course, this result is symmetric so a cap-and-trade policy acts as a brake on domestic exports when terms of trade move in the favor of the economy.

There is a long history of literature evaluating the environmental policy's instrument choices that regulators face. Several studies have considered environmental policy instruments in the presence of uncertainty in terms of both benefit and cost when they are correlated (Quirion, 2010; Shrestha, 2001; Stavins, 1996). Antoniou, Hatzipanayotou, and Koundouri (2012); Heuson (2010) and Quirion (2005) have considered the effect of the choice of environmental policies on both uncertain economic growth and uncertain abatement costs. Antoniou, Hatzipanayotou, and Koundouri (2012) considers the instruments under international duopoly in a static model, while Heuson (2010) considers the choice under uncertainty in market power and abatement costs. Quirion (2005) considers the choice of environmental instruments under both uncertain economic growth and abatement cost under autarky. This literature has focused on either economies under autarky or has used a static modeling framework with a focus on strategic interaction among agents; thus, the literature ignores an additional channel of international trade and capital flows that may smooth business cycles' intensity.

There is considerable evidence that environmental regulation can affect international trade flows. For example, Copeland (1994) and Copeland and Taylor (2003) recognize the interaction between international trade and pollution in a small open economy. Ederington, Levinson, and Minier (2005) shows that environmental regulations have a significant impact on trade flows between developed and developing nations, particularly in more mobile industries. McAusland (2008) analyzes environmental regulation's impact on international trade flows while comparing pollution associated with production and consumption. This literature relies on static models and assumes a constant marginal utility of consumption. We relax those assumptions to incorporate environmental regulation's intertemporal effects under uncertainty. The intertemporal effects are important in consumers' investment decisions under uncertainty because regulations like cap-and-trade fix the amount of emissions while inducing uncertain outcomes in the abatement cost. An emissions tax fixes the abatement cost while inducing uncertain outcomes in emissions. These effects are even more important in economies open to international trade and capital because of the additional investment channel. We contribute to this literature by showing that the choice of environmental policy instrument affects the levels of international trade and investment flows.

Most similar to our study are four recent papers examining the robustness of different environmental policy instruments to business cycle shocks. Heutel (2012) evaluates the optimal evolution of dynamic environmental regulation across the business cycle and finds that the optimal carbon taxes and cap-and-trade policies to be pro-cyclical. We employ a static exogenous environmental regulation to evaluate how economies respond to the exogenous environmental regulation rather than evaluating the path for optimal policy that policy makers may not implement during business-cycle peaks and troughs. Fischer and Springborn (2011) evaluates carbon taxes, emissions caps, and emissions intensity standards across the business cycle. The results suggest that emissions caps reduce productivity shocks' intensity relative to an emissions tax while the emissions tax is more volatile. Also, they find that an emission intensity standard has lower volatility than business as usual and is also welfare enhancing. They do not find any significant difference in welfare cost across the emissions cap and carbon tax policies. We expand on this approach by incorporating a labor-leisure choice in a small open-economy model. Most recently, Annicchiarico and Dio (2015) compares a cap-and-trade policy with an emissions tax and an intensity target in a New Keynesian model and shows that cap-and-trade policies dampen the macroeconomic dynamics but that the degree of price rigidity matters in terms of welfare. In a review article, Fischer and Heutel (2013) describes the emerging literature employing real business-cycle models to evaluate environmental policy. These models, however, do not include international trade or capital flows and, therefore, cannot consider the impact of a terms-of-trade shock. We extend these results by comparing exogenous environmental policy instruments across the business cycles for economies open to international trade and capital mobility.

The remainder of this paper is organized as follows. Section 2 outlines the model and functional forms. Section 3 solves the model in the steady state and evaluates the policies in the absence of uncertainty. Section 4 presents the model's numerical analysis and evaluates environmental policy instruments in the face of increased productivity and adverse terms of trade. Section 5 evaluates welfare costs across the environmental policy instruments under the uncertainties. Section 6 concludes this paper.

2 The Model

We consider an economy that has a continuum of households with identical preferences. The infinitely lived households consume domestically produced and imported goods and enjoy leisure activities to maximize expected life-time utility. Households supply labor and capital to firms, which produce goods using two factor inputs: labor and capital. Pollution is generated during the production of goods, and in our model pollution is treated as an input. Pollution is assumed to be generated in proportion to fossil-fuel use in the production process. Alternatively, a fixed amount of pollution per unit of fossil fuel is implicit in our model.

The economy under consideration is open to free trade and capital is allowed to flow internationally; however, labor is immobile. The domestic government's role is limited to implementing an environmental policy and redistributing revenues, if any, to households in a lump-sum. Therefore, in this economy, outputs are either domestically consumed, invested, or exported. If domestic absorption exceeds production, the economy imports from the rest of the world, meaning that households can satisfy both their consumption and investment needs by raising foreign debt. This point is the key point of departure from models in the literature.[3] Further, we assume that our econ-

[3] See Fischer and Springborn (2011); Angelopoulos, Economides, and Philippopoulos (2013) and

omy is small compared to the rest of the world's, meaning the domestic environmental policy change will not affect capital's international interest rate and is exogenous to this economy. The firms are price takers, and they make export and import decisions given the world's fixed prices.

Households' problem

With imperfect capital mobility, households can borrow internationally but face an upward-sloping supply schedule of borrowing because of a country-specific risk premium that increases with the level of debt (see Schmitt-Grohé and Uribe (2003); Mendoza and Uribe (2000); Schmitt-Grohé and Uribe (2001)). Under the debt-elastic interest rate, the domestic interest rate is a function of an exogenous international interest rate and a premium

$$R_t = R^* + P(exp^{\widetilde{D_t} - \overline{D}} - 1) \tag{1}$$

where R^* is the exogenous interest rate in international capital markets, $P(.)$ is the economy's risk premium, $\widetilde{D_t}$ is the economy's aggregate debt, and $\overline{D}$ is the steady-state debt level. Borrowing costs increase with the stock of debt issued ($P' > 0$). In a representative economy, $\widetilde{D_t} = D_t$, a representative household's debt level.

The representative household maximizes her expected lifetime utility in present value

$$\max_{C_t, H_t} \quad E_0 \sum_{t=0}^{\infty} \beta^t \, U(C_t, H_t) \tag{2}$$

where $\beta \in (0, 1)$ is the fixed subjective discount factor, C_t is consumption, and H_t represents the amount of labor the household supplies. We assume that the representative household is endowed with one unit of time, and we abstract from population growth. Thus, $1 - H_t$ represents leisure activities. The utility's functional form satisfies: $U_C > 0$, $U_H < 0$, $U_{CC} < 0$, $U_{HH} < 0$ and $U_{CH} > 0$.

Annicchiarico and Dio (2015). Note that these studies assume a closed economy and require that domestic absorption be equal to domestic production each period.

The household is subject to the following budget constraints:

$$D_t = (1 + R_{t-1})D_{t-1} + p_t C_t + I_t + \Phi(K_t - K_{t-1}) - w_t H_t - r_t K_{t-1} - G_t - \Pi_t \quad (3)$$

where D_t is the household's stock of foreign debt, p_t is the relative price of consumption, K_t is the stock of capital, I_t is investment, $\Phi(.)$ is investment-related adjustment cost (with $\Phi(0) = 0$, $\Phi'(0) = 0$), w_t is the wage-per-unit of labor supplied to firms, r_t is the rental rate per unit of capital supplied to firm, G_t is a lump-sum transfer from government(if any), and Π_t represents a dividend from firms. We consider the debt to be denominated in terms of the world's export price of outputs. In our model, all prices are relative to the world's price of outputs.

Capital stock evolves as

$$K_t = I_t + (1 - \delta)K_{t-1} \quad (4)$$

where δ is the depreciation rate.

The representative household chooses processes $[C_t, H_t, K_t, D_t]_{t=0}^{\infty}$ to maximize her life-time expected utility Eq.(2) subject to the budget constraint Eq.(3), a no-ponzi constraint, $\lim_{j\to\infty} E_t \left(\frac{D_{t+j}}{\prod_{s=1}^{j}(1 + R_s)} \right) \leq 0$ and initial stocks of capital and a debt. With λ_{1_t} being the Lagrangian multiplier for the budget constraint, the representative household's maximization problem can be represented by the following Lagrangian:

$$\max_{C_t, H_t, K_t, D_t} \mathscr{L} = E_t \sum_{t=0}^{\infty} \beta^t \Big[U(C_t, H_t) + \lambda_{1_t} \Big\{ D_t - (1 + R_{t-1})D_{t-1} - p_t C_t - K_t + (1 - \delta)K_{t-1} - \Phi(K_t - K_{t-1}) + w_t H_t + r_t K_{t-1} + G_t + \Pi_t \Big\} \Big] \quad (5)$$

The optimality conditions are

$$C_t : U_{C_t}(C_t, H_t) = \lambda_{1_t} p_t \quad (6)$$

$$H_t : -U_{H_t}(C_t, H_t) = \lambda_{1_t} w_t \tag{7}$$

$$K_t : \lambda_{1_t}\left[1 + \Phi'(K_t - K_{t-1})\right] = \beta\, E_t \left[\lambda_{1_{t+1}} \left\{(1 - \delta + r_{t+1} + \Phi'(K_{t+1} - K_t)\right\}\right] \tag{8}$$

$$D_t : \lambda_{1_t} = \beta\, E_t\, \lambda_{1_{t+1}}\, (1 + R_t) \tag{9}$$

These are standard Euler equations. Eq. (6) shows that households' optimal consumption level occurs when marginal utility from consumption is equal to the marginal utility from wealth. In Eq. (7), we see that households optimally supply labor when marginal utility from leisure is equal to the wage per unit of labor supplied. Eq. (8) shows that households optimally invest one unit of capital when marginal cost of the investment (in terms of utils) is equal to the expected present value of marginal benefit of the investment next period. The investment's marginal cost is shown in the LHS of Eq. (8), and the expected present value of marginal benefit of the investment next period is shown in the equation's RHS. Likewise, Eq. (9) shows the cost and benefit of borrowing a unit of debt. The LHS of Eq. (9) is the utility the agent receives from one unit of borrowing while the RHS is the expected present value of the debt's repayment cost(in utils).

Firms' problem

We model the representative firm's problem as follows; The representative firm maximizes profit

$$\max_{K_t, M_t, H_t} E_t \sum_{t=0}^{\infty} \beta^t \Pi_t = E_t \sum_{t=0}^{\infty} \beta^t \left[Y_t(A_t, K_{t-1}, M_t, H_t) - w_t H_t - r_t K_{t-1} - q_t M_t\right] \tag{10}$$

where $Y_t = A_t K_{t-1}^{\alpha_1} M_t^{\alpha_2} H_t^{1-\alpha_1-\alpha_2}$, A_t is the total factor productivity (exogenous), M_t is the fossil fuel level (or pollution level proportional to the fossil fuel level), and q_t is the price of fossil fuel.[4] Note that q_t also represents per-unit emission tax since

[4]Fischer and Springborn (2011) also used a similar Cobb-Douglas form of production.

M_t represents pollution level. The capital share in output is α_1, and the fossil-fuel expenditure's share in output is α_2; thus, $1-\alpha_1-\alpha_2$ is the share of labor in production. The factor shares, α_1 and α_2, are bounded by $(0, 1)$. We assume that the economy has an abundant supply of fossil fuels and that the fossil fuel expenditure $q_t M_t$ remains within the economy as $q_t M_t$ is treated as the emissions tax revenue transferred to the households in a lump sum.[5] Note that output is the numeraire good; thus, the prices are relative to the output's export price.

In the absence of environmental regulation (i.e., under business as usual), Eq. (10) represents the firms' problem. Following Fischer and Springborn (2011), we abstract pollution from the households' welfare function since we intend to capture only the environmental regulation's welfare cost. This welfare cost is measured through the reduced consumption of households keeping fixed labor, which is a standard procedure in the DSGE framework. To address the externalities associated with pollution emissions, we assume the government imposes an environmental policy $CAP(Y_t)$, which could be a cap-and-trade, an emissions tax, or an emission intensity target. These policies are cost-less to administer, and firms comply with the environmental policies. Under cap-and-trade, firms are required to possess a permit to emit a unit of pollution in each period and pay a permit price (the constraint's shadow value in the case of cap-and-trade). In this case, $CAP_t = M_t$, which is exogenously fixed. Under an emissions-tax policy, firms are required to pay a tax for each unit of emissions generated. In the case of an emission intensity target, the policy exogenously fixes a ratio of M_t to Y_t. Note that these policies are exogenously chosen to reduce emissions and could be sub-optimal.[6]

[5]In the model, firms perfectly comply with environmental regulations. Since fossil fuel expenditure is observable and is accurately measured, the treatment of fossil fuel expenditure is justifiable.

[6]Heutel (2012) assumes efficient environmental policy and analyzes how that optimal policy should evolve across the business cycle. We focus on static policies, which are certainty equivalent in emission reductions, and compare the responses of static policies across the real business cycle and terms of trade shocks.

We assume that the environmental policy is binding on firms

$$CAP(Y_t) = M_t \tag{11}$$

and the Lagrangian of the representative firm's problem is

$$\max_{H_t, K_t, M_t} \mathscr{L} = E_t \sum_{t=0}^{\infty} \beta^t \left[Y_t(A_t, K_{t-1}, M_t, H_t) - w_t H_t - r_t K_{t-1} - q_t M_t + \lambda_{2_t} \Big(CAP(Y_t) - M_t \Big) \right] \tag{12}$$

where λ_{2_t} is the policy constraint's shadow price.

The first order conditions are

$$H_t : Y_{H_t}(A_t, K_{t-1}, M_t, H_t)(1 + \lambda_{2_t} Cap_{Y_t}) = w_t \tag{13}$$

$$K_t : Y_{K_t}(A_{t+1}, K_t, M_{t+1}, H_{t+1})(1 + \lambda_{2_{t+1}} Cap_{Y_{t+1}}) = r_{t+1} \tag{14}$$

$$M_t : Y_{M_t}(A_t, K_{t-1}, M_t, H_t)(1 + \lambda_{2_t} Cap_{Y_t}) = q_t + \lambda_{2_t} \tag{15}$$

These are standard Euler equations for the firm's problem. Firms choose factor inputs: labor (Eq. (13)), capital (Eq. (14)), and fossil fuels (Eq.(15)) based on their marginal factor returns.

Our economy responds to two exogenous shocks: home productivity and terms of trade. The economy may face a sudden improvement in technology, leading to a boom in the economy. We model such economic growth through a temporary positive shock to the total factor productivity. On the other hand, the economy may face a deterioration in terms of trade because of import competition from sudden surge-of-trade flows from countries like China. We model such terms of trade shock through an exogenous positive temporary shock to consumption's relative price. These two shocks follow stationary autoregressive processes as below:

$$\log A_t = \rho_A \log A_{t-1} + \epsilon_{A_t} \tag{16}$$

$$\log p_t = \rho_p \log p_{t-1} + \epsilon_{p_t} \tag{17}$$

where, ρ_A and ρ_p are persistency of the shocks and are bounded by 0 and 1. The parameters ϵ_{A_t} and ϵ_{p_t} are serially uncorrelated shocks normally distributed with mean zero and standard deviations σ_A and σ_p, respectively.

The following market-clearing conditions are satisfied. The representative firm's zero profit condition is

$$Y_t(A_t, K_{t-1}, M_t, H_t) = w_t H_t + r_t K_{t-1} + q_t M_t \tag{18}$$

and the resource constraint in an open economy is

$$D_t = (1 + R_{t-1})D_{t-1} - Y_t + p_t C_t + I_t + \Phi(K_t - K_{t-1}) \tag{19}$$

Note that, $q_t M_t$ is eliminated from the resource constraint because of our assumption that the economy has an abundant supply of fossil fuels and that firms' expenditure on fossil fuels in the form of pollution tariff revenue is returned to the households in a lump sum.

The trade balance is defined as domestic production minus domestic absorption.

$$tb_t = Y(A_t, K_{t-1}, M_t, H_t) - p_t C_t - I_t - \Phi(K_t - K_{t-1}) \tag{20}$$

The economy's net asset position captures the capital flow, and the current account is the net of the trade balance and the serviced debt amount.

$$ca_t = tb_t - R_{t-1} * D_{t-1} \tag{21}$$

Note that the government balances the budget each period, and G_t is the transfer from the government. Then, the import tariff revenue or any government collection from environmental policy are eliminated from the resource constraint since these components are returned to the representative household in a lump sum.

2.1 Functional Forms

We employ a Cobb-Douglas utility function with an intertemporal elasticity of substitution across periods as is standard in the literature

$$U(C_t, H_t) = \frac{[C_t^{\alpha}(1 - H_t)^{1-\alpha}]^{1-\sigma} - 1}{1 - \sigma} \tag{22}$$

where, α is the share of income that households spend on consumption, and σ is the intertemporal elasticity of substitution across periods (also known as the relative risk-aversion parameter).

Production has a Cobb-Douglas function with the constant returns to scale $Y_t = A_t\ K_{t-1}^{\alpha_1}\ M_t^{\alpha_2}\ H_t^{1-\alpha_1-\alpha_2}$. The adjustment cost of investment has a quadratic function $\Phi(K_t - K_{t-1}) = \frac{\phi}{2}(K_t - K_{t-1})^2$ where, $\phi(> 0)$ is an adjustment cost shift parameter.

3 Steady State Analysis

This section solves for the economy's response to the introduction of each of the selected policies in the absence of shocks. In the steady state, there is no uncertainty in the economy, and the system is in long-run equilibrium; therefore, we abstract by using time subscripts. Incorporating the functional forms and the household's and firm's problems, the steady state is represented by the following ratios

$$z: \frac{H}{1-H} = \frac{\alpha}{1-\alpha}(1-\alpha_1-\alpha_2)\,\frac{(1+\lambda_2 CAP_Y)}{p\,c} \tag{23}$$

$$k: \frac{K}{Y} = \frac{\alpha_1\,(1+\lambda_2 CAP_Y)}{R^*+\delta} \tag{24}$$

$$m: \frac{M}{Y} = \frac{\alpha_2(1+\lambda_2 CAP_Y)}{q+\lambda_2} \tag{25}$$

$$c: \frac{C}{Y} = \frac{1}{p}\left(1-\delta k - R^*\bar{d}\right) \tag{26}$$

where, z is the labor-leisure ratio, and k, m and c are the capital-to-output, emission-to-output, and consumption-to-output ratios, respectively. $\bar{d}$ is the long-run debt such that the debt-to-output ratio is equal to the long-run ratio of the small economy under consideration.

No policy

In the environmental policy's absence, $\lambda_2 = 0$ yielding the capital-to-output ratio $k = \frac{\alpha_1}{R^*+\delta}$, emission-to-output ratio $m = \frac{\alpha_2}{q}$, and the consumption-to-output ratio $c = \left(1 - \frac{\delta\alpha_1}{R^*+\delta} - R^*\bar{d}\right)\frac{1}{p}$. We note that the ratio c is smaller compared to that in a closed economy because of the debt-servicing requirement in an open economy. We find the labor-leisure ratio $z = \frac{\alpha}{1-\alpha}\frac{(1-\alpha_1-\alpha_2)}{\left(1-\frac{\delta\alpha_1}{R^*+\delta}-R^*\bar{d}\right)}$ under no policy. Increases in the debt-to-output ratio are associated with increased employment in this economy compared to the closed economy since more output is needed to service the debt.

Cap and Trade

Under a cap-and-trade system, the government imposes a fixed cap on emissions to regulate pollution. In this policy, the emission is bounded by exogenous level of $\bar{M} = CAP$ and $CAP_Y = 0$. This provides emission-to-output ratio $m = \frac{\alpha_2}{q+\lambda_2}$, capital-output ratio $k = \frac{\alpha_1}{R^*+\delta}$, and consumption-to-output ratio of $c = \left(1 - \frac{\delta\alpha_1}{R^*+\delta} - R^*\bar{d}\right)\left(\frac{1}{p}\right)$. We find the labor-leisure ratio $z = \frac{\alpha}{1-\alpha}\frac{(1-\alpha_1-\alpha_2)}{\left(1-\frac{\delta\alpha_1}{R^*+\delta}-R^*\bar{d}\right)}$. Under this policy, the effective shadow price $\lambda_2 = \frac{\alpha_2 - q\, m}{m}$ restricts the emissions level to $\bar{M}$.

Tax

In the case of an environmental tax policy, the government imposes a constant pollution tax (T) charged for each unit of pollution. In our model, the effective shadow price λ_2 is the corresponding emissions tax rate that reduces emissions to CAP (i.e. $\lambda_2 = T$). The tax rate restricts the emissions level in the steady state equivalent to that under the cap-and-trade policy. In such a case, tax revenue is distributed to households in a lump sum transfer and $CAP_y = 0$. We find the emission-to-output ratio $m = \frac{\alpha_2}{q+T}$, capital-to-output ratio $k = \frac{\alpha_1}{R^*+\delta}$, and consumption-to-output ratio of $c = \left(1 - \frac{\delta\alpha_1}{R^*+\delta} - R^*\bar{d}\right)\left(\frac{1}{p}\right)$. We find the labor-leisure ratio $z = \frac{\alpha}{1-\alpha}\frac{(1-\alpha_1-\alpha_2)}{\left(1-\frac{\delta\alpha_1}{R^*+\delta}-R^*\bar{d}\right)}$. These ratios are similar to that under the cap-and-trade policy. The tax rate required to restrict the emission under this policy is $T = \frac{\alpha_2 - q\, m}{m}$.

Intensity Target

For an intensity target, the government requires a maximum fixed ratio of emissions-per-unit output $\bar{m} = \frac{M}{Y}$. Then, the intensity target policy can be represented by $CAP(Y) = \bar{M} = \bar{m}\ Y$ where $\bar{M}$ is the emission level restricted under the cap-and-trade policy. Since $CAP_Y = \bar{m}$ and emission-to-output ratio $m = \bar{m}$, we find the capital-to-output ratio $k = \frac{\alpha_1(1+\lambda_2\bar{m})}{R^*+\delta}$. The consumption-to-output ratio $c = \frac{1}{p}\left(1 - \frac{\delta\alpha_1(1+\lambda_2\bar{m})}{R^*+\delta} - R^*\bar{d}\right)$. The labor-leisure ratio $z = \frac{\alpha}{1-\alpha}\frac{(1-\alpha_1-\alpha_2)(1+\lambda_2\bar{m})}{\left(1-\frac{\delta\alpha_1(1+\lambda_2\bar{m})}{R^*+\delta}-R^*\bar{d}\right)}$. Under this policy, the effective shadow price $\lambda_2 = \frac{\alpha_2 - q\bar{m}}{\bar{m}(1-\alpha_2)}$ restricts emissions to the same level under the cap-and-trade policy. The shadow price is bigger than that under the cap-and-trade policy, meaning the emission-to-output ratio under the intensity target that restricts the emissions level equivalent to the cap-and-trade policy is smaller, yielding outputs under this policy higher than those under the cap-and-trade policy.

4 Numerical Analysis

4.1 Data Aggregation and Model Calibration

In this section, we summarize the long-run empirical relationships used to identify our model's deep structural parameters. The long-run relationship corresponds to Canada's historical annual expenditure-based GDP for 1981-2010. This information is available from Statistics Canada.[7] The model is further parameterized such that the calibrated economy's structure simulates the Canadian economy's business cycles.[8] To be consistent with our model specification, GDP is calculated by netting out government expenditure. Households' consumption includes goods and services, investment includes gross fixed-capital formation, and net export of goods and services accounts for trade flows. For the terms of trade, we use the export and import prices in the Penn World Table, which is available for 1950-2010.[9].

The deep structural parameter values used in the steady state to represent Canada's historical economy are shown in Table 1, and the key macroeconomic ratios in the steady state are shown in Table 2. During the period considered, households' consumption of goods and services accounts for 68% of GDP, investment accounts for 26%, and the net export of goods and services accounts for the remaining GDP (6%). The average compensation to employees is 45% of gross outputs during the period.[10] We set 0.45 as the labor share in outputs. For the share of fossil fuel expenditures, we follow Fischer and Springborn (2011) and estimate the share as 9% of GDP.[11] We set the share of capital $\alpha_1 = 0.46$ and the share of fossil fuel expenditure $\alpha_2 = 0.09$. The

[7]Source: Statistics Canada. Table 380-0106 - Gross domestic product.

[8]The second moments in our model are consistent with the literature.

[9]For more details, see PWT 8.1 in Feenstra, Inklaar, and Timmer (2015)

[10]Calculated over our sample period. Source: Statistics Canada. Table 383-0032 - Multifactor productivity, gross output, value-added, capital, labor and intermediate inputs at a detailed industry level by the North American Industry Classification System (NAICS).

[11]We also find that the share of abatement cost expenditure in manufacturing outputs is 7.5% in Canada as reported in surveys conducted during 1996-2010. However, these estimates are not reported regularly (Source: Canadian Statistics).

exogenous international interest rate is fixed at 4% per annum; the annual depreciation rate of capital is fixed at 10%; the intertemporal elasticity of substitution across periods is fixed at 2. These amounts are standard in the literature. The persistency parameters and the standard deviation correspond to data from the Penn World Table.[12] We estimate uni-variate AR(1) processes for the total factor productivity and the relative price of imports-to-exports to set the persistency of total factor productivity and the terms of trade, which are 0.533 and 0.319, respectively. The corresponding standard deviations of the shocks are 0.0149 and 0.0296, respectively. Since our sample period captures recent years, the estimates for the total factor productivity shock are a slightly higher than those in the literature (Uribe, 2013).

The parameters' values $\bar{d}$, α, ψ and ϕ are chosen to mimic the dynamic performance of the Canadian economy's business cycles as found in the literature. We set $\bar{d} = 0.909$ such that the long-run trade balance to GDP ratio in our model is 0.0638 to match the historical average trade flow share of goods and services to the GDP in the sample period. The share of income that households spend on consumption is calibrated as 33% ($\alpha = 0.33$) such that households' labor supply in the steady state is 27%. The country-specific risk premium is set at $\psi = 0.0742$ to match the dynamic performance of trade balance and current account as shown in the literature. We choose a hp-filter of smoothing parameter 100 to filter the trend in our calibrated model. Table 3 provides the calibrated model's theoretical second moments.

The relative prices of consumption and fossil fuels in terms of the output's world price are set at 1 in the steady state. The total factor productivity is also set at 1 in the steady state. These normalizations let us evaluate the model's responses to shocks as cyclical responses rather than as a trend.

Table 1: Parameters in the Model

Parameter	Description	Value
	Deep structural parameters	
R^*	Exogenous international interest rate	0.04
α_1	Capital share in output	0.46
α_2	Energy expenditure share in output	0.09
$1-\alpha_1-\alpha_2$	Labor share in output	0.45
$\bar{h}$	Household's endowment of labor	1
δ	Annual depreciation rate	0.1
ρ_A	Autocorrelation of total factor productivity shock	0.533
ρ_p	Autocorrelation of terms of trade shock	0.319
σ_A	Standard deviation of the productivity shock	0.0149
σ_p	Standard deviation of the terms of trade shock	0.0296
$\frac{\bar{tb}}{\bar{Y}}$	Trade balance-to-output ratio	0.0644
	Calibrated parameters	
σ	Intertemporal elasticity of substitution (risk parameter)	2
ϕ	Shift parameter in capital adjustment cost	0.008
ψ	Country specific risk-premium	0.0742
α	Share of consumption expenditure on households' income	0.33
$\bar{d}$	Long-term debt level	0.909

Table 2: Empirical and Steady State Performance of the Model

Description	Canadian Data (1981-2010)	Model
Trade balance-to-GDP ratio	6.44%	6.38%
Consumption-to-GDP ratio	67.68%	64.70%
Debt-to-GDP ratio	160.90%	159.49%

Table 3: Theoretical Second Moments of the Model

	Standard deviation	Auto-correlation	Correlation with GDP
GDP	2.20	0.47	1
Consumption	0.71	0.54	0.91
Capital	1.01	0.43	0.97
Labor supply	1.15	0.49	0.98
Trade-balance/GDP		-0.20	-0.18
Current account/GDP		-0.18	-0.19

Note: The theoretical second moments are for one standard deviation shock to total factor productivity. Standard deviations are measured in percentage points from the theoretical mean.

4.2 Deterministic Responses to Environmental Policies

The economic responses in a deterministic case is shown in Table 4. In the absence of uncertainty, no difference exists between the cap-and-trade and tax policies; but

[12]See the appendix for details.

Table 4: Steady-State Levels Across Policies

Variables	Policy Cases				% Change from No Policy		
	No policy	Cap-and-Trade	Tax	Intensity Target	Cap-and-Trade	Tax	Intensity Target
Output	0.570	0.550	0.550	0.568	-3.4%	-3.4%	-0.2%
Consumption	0.346	0.333	0.333	0.341	-3.8%	-3.8%	-1.3%
Investment	0.188	0.181	0.181	0.191	-3.4%	-3.4%	1.7%
Labor supply	0.272	0.272	0.272	0.278	0.0%	0.0%	2.2%
Capital Stock	1.876	1.811	1.811	1.908	-3.4%	-3.4%	1.7%
Emissions	0.051	0.041	0.041	0.041	-20%	-20%	-20%

the intensity target produces higher levels of consumption, labor supply, outputs, investment, and capital stocks than the cap-and-trade or tax policies. These findings are consistent with our analytical results. GDP decreases by 3.4% under the cap-and-trade and tax cases while it decreases by 0.2% under the intensity target. Consumption falls by 3.8% from no policy under the cap-and-trade or tax cases, but the fall is 1.3% under the intensity target. Investment decreases by 3.4% under the cap-and-trade and tax cases while investment increases by 1.7% under the intensity target case. Under the cap-and-trade and tax cases, the labor supply remains similar to the no-policy case, but the supply of labor increases by 2.2% under the intensity target. This means, to maintain the same emissions level from the cap-and-trade case under the intensity target, firms substitute emissions with labor and capital which are clean inputs. Furthermore, the required ratio under the intensity target to maintain the same level of emissions, as explained in the analytical analysis, is stricter than under the cap-and-trade. As a result, the labor supply and investment are higher than the no-policy baseline, but the increment in inputs is not that much higher than in the no-policy case to affect the outputs in order to increase. Also, the permit price under the intensity target case must increase by 27.4% compared to the cap-and-trade case.

4.3 Uncertainty and Environmental Policy

This section evaluates the dynamic properties of the emissions tax, cap-and-trade, and intensity target in the presence of uncertainties. We simulate the uncertain economic growth by employing an exogenous temporary stochastic shock to the total factor productivity and separately, a shock to the terms of trade through an exogenous temporary positive stochastic shock to the world's relative price of imports to exports, meaning an adverse terms of trade shock. We compute the first and second moments of the key macroeconomic variables and trace their impulse response functions. The simulation results are computed using the "pure" perturbation method, which relies on a second-order Taylor approximation of the model around its initial steady state.[13]

In the model, the cap-and-trade policy is employed by setting the emissions level at 0.041 emissions level which represents the 20% reduction in emissions level from the no policy case. The emissions tax is set at 0.207 per emissions unit which represents the emissions cap's shadow price set in the cap-and-trade policy. An emission-to-output ratio 0.722 is set in the intensity target policy such that the policy yields 0.041 emissions level in the steady state. Note that the three policies are certainty equivalent in emissions level meaning in the steady state the policies yield the 20% reduction of emissions from the no policy case.

4.3.1 Productivity Shock

In this section, we describe the economy's responses under uncertain economic growth as the result of one period of unanticipated temporary productivity shock with a magnitude of one standard deviation. First, we solve the model for the no-policy case, a baseline scenario with no additional environmental regulations. Then as in Fischer and Springborn (2011), we model a 20% emission reduction from the steady-state level of emissions from the no-policy case.[14] Therefore, we model an emissions cap at 20% below the baseline emissions level and then introduce emission taxes and intensity

[13]The model is solved in Dynare. See Adjemian, Bastani, Juillard, Mihoubi, Perendia, Ratto, and Villemot (2011) for more details.

[14]The European Union has a target reducing emissions 20% from 1990 levels by 2020, and both the Waxman-Markey and Kerry-Lieberman bills proposed in the U.S. Congress targeted a 20% emissions reduction.

targets such that the amount of emission reductions is the same across each of the environmental policies in the steady state.

Figure 1 and 2 plot the impulse response functions of several variables on interest to a total factor productivity shock of 1 standard deviation in period 0 under the four different policies: i) no policy, ii) cap-and-trade, iii) emission tax, and iv) intensity target. The model is simulated for 10,000 periods, and the first 100 periods are discarded. We use the Hodrick-Prescott filter (with a smoothing parameter of 100) before recording the statistical moments, and the responses are plotted in terms of deviation from the steady-state level of each variable. The model predicts an increase in outputs, consumption, labor, investment, debt and interest rate as well as a deterioration of the trade-balance. The consumption's initial response is relatively smaller by an order of magnitude of two than the initial investment response. As the domestic absorption (consumption and investment) is higher than the domestic production, the trade balance's initial response is negative, leading to a rise in debt and, thus, the risk premium on interest rate. As a result, the effective interest rate increases, affecting households' consumption smoothing behavior over time. This effect means that although consumption is dominated by the positive income effect compared to the negative price effect, households save most of their increased income, showing the price effect's significant influence on consumption.

Under the cap-and-trade policy, which fixes emissions level, outputs are dampened. As a result, households save relatively less to smooth consumption compared to the no-policy case. The effective interest rate increases relatively less than in the no-policy case, leading to dampened consumption over time. However, under the emissions tax policy, which fixes the emissions' price allow emissions to rise leading to relatively higher outputs than the cap-and-trade policy. As a result, households save relatively more under the emissions tax policy to smooth consumption but not as much as in the no-policy case. The effective interest rate's increase under the emissions tax is relatively higher than under the cap-and-trade policy but not higher than in the no-policy case. This leads to dampened consumption but relatively less dampened than with the cap-and-trade policy. Under the intensity target, a stricter level of emissions-to-output ratio is required to maintain the same emissions level under the cap-and-trade, leading to a relatively bigger rise in outputs and thus savings, which dampen consumption over time but less than in the no-policy case.

The literature discusses variations in economic variables across the business cycle to evaluate environmental policies. We follow this precedent by calculating the coefficient of variation (CV) across the business cycle for each environmental policy and for the no-policy baseline. The results are reported in Table 5. Each CV provides a measure of the corresponding variable's dispersion as a percentage of its theoretical mean. We find that the cap-and-trade policy consistently has the lowest CV for the economic variables. For emissions, this finding is obvious; after the positive productivity shock, the emissions level remains unchanged at 20% below the baseline case, so there is no variation. This inflexible emissions cap reduces the positive productivity shock's benefits so that output, consumption, investment, labor, capital, debt, and trade flows all increase less under a cap-and-trade policy than under the other policy instruments. Thus, the cap-and-trade policy reduces the real business cycle's severity, a finding which is consistent with the results in Fischer and Springborn (2011).[15] Under the tax policy, the variations of consumption, labor, and output are similar from those of the no policy, except that investment is higher in the tax case. Under the intensity target, variations are not very different than in the no-policy case.

We also check the results' robustness by employing the higher magnitude and higher persistency shock, which helps to magnify the differences in responses across the policies. The results for the shock of 1.5 standard deviation with a 90% persistency level

[15]The model is symmetric so a negative productivity shock modeling the business cycle's trough would give the same results. Reduced economic activity would reduce both the cap's shadow price and the shock's negative impact, once again dampening the business cycle.

are shown in the appendix (Table A2 and in Figures A1 and A2). We find similar results. The cap-and-trade policy dampens the shock's intensity, and the emissions tax policy has higher variation, whereas the intensity target policy has variation similar to that of the no-policy case.

Table 5: Variations Under the Productivity Shock

Variables	No policy	Cap	Tax	Intensity Target
Consumption	0.71	0.61	0.71	0.71
Labor	1.15	1.01	1.15	1.14
Investment	10.29	8.86	10.48	10.13
Output	2.20	1.92	2.21	2.19
Emission	2.20	0.00	2.21	2.19

Note: The table shows the coefficient of variations for 1 standard deviation positive temporary shock to the total factor productivity. The coefficient of variation is the standard deviation divided by the theoretical mean level (in percentage points).

4.3.2 Terms of Trade Shock

In this section, we describe the economy's dynamic responses to the negative terms of trade shock as a result of import competition. We consider this case to try to capture how environmental policies would react in response to a surge in imports similar to Chinese entry into the world economy. We model the terms of trade shock as a one standard deviation unanticipated positive shock to the relative price of consumption. As under the productivity shock, the model is solved for the no-policy case and for the three environmental policies that reduce 20% emission from the no-policy case's emissions level in the steady state. As before, the model is simulated for 10,000 periods, the first 100 periods are discarded, and the Hodrick-Prescott filter (with a smoothing parameter of 100) is employed.

Figure 3 and 4 plot impulse response functions for select macroeconomic variables and emissions levels across the four environmental policies: i) no policy, ii) cap-and-

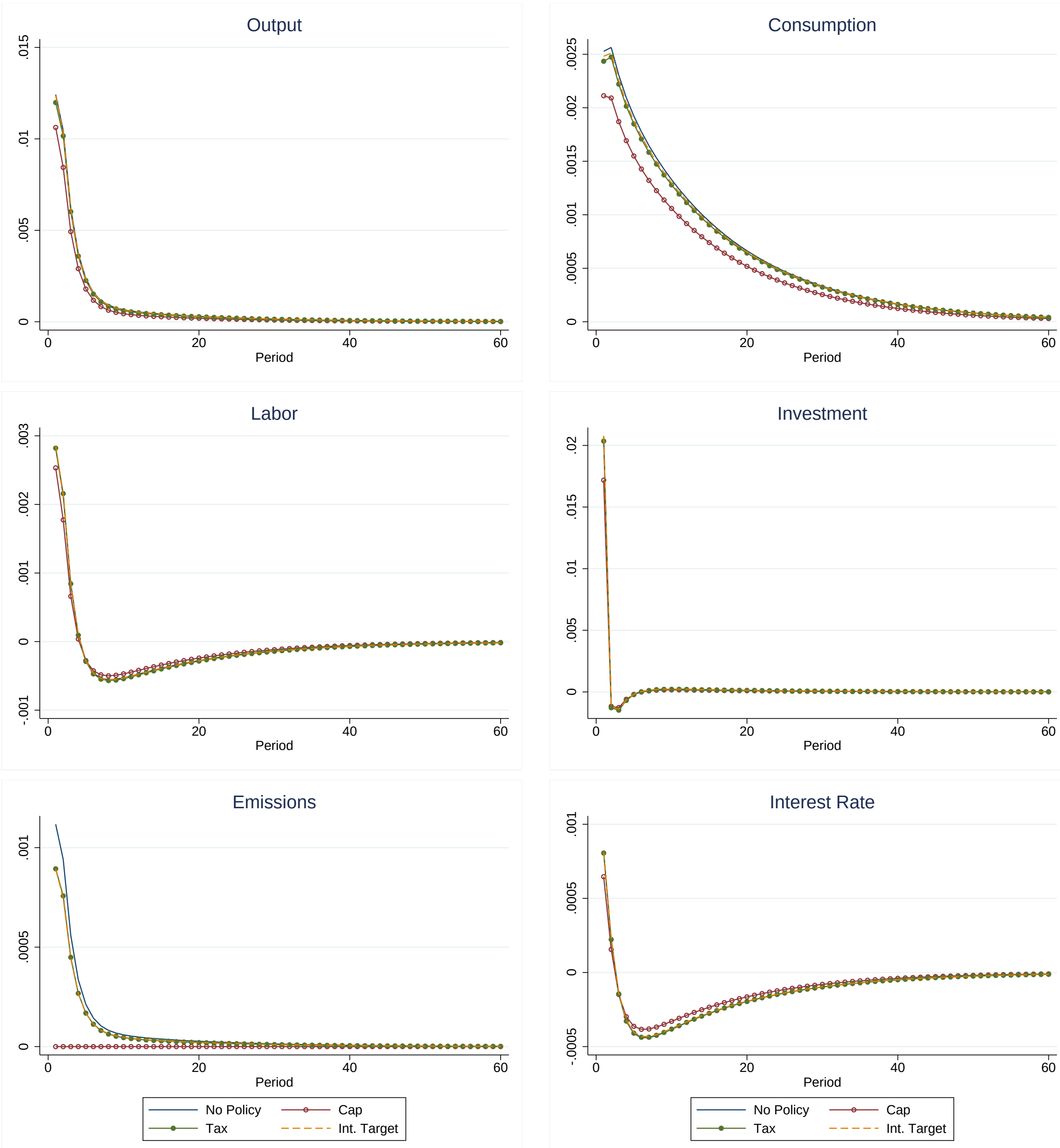

Figure 1: Impulse Responses Under the Productivity Shock (Panel A)

Note: The figures show the impulse response functions of output, consumption, labor, capital, emissions, debt, current account, and trade balance in response to the positive productivity shock of one standard deviation as shown on the bottom-right corner panel of Figure 2. Zero on the vertical axis on each graph represents corresponding variable's steady-state level. The responses are in terms of deviation from the steady-state level.

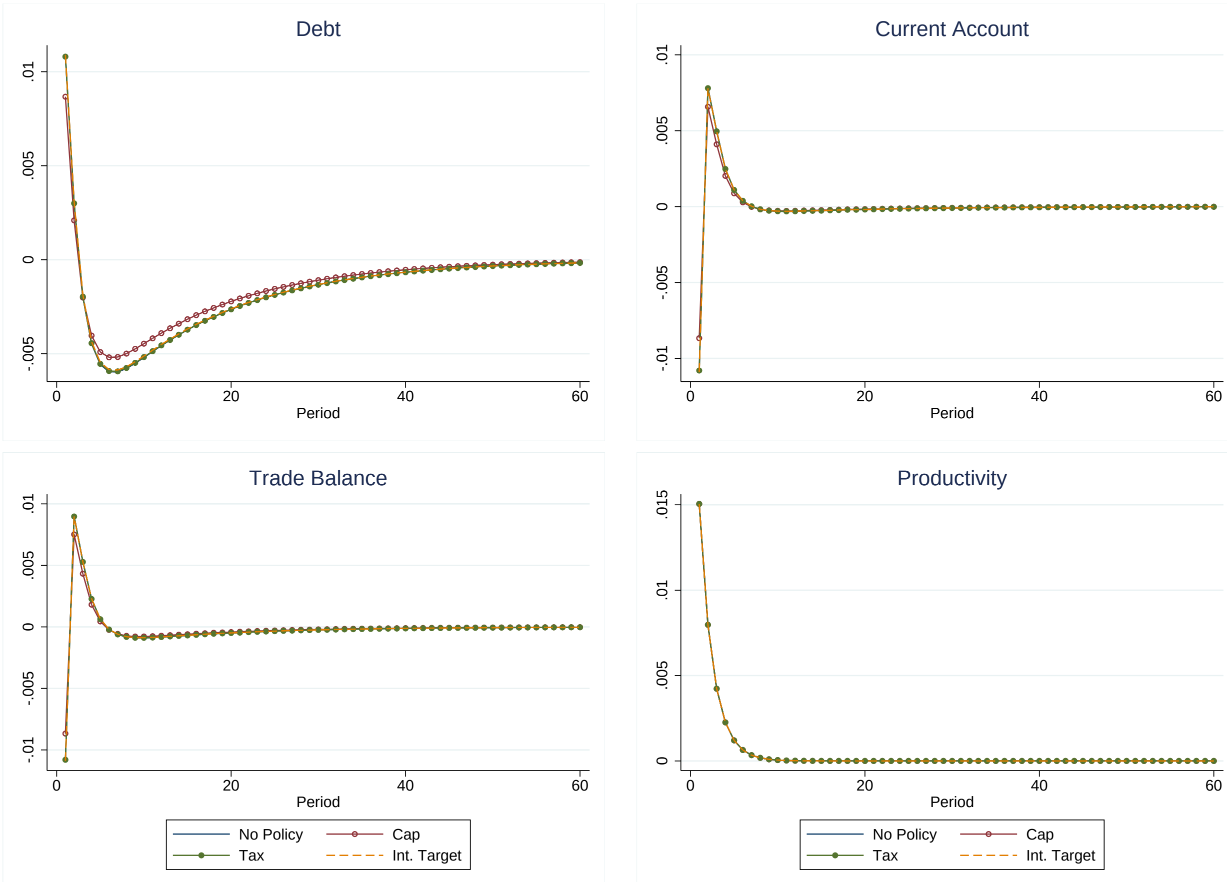

Figure 2: Impulse Responses Under the Productivity Shock (Panel B)

Note: Note: The figures show the impulse response functions of output, consumption, labor, capital, emissions, debt, current account and trade balance in response to the positive productivity shock of one standard deviation as shown on the bottom right corner panel. Zero on the vertical axis on each graph represents corresponding variable's the steady state level. The responses are in terms of deviation from the steady state level.

trade, iii) emission tax, and iv) intensity target. We begin by analyzing the impacts of the import shock relative to the productivity shock presented above. The negative terms of trade shock which produces the import surge, as expected, generates the opposite path from the positive productivity shock. The model predicts a decline in consumption, output, labor, and investment. The mechanism is straightforward: in response to the import shock the trade balance deteriorates and debts increase, which leads to an increased interest rate.

In response to the import shock, the initial decline in consumption is relatively larger than the decline in investments. Households dissave in response to declining output to smooth the decline in consumption. In the model, however, the initial decline in domestic absorption (consumption and investment) is smaller than the decline in domestic production, leading to deterioration in the trade balance. This deterioration leads to an increase in the effective interest rate as debts increase, suggesting an increase in return on investment. Thus, both the income effect and the price effect negatively influences the households' consumption. As a result, we see a stronger consumption response to the negative terms of trade shock.

We now compare the relative effects of different environmental policy instruments to the import shock. The fixed emissions level in the cap-and-trade policy yields a smaller decline in output than in the no-policy case. This leads to a smaller decline in investment. Households dissave relatively less than in the no-policy case, leading to an increased interest rate compared to the no-policy case. This is driven by a stronger price effect on consumption relative to the no-policy case. In the emissions tax policy, which fixes the emissions price, the decline in output is relatively higher than in the cap-and-trade policy. Households respond by dissaving relatively more than the cap-and-trade policy, leading to a smaller increase in the interest rate. This means consumption is affected relatively less by the price effect under an emissions tax. In the intensity target ratio, the decline in output is relatively bigger than in the cap-and-trade and emissions tax policy but smaller than in the no-policy case. Households respond by disinvestment, which is relatively bigger than the cap-and-trade and emissions tax policy, leading to the smallest rise in interest rate. This means that under the intensity target the price effect has the smallest effect on consumption compared to the cap-and-trade and emissions tax.

Table 6 shows coefficients of variation (CVs) under the terms of trade shock. Consumption has higher variation compared to the productivity shock. However, we do not see any significant difference in terms of which policy is to be pursued to reduce the terms of trade shock's severity on consumption and labor. The cap-and-trade policy consistently has the lowest CV for the economic variables, but the variations in terms of percentage change are very small in differences across the policy instruments, with the exception of investment and trade balance. The CV of investment and the trade balance under the cap-and-trade is significantly lower compared to other policy instruments. This finding is in line with our intuition that the cap-and-trade policy has stronger price effects under the terms of trade shock. Therefore, the cap-and-trade policy is not different from the other two environmental policies in reducing the trade shock's general macroeconomic effects. However, the cap-and-trade policy does reduce the shock's intensity on investment and trade balance, meaning the policy instrument is effective in limiting imports and investment.

Table 6: Variations Under the Terms of Trade Shock

Variables	No policy	Cap	Tax	Intensity Target
Consumption	2.20	2.19	2.20	2.20
Labor	0.52	0.51	0.52	0.52
Investment	1.39	1.24	1.39	1.35
Output	0.25	0.22	0.25	0.24
Emission	0.25	0.00	0.25	0.24
Trade balance	2.72	2.53	2.70	2.67

Note: The table shows the coefficient of variation under 1 standard deviation negative temporary shock to the terms of trade, which is employed using a positive shock to the relative price of consumption in the model. The coefficient of variation is the standard deviation divided by the theoretical mean level (in percentage points).

Under cap-and-trade policy the quantity of emissions is fixed and the price variable. When the import surge hits domestic production and thus demand for emissions falls. This leads to a drop in the price of emissions, which acts as a stimulus countervailing the effects of the import shock. In this sense, cap-and-trade based environmental policies may act as a type of unintended trade friction. The result is analogous to cap-and-trade's ability to cool the economy by raising the price of pollution emissions during a productivity shock driven boom. We discuss the policy impacts of this result further in the conclusions.

We also check the results' robustness by introduction a shock of higher magnitude and persistency. As before, the higher magnitude and persistent shock magnifies the differences in variation across policy instruments. The results for 1.5 standard deviation shocks with 90% persistency level are shown in the appendix (Table A3, in Figure A3, and in A4). We find similar results. The cap-and-trade policy has little effect on consumption and labor, and is equivalent to the other policy instruments. As explained above, the cap-and-trade reduces the shock's intensity on trade balance and investment.

4.3.3 Correlated Shocks

In the introduction, we discuss the terms of trade shock considering the potential link of business cycles to the fluctuations in the terms of trade. As we noted, responses under the terms of trade shock are not different from productivity shock for key macroeconomic variables, but these shocks are seldom uncorrelated. We now turn to the understanding the effects on macroeconomic dynamics across the selected environmental policy instruments if the two shocks are correlated. We introduce the correlated shocks as follows:

$$\begin{bmatrix} \log A_t \\ \log p_t \end{bmatrix} = \begin{bmatrix} \rho_A & 0 \\ 0 & \rho_p \end{bmatrix} \begin{bmatrix} \log A_{t-1} \\ \log p_{t-1} \end{bmatrix} + \begin{bmatrix} 1 & \nu \\ \nu & 1 \end{bmatrix} \begin{bmatrix} \epsilon_{A_t} \\ \epsilon_{p_t} \end{bmatrix} \tag{27}$$

where, $\nu = corr(\epsilon_{A_t}, \epsilon_{p_t})$ is the correlation parameter between the two shocks. Our estimation shows that the correlation between the two innovations as -0.0045.[16]

Table 7 shows the results under the correlated positive total factor productivity and negative terms of trade shocks.[17] The CVs are higher under the correlated shocks, but

[16]The correlation is estimated using the two residual series from the univariate AR(1) process of the total factor productivity and terms of trade (hp-filtered with smoothing parameter 100).

[17]We also employ the productivity shock correlated with the terms of trade shock and separately

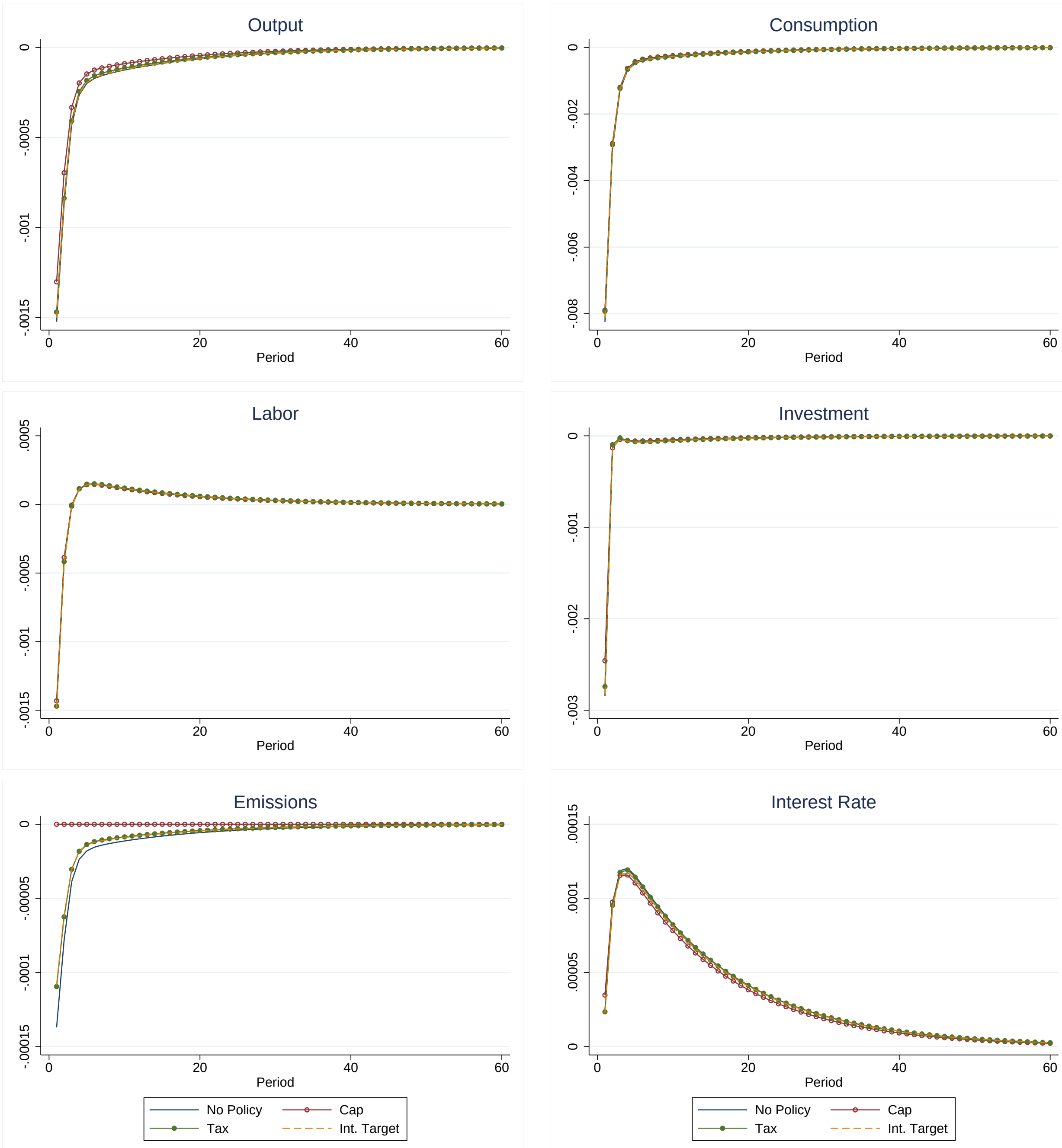

Figure 3: Impulse Responses Under the Terms of Trade Shock (Panel A)

Note: The figures show the impulse response functions of output, consumption, labor, capital, emissions, debt, current account, and trade balance in response to the terms of trade shock of one standard deviation by employing a positive shock to the relative price of consumption as shown on the bottom right corner panel in Figure 4. Zero on the vertical axis on each graph represents corresponding variable's steady state level. The responses are in terms of percentage deviation from the steady-state level.

terms of trade shock correlated with the productivity shock. In each case, the results are qualitatively similar to when faced with a separate shock. The separate shocks are more dominant than the correlated shock.

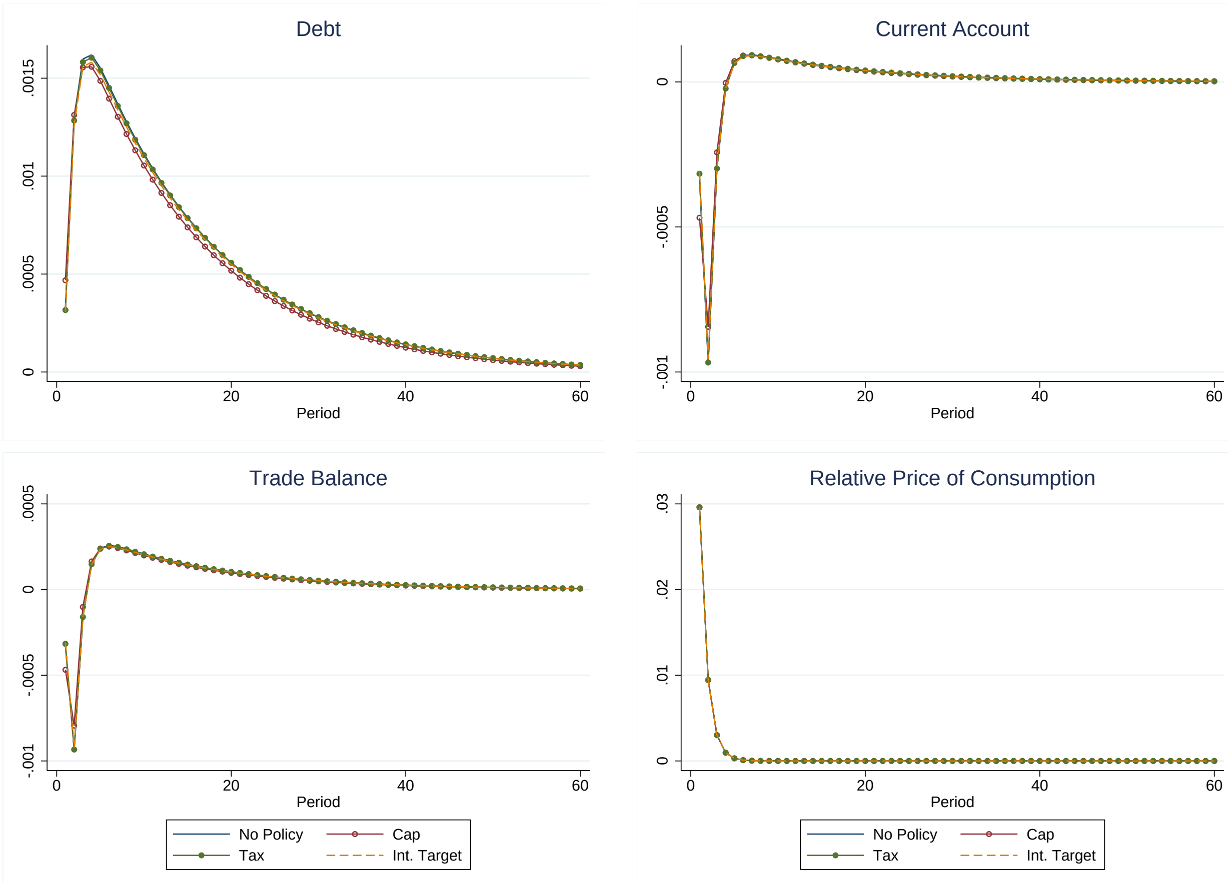

Figure 4: Impulse Responses Under the Terms of Trade Shock (Panel B)

Note: The figures show the impulse response functions of debt, current account, and trade balance in response to the terms of trade shock of one standard deviation by employing a positive shock to the relative price of consumption as shown on the bottom right corner panel. Zero on the vertical axis on each graph represents corresponding variable's steady state level. The responses are in terms of deviation from the steady state level.

the results on smoothing the business cycles' intensity are similar to that under just the productivity shocks. The cap-and-trade policy reduces the intensity of business cycles' shocks, and this result holds under both positively and negatively correlated shocks. Therefore, the consumption smoothing under the terms of trade shocks fades away when these shocks are weakly correlated. However, we find that the correlation's degree and direction may influence the dynamic performance. The stronger the positive correlation across the two shocks, the more consumption smoothing occurs regardless of the environmental policy instruments, making those policy instruments equivalent in terms of variation on consumption. At a correlation of around 0.3 between the two shocks the policies become essentially equivalent. Table A5 in the appendix shows the effects under higher correlations. We do not find such an effect on other variables, and their variations decrease under the cap-and-trade policy.

Table 7: Variations Under Correlated Shocks

Variables	No policy	Cap	Tax	Intensity Target
	$\nu = -0.0045$			
Consumption	2.28	2.25	2.28	2.28
Labor	1.25	1.11	1.25	1.23
Investment	10.46	9.01	10.65	10.30
Output	2.20	1.92	2.21	2.19
Emission	2.20	0.0	2.21	2.19
	$\nu = 0.0045$			
Consumption	2.28	2.24	2.28	2.28
Labor	1.24	1.11	1.25	1.23
Investment	10.45	9.00	10.64	10.29
Output	2.20	1.92	2.21	2.19
Emission	2.20	0.00	2.21	2.19

Note: The table shows the coefficient of variations under 1 standard deviation temporary correlated shocks of the terms of trade and total factor productivity. The coefficient of variation is the standard deviation divided by the theoretical mean level (in percentage points).

5 Welfare Cost

We follow the common practice in the emerging environmental macro literature and calculate welfare costs of environmental policy instruments. For each environmental policy instrument, we measure the reduction in consumption from the no-policy case, which would be necessary to make households indifferent between the no-policy case and the environmental policy cases. To do so, for each policy instrument, we calculate the discounted welfare's present value, keeping the supply of labor fixed at the steady-state level in the no-policy case. To ensure the consumption variable's response converges to the steady-state level, we choose 100 periods in the simulation.

Table 8 shows the changes in welfare cost across the policy cases as a difference from the welfare under the no-policy case.[18] Under the productivity shocks, the results show that the cap-and-trade policy has the highest welfare cost across the policy instruments while the intensity target has the lowest welfare cost; but the welfare cost difference is about 0.04 percentage point between cap-and-trade and tax policies, supporting the result in Fischer and Springborn (2011). However, under the terms of trade shock, the cap-and-trade's welfare cost is lower than the emissions tax policy by about 1 percentage point, making the two policies' welfare costs not significantly different. The intensity target has the lowest welfare cost irrespective of the shocks. The results also hold for highly persistent and higher magnitude shocks (See Table A4 in appendix).

Table 8: Welfare Differences Across Environmental Policy Instruments

Description	Change from No Policy				% Change from No Policy		
	No policy	Cap-and-Trade	Tax	Intensity Target	Cap-and-Trade	Tax	Intensity Target
	Productivity Shock						
Change in welfare		-0.5834	-0.5765	-0.1970	-3.19%	-3.15%	-1.08%
	Terms of Trade Shock						
Change in welfare		-0.5767	-0.5774	-0.1968	-3.14%	-3.15%	-1.07%

Note: The table shows the differences in welfare across environmental policy instruments from the no-policy case in response to productivity and terms of trade shocks of 1 standard deviation. In estimating the changes, total welfare is calculated as the sum of discounted utility, keeping the supply of labor fixed from the steady state under the no-policy case.

[18]Note that the welfare cost does not include improvement in welfare from reduced emissions level under the environmental policy instruments. Our focus is not on the cost of environmental policy, but the relative merits of the policy instruments.

6 Conclusions

Policy makers can choose a variety of policy instruments to limit pollution emissions. Among many important criteria such as cost effectiveness and political feasibility, an emerging literature suggests that these polices could have different effects across the business cycle. As countries become increasingly integrated into the world economy, the environmental policy's impact on trade flows has also become a consideration. To address these questions, we develop a DSGE model incorporating polluting production, international trade and capital mobility. We evaluate a pollution tax, a cap-and-trade policy, and an intensity target across the business cycle and through a surge in import competition.

We find that cap-and-trade reduces the business cycle's intensity by (effectively) increasing the cost of emissions over the peak and lowering the cost of emissions through the trough. However, we do not see a significant difference in environmental policy instruments' impact on consumption or labor supply in response to an import shock. The cap-and-trade policy does reduce the severity of the import surge which could be an important consideration for policy makers. The cap-and-trade policy also reduces the intensity of the business cycle. The business cycle results are consistent with those in Fischer and Springborn (2011) and Annicchiarico and Dio (2015) but they employ closed economy models, meaning they cannot consider how the policy instruments respond to an import shock. When the business cycle and import shocks are correlated, the cap-and-trade policy continues to best smooth the business cycle. However, if the shocks are positively and highly correlated, then the variation of consumption across the environmental policy instruments are equivalent.

The welfare cost is the lowest under the intensity target both across the business cycle and in response to an import shock. The cap-and-trade policy has a higher welfare cost than the emissions tax in the event of productivity shock, but the difference in the welfare cost between the cap-and-trade and emissions tax policies is small. In the event of an import shock, the welfare costs under the cap-and trade are lower than those of the emissions tax policies, but the difference is not economically significant. These results also hold for larger and highly persistent shocks. We note that pollution does not enter directly into the utility function, so differences in emissions across the policy instruments is not accounted for in these welfare comparisons.

When we consider all the results presented here, and elsewhere in the literature, there appears to be an emerging consensus that a cap-and-trade policy instrument best smooths the business cycle. The fact that cap-and-trade can also lessen the severity of an import surge could be seen as either a strength or weakness of the policy instrument. Policy makers might appreciate the fact that when faced with a sudden surge in imports the cap-and-trade policy can lessen the intensity of the foreign competition. From a global welfare perspective the ability of cap-and-trade to reduce import shocks could serve as an impediment to the global trading leading to inefficiencies both in the regulating country and the rest of the world.

Evaluating environmental policies' macroeconomic dynamics in an open-economy modeling framework that incorporates trade and capital flows is itself an important venture, which is also discussed in Fischer and Heutel (2013). We believe that our study represents a first-step with several possible extensions in the spirit of incorporating environmental policy into open-economy macroeconomic dynamic models. For example, this paper has focused on environmental regulation by the small open economy in isolation. It may be worthwhile to consider how the decision to regulate domestic pollution emissions affects the levels of economic activity, pollution emissions and environmental regulation in the rest of the world.

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Appendix

AR(1) Process

Table A1: AR(1) Process of Productivity and Terms of Trade Shocks

	(1) Total Factor Productivity	(2) Terms of Trade
ARMA		
L.ar	0.533***	0.319**
	(0.0967)	(0.136)
sigma		
Constant	0.0149***	0.0296***
	(0.00177)	(0.00294)
chi2	30.42	5.472
N	61	61

Note: This table shows the estimates of serial autocorrelation (persistency) for real GDP (in terms of trillion dollars Canadian GDP) and the relative price of import to exports, respectively. We use AR(1) process to estimate the coefficients using hp-filtered smoothing parameter of 100 for both series. The standard deviation of the shocks for each variable is shown as 'sigma'. Standard errors are in parentheses.
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Persistent Shocks

Table A2: Variations Under the 1 s.d. Positive Productivity Shock

Variables	No policy	Cap	Tax	Intensity Target
Consumption	1.74	1.49	1.74	1.72
Labor	1.44	1.25	1.45	1.43
Investment	19.00	16.69	19.42	18.79
Output	3.62	3.13	3.64	3.60
Emission	3.61	0.00	3.64	3.60

Note: The table shows the coefficient of variations of key variables under the productivity shock of 1.5 times the standard deviation with 90% persistency. The coefficient of variation is the standard deviation divided by the theoretical mean level (in percentage points).

Table A3: Variations Under the 1 s.d. Negative Terms of Trade Shock

Variables	No policy	Cap	Tax	Intensity Target
Consumption	3.88	3.86	3.88	3.88
Labor	0.44	0.43	0.44	0.43
Investment	1.71	1.54	1.73	1.69
Output	0.26	0.22	0.26	0.26
Emission	0.26	0.00	0.26	0.26

Note: The table shows the coefficient of variations of key variables under the terms of trade shock of 1.5 times the standard deviation with 90% persistency. The coefficient of variation is the standard deviation divided by the theoretical mean level (in percentage points).

Table A4: Welfare Differences Across Environmental Policy Instruments Under Persistent Shocks

Description	Change from No Policy				% Change from No Policy		
	No policy	Cap-and-Trade	Tax	Intensity Target	Cap-and-Trade	Tax	Intensity Target
	Productivity Shock						
Change in welfare		-0.6089	-0.5740	-0.1972	-3.36%	-3.17%	-1.09%
	Terms of Trade Shock						
Change in welfare		-0.5766	-0.5796	-0.1973	-3.11%	-3.13%	-1.07%

Note: The table shows the changes in welfare across environmental policy instruments from the no policy case under the shocks of 1.5 times their corresponding standard deviations with 90% persistency. In estimating the changes, total welfare is calculated as the sum of discounted welfare keeping labor fixed from the steady state in the no policy case.

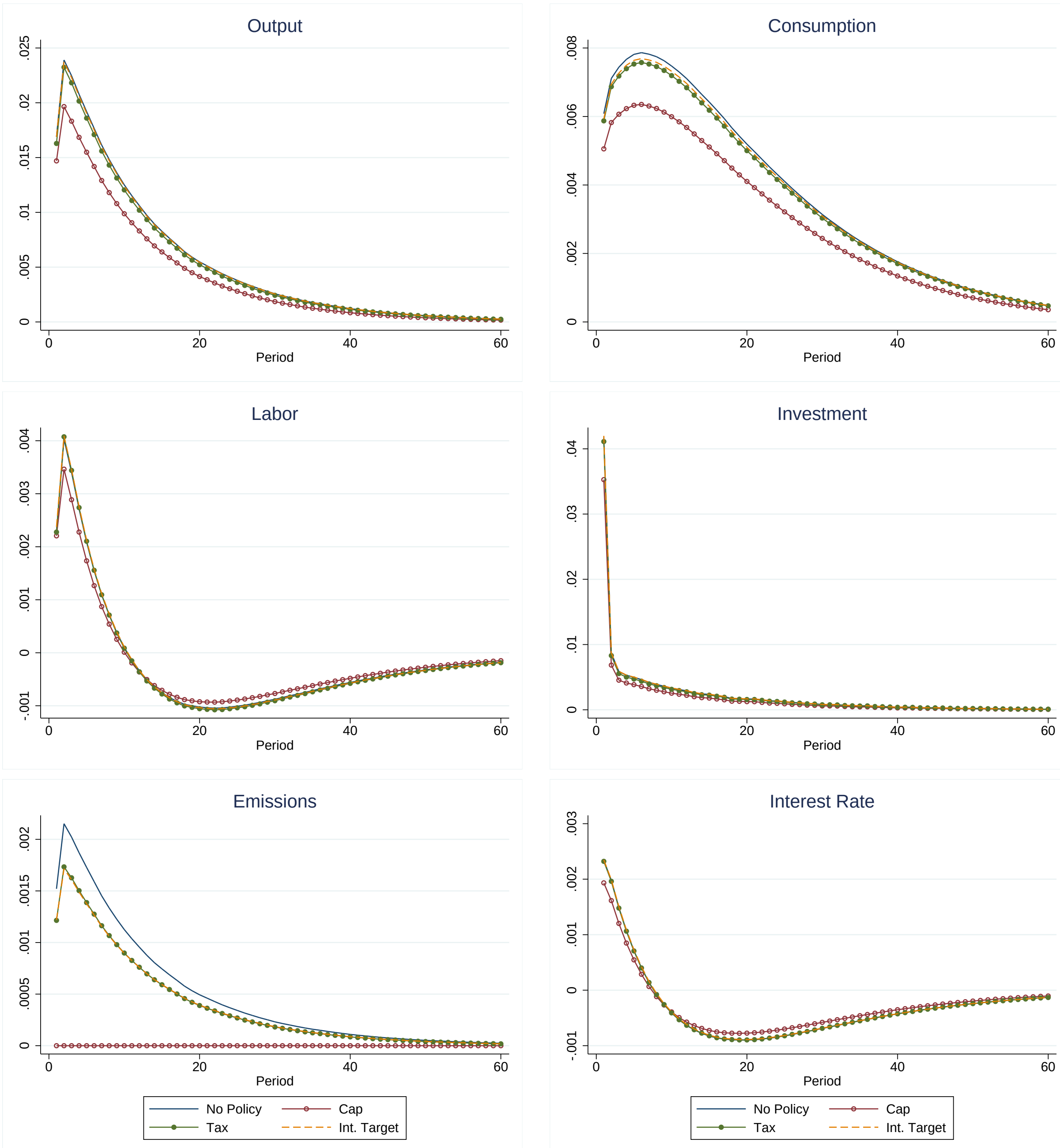

Figure A1: Impulse Responses Under the Productivity Shock (Panel A)

Note: The figures show the impulse responses of output, consumption, labor, capital, emissions and interest rate in response to the positive productivity shock of 1.5 times the standard deviation with high (90%) persistency. The shock is shown on the bottom right corner panel in Figure A2. Zero on the vertical axis on each graph represents corresponding variable's steady state level. The responses are in terms of deviation from the steady state level.

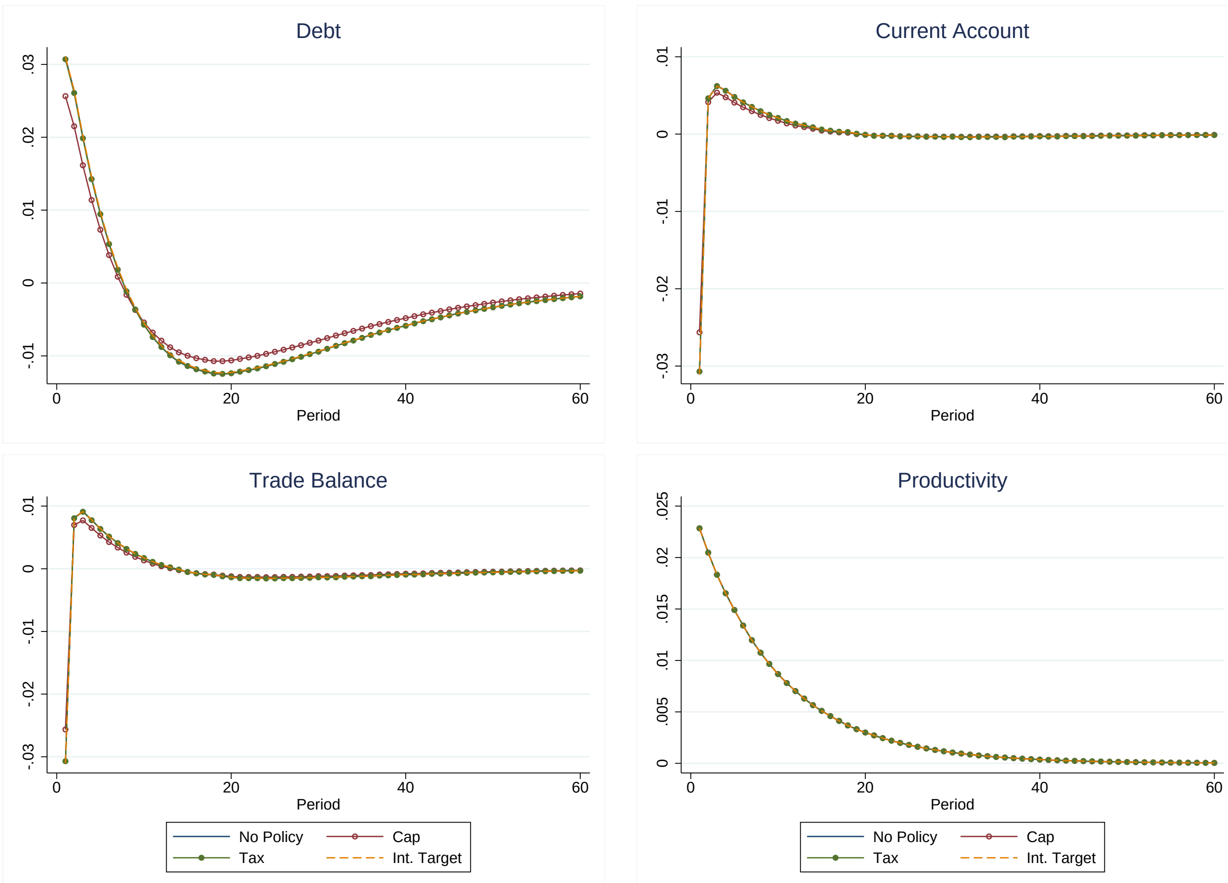

Figure A2: Impulse Responses Under the Productivity Shock (Panel B)

Note: The figures show the impulse responses of debt, current account and trade balance in response to the positive productivity shock of 1.5 times the standard deviation with high (90%) persistency. The shock is shown on the bottom right corner panel. Zero on the vertical axis on each graph represents corresponding variable's steady state level. The responses are in terms of deviation from the steady state level.

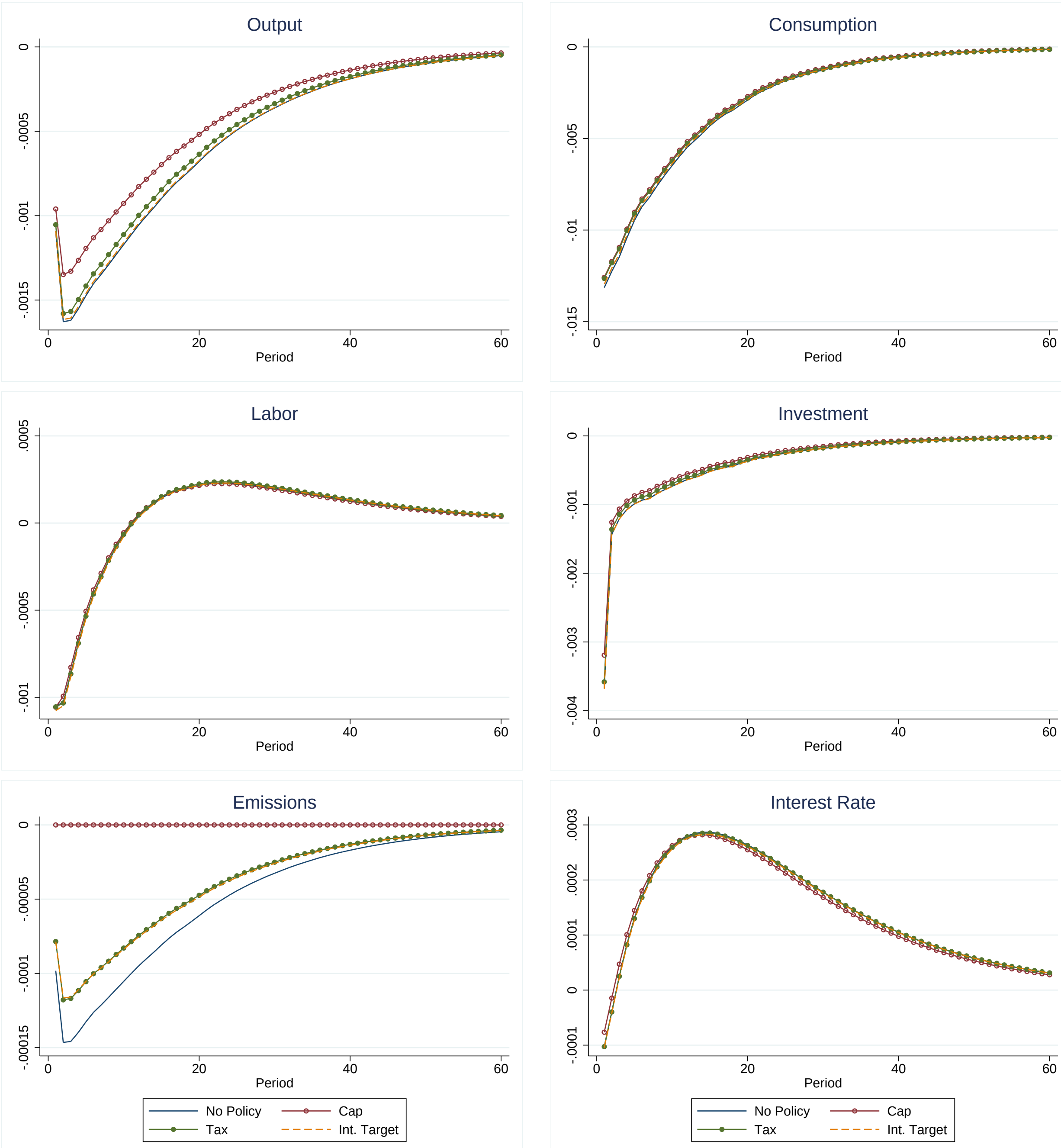

Figure A3: Impulse Responses Under the Terms of Trade Shock (Panel A)

Note: The figures show the impulse responses of output, consumption, labor, capital, emissions and interest rate in response to the negative terms of trade shock of 1.5 times the standard deviation with high(90%) persistency. The shock is employed through a positive shock to the relative price of consumption as shown on the bottom right corner in Figure A4. Zero on the vertical axis on each graph represents corresponding variable's steady state level. The responses are in terms of deviation from the steady state level.

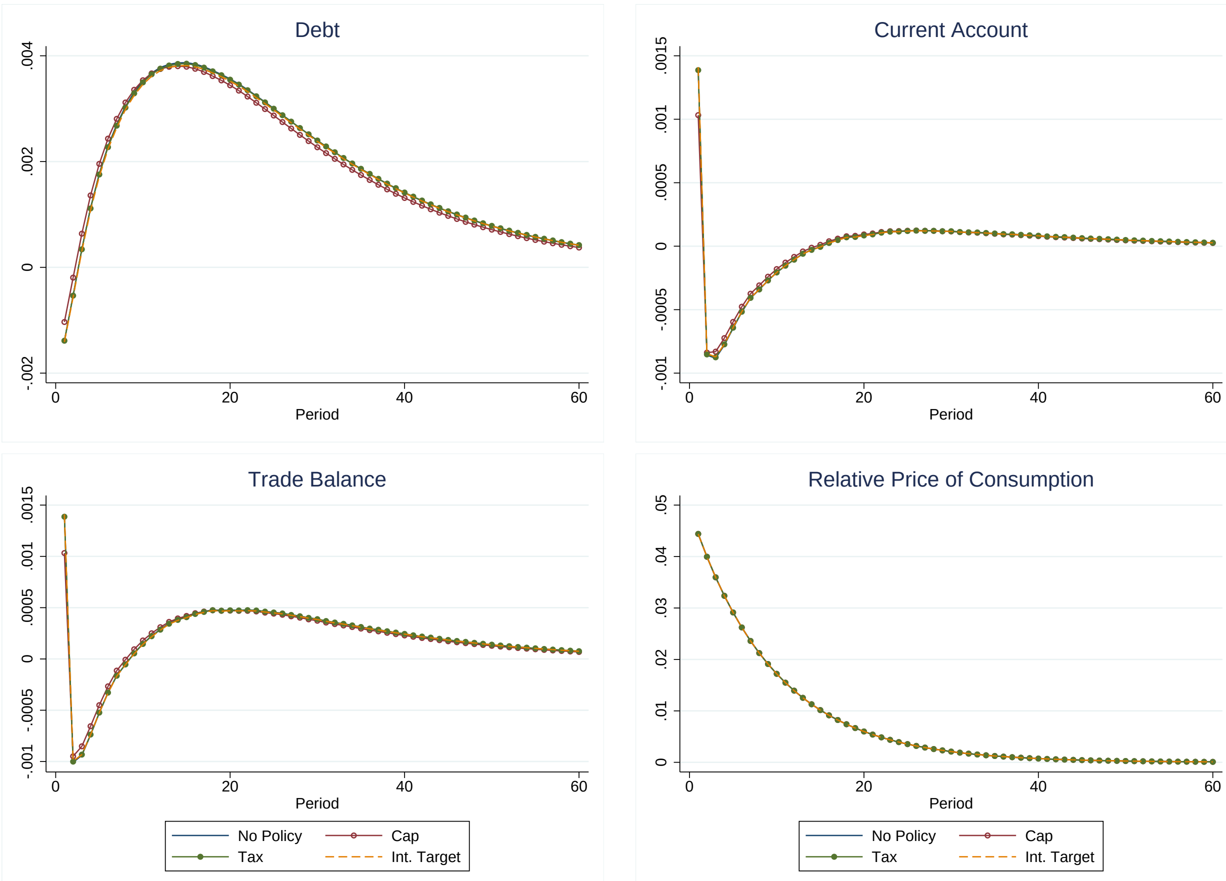

Figure A4: Impulse Responses Under the Terms of Trade Shock (Panel B)

Note: The figures show the impulse responses of debt, current account and trade balance in response to the negative terms of trade shock of one standard deviation with high(90%) persistency. The shock is employed through a positive shock to the relative price of consumption as shown on the bottom right corner. Zero on the vertical axis on each graph represents corresponding variable's steady state level. The responses are in terms of percentage deviation from the steady state level.

Highly Correlated Shocks

Table A5: Variations Under Highly Correlated Shocks

Variables	No policy	Cap	Tax	Intensity Target
	$\nu = -0.045$			
Consumption	2.30	2.26	2.30	2.30
Labor	1.26	1.13	1.27	1.25
Investment	10.52	9.06	10.71	10.35
Output	2.21	1.93	2.22	2.20
Emission	2.21	0.00	2.22	2.20
	$\nu = -0.45$			
Consumption	2.47	2.42	2.48	2.47
Labor	1.43	1.29	1.43	1.41
Investment	11.07	9.55	11.26	10.89
Output	2.31	2.01	2.31	2.30
Emission	2.31	0.00	2.31	2.30
	$\nu = 0.045$			
Consumption	2.26	2.23	2.26	2.26
Labor	1.23	1.09	1.23	1.21
Investment	10.40	8.95	10.59	10.23
Output	2.19	1.91	2.20	2.18
Emission	2.19	0.00	2.20	2.18
	$\nu = 0.45$			
Consumption	2.09	2.08	2.09	2.09
Labor	1.04	0.91	1.04	1.03
Investment	9.82	8.44	10.01	9.67
Output	2.09	1.82	2.10	2.09
Emission	2.09	0.00	2.10	2.09

Note: The table shows the coefficient of variations for 1 standard deviation terms of trade and total factory productivity shocks under the selected correlations between the shocks. The coefficient of variation is the standard deviation divided by the theoretical mean level (in percentage points).