Environmental Policy and Business Cycles: Long-Run Gain, Short-Run Pain?*

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Abstract

This paper examines the welfare cost of short-run fluctuations using a real business cycle model incorporating pollution and environmental policy; households derive utility from the quality of environment and firms pay green taxes to finance government expenditure for reducing pollution. We find that the taxation may result in short-run welfare gain, in addition to its long-run social improvement. Such short-run benefit of the environmental policies has not been documented in the previous literature. We further show that Ramsey taxation is more effective in mitigating the welfare cost.

JEL classification: E13, E32, Q52, Q58

Keywords: Environment, policy, welfare cost, business cycles

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1 Introduction

The increasing intensity of the climate change calls for an immediate intervention through various environmental policies. While the need for and the benefit of such policy measures in the long-run are easily agreed upon, the implementation of the policies is not as straightforward in practice; environmental regulations are often viewed as added costs especially from the microeconomic perspective, and few studies evaluate their overall welfare implications in the short-run at the business-cycle frequency relative to the long-run gain. Rather, previous literature that augments environment in a business-cycle model has focused on optimal policy design from a given set of policy tools (e.g., Annicchiarico and Di Dio 2015, Heutel 2012 and Dissou and Karnizova 2016).[1]

We construct a real business cycle (RBC) model extended with environment to study the short-run consequences of an environmental policy implementation. Our model introduces an environmental sector into an otherwise standard RBC model by adding the quality of environment to the household utility function á la Angelopoulos, Economides, and Philippopoulos (2013). In particular, firms pay environmental tax to finance the government spending to improve the environmental quality. Different from Angelopoulos, Economides, and Philippopoulos (2013), the representative household is allowed to endogenously determine its labor supply, which plays an important role in determining the sign and magnitude of the welfare cost in the model where the cost is computed by comparing the lifetime value of living in the steady state and that of living in the volatile economy (see Cho, Cooley, and Kim 2015 and Kim and Shim 2020 for more discussions).

We first confirm that the household can achieve long-run (steady-state) welfare gain when environmental tax is imposed. More importantly, we show that the environmental policy can generate an unintended welfare improvement also in short-run; the taxation lowers the fluctuations of the environmental quality, which directly affects the social welfare, but has been neglected by the previous literature. Such benefit from the less volatile environmental quality dominates the cost incurred by the tax, i.e., lower consumption, within a certain tax rate range, and hence results in the short-run welfare gain. Our finding stands robust to the alternative tax schemes of varying tax bases and the use of different values for parameters such as the Frisch elasticity and cleanup efficiency. We also analyze the

[1] One notable exception is Fischer and Springborn (2011), where the welfare cost of the economic fluctuations in an environment-augmented model is computed. However, our work is more suitable for the welfare analysis at the short-run because we (1) allow more flexible labor adjustment that captures the mean effect (Cho, Cooley, and Kim 2015) and (2) solve the model with the second-order approximation (Fischer and Springborn (2011) solves the model with linearization).

extent to which Ramsey taxation can improve the social welfare at the business cycle frequency.

2 The Model

Our model extends Angelopoulos, Economides, and Philippopoulos (2013) by introducing endogenous labor supply decisions. Optimality conditions are provided in Appendix A.1.

2.1 Household Problem A representative household derives utility from consumption, leisure, and the quality of environment[2]:

$$\mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t U(C_t, N_t, Q_t) \tag{1}$$

$$U(C_t, N_t, Q_t) \equiv \ln C_t - \theta \frac{N_t^{1+\eta}}{1+\eta} + \mu \ln Q_t \tag{2}$$

where $\beta \in (0,1)$ is the discount factor, $\eta > 0$ is the inverse of the Frisch elasticity, $\theta > 0$ is a relative weight on disutility from labor, $\mu > 0$ denotes a weight on the environmental quality, C_t is consumption, N_t is hours worked, and Q_t denotes the environment quality in period t. The household enjoys utility from better environmental quality while it takes the environmental quality, $\{Q_t\}_{t=0}^{\infty}$, as given. The household faces the following constraints:

$$C_t + I_t = W_t N_t + r_t K_t + \pi_t \tag{3}$$

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

where W_t is the hourly wage rate, r_t is the real interest rate, π_t is the profit of the firm, and $\delta \in (0,1)$ denotes the rate of depreciation of physical capital.

2.2 Firm Problem A representative firm solves the usual profit maximization problem:

$$\max \pi_t \equiv (1-\tau_t^E) A_t K_t^{\alpha} N_t^{1-\alpha} - r_t K_t - W_t N_t. \tag{5}$$

[2] We can also consider CRRA function instead of the log utility but findings are similar as it only affects the curvature of the utility function.

where $\alpha \in (0,1)$ is the capital share and τ_t^E is the rate of environmental tax levied on firm's revenue. The level of Total Factor Productivity (TFP) follows an autoregressive (1) (AR (1)) process, i.e., $A_t = (1-\rho_a) + \rho_a A_{t-1} + \varepsilon_t^a$, with AR parameter $\rho_a \in (0,1)$ and $\varepsilon_t^a \sim \mathbb{N}(0, \sigma_a)$.[3] A shock to TFP is the source of business cycles in this economy.

2.3 Pollution and Environmental Quality

As in Angelopoulos, Economides, and Philippopoulos (2013), the above production process emits pollution P_t as a byproduct, i.e.,

$$P_t = \phi Y_t = \phi A_t K_t^{\alpha} N_t^{1-\alpha}, \tag{6}$$

where $\phi \in (0,1)$ determines the pollution intensity. The environmental quality stock evolves over time as follows:

$$Q_{t+1} = (1-\delta^q)\bar{Q} + \delta^q Q_t - P_t + \nu G_t, \tag{7}$$

where $\bar{Q} > 0$ is the quality level of environment without pollution and G_t is government expenditure to improve the environment. The persistence of environmental quality and the efficiency of the government's pollution abatement expenditure are denoted by $\delta^q \in (0,1)$ and $\nu > 0$, respectively.

2.4 Government Problem

A government keeps the budget balance:

$$G_t = \tau_t^E Y_t \tag{8}$$

2.5 Parameterization

Most of model parameters are calibrated following Angelopoulos, Economides, and Philippopoulos (2013) and reported in Table 1. $\theta > 0$ is chosen to ensure that steady-state working hours is at $\frac{1}{3}$.

3 Welfare Analysis

The model is solved by the second-order approximation of the equilibrium conditions (Schmitt-Grohé and Uribe 2004). We define and compute the lifetime value of living in the steady-state economy

[3] Following Lester, Pries, and Sims (2014), we define the process in levels, rather than in logs.

Table 1: Baseline Calibration

Parameter	Value	Description
β	0.97	discount factor
η	1	inverse of Frisch elasticity of labor supply
α	0.33	capital share in production
μ	0.4	weight on environment in utility
$\bar{Q}$	1	environment quality without pollution
δ	0.1	capital depreciation rate
δ^q	0.900	persistence of environmental quality
ϕ	0.05	pollution intensity
ν	1.5	efficiency of government abatement spending
ρ_a	0.933	persistence of a TFP shock
τ_t^E	[0, 0.5]	environmental tax rate
N^s	1/3	steady-state working hours
σ_a	0.01	standard deviation of technology shocks

($V^s(C,N,Q)$) and that in the fluctuating economy ($V^f(\mathbf{C}_t,\mathbf{N}_t,\mathbf{Q}_t)$) as follows[4]:

$$V^s(C,N,Q) \equiv \frac{1}{1-\beta}U(C,N,Q), \tag{9}$$

$$V^f(\mathbf{C}_t,\mathbf{N}_t,\mathbf{Q}_t) \equiv U(C_t,N_t,Q_t) + \beta\mathbb{E}_t V^f(\mathbf{C}_{t+1},\mathbf{N}_{t+1},\mathbf{Q}_{t+1}), \tag{10}$$

where $\mathbf{X}_t \equiv \{X_\tau\}_{\tau=t}^{\infty}$ for any variable X_t.

Define λ^{SR} an adjustment factor for consumption flows of households, with which living in the volatile economy yields the same level of lifetime utility as in the economy in the steady state, i.e.,

$$V^s(C,N,Q) = V^f((1-\lambda^{SR})\mathbf{C}_t,\mathbf{N}_t,\mathbf{Q}_t). \tag{11}$$

If $\lambda^{SR}=0$, no cost is associated with living in the volatile economy. If λ^{SR} is negative (positive), however, the lifetime value of the two economies are equivalent when the consumption schedule in the volatile economy is adjusted upward (downward) by the factor λ^{SR}, implying that business cycles are costly (beneficial).

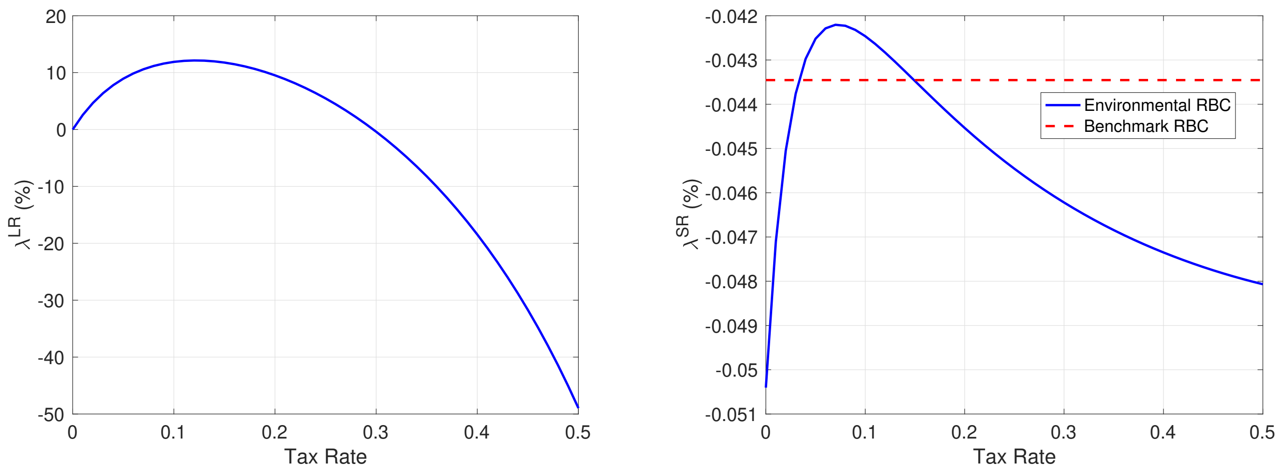
Similarly, we can compute compensating variations in consumption that the household living in the steady-state economy with environmental tax should receive to maintain the same level of utility in the

[4] In Appendix A.2 and A.3, detailed descriptions are provided.

steady-state economy without tax. Formally,

$$V^s(C, N, Q; \tau^E = 0) = V^s((1 - \lambda^{LR})C, N, Q; \tau^E), \tag{12}$$

where λ^{LR} measures the long-run welfare gain/cost of the green tax.



(a) Long-Run Welfare Gain (λ^{LR})

(b) Short-Run Welfare Gain (λ^{SR})

Figure 1: Welfare Consequences of Environmental Quality: Long-Run and Short-Run

Note: $\lambda < 0$ (resp. $\lambda > 0$) implies that taxation and business cycles are welfare-detrimental (resp. welfare-improving). The x-axis is the environmental tax rate levied on the firm. The red dotted line in the second panel represents the welfare cost in a model without changes in the environmental quality (Q=1).

3.1 Cost of Business Cycles We first present long-run welfare gain of environmental taxes in Figure 1-(a). Taxes improve the quality of environment but lower consumption at the same time, posing a trade-off between the two. We find that the welfare gain is maximized in the model economy when the tax rate is at 12%; if it goes higher than 12%, the long-run welfare gain diminishes and eventually becomes negative, as declines in consumption dominate higher utility from cleaner environment.

Figure 1-(b) plots λ^{SR} associated with the business cycle. To better understand the short-rum impacts of environmental taxes, we first consider the benchmark RBC economy, where $Q_t = \bar{Q} = 1$ for all t and compute welfare loss due to business-cycle fluctuations caused by TFP shocks. Of note, there is no change in the quality of environment in the benchmark, or one can alternatively think that household utility is not affected by environment. The solid blue line, on the contrary, corresponds to the environmental RBC model outlined in Section 2. In the absence of any tax, the welfare cost of business cycle is smaller in the benchmark RBC model than in the RBC model with pollution. However, the

welfare cost decreases, as environmental tax is imposed and ultimately reduces pollution. It reaches to the minimum of -0.0422% when the tax rate is at 7%. It should be noted here that the welfare cost when the tax rate is in the range from 4% to 14% is even lower than that of the benchmark RBC economy. Therefore, imposing environmental tax not only induces long-term welfare gain, but also allows welfare improvement in the short run. Nonetheless, the magnitude is much smaller in the short-run; while the long-run gain amounts to around 10 p.p., the short-run gain is at most around 0.01 p.p. Considering the US real personal consumption expenditure per capita in 2022, which was about $42,000, the short-run gain of the environmental policy at the aggregate level can be translated into $1.3 billion per year.[5]

Our findings show that accounting for environment and resulting externality in a RBC model could have a material implication when considering the welfare gain/loss from the fluctuations. For example, higher GDP may lead to higher consumption and subsequent welfare gain, as shown in e.g., Cho, Cooley, and Kim (2015). However, it can be more than offset by increased pollution generated during the boom following equation (7) that can lower overall utility. More importantly, our findings highlight that environmental regulation such as emission taxes can improve welfare even in the short-run by mitigating the disutility arising from pollution. In Appendix A.4, our findings are shown to be robust to the alternative tax schemes of varying tax bases and the use of different values for parameters such as the Frisch elasticity and cleanup efficiency.

3.2 Ramsey Optimal Taxation

The tax rate on the firm has so far been assumed to be constant over time. In this subsection, we further analyze a Ramsey taxation problem, which chooses $\{\tau_t^E\}_{t=0}^{\infty}$ to maximize the total expected discounted sum of utility given the relevant constraints outlined in Section 2. The estimated welfare costs are reported in Table 2. The most noticeable finding is that the welfare cost of business cycles under the Ramsey taxation is 0.01 p.p. lower than the benchmark RBC model without the environment, which is an order of magnitude smaller than the gain from the fixed tax rate.

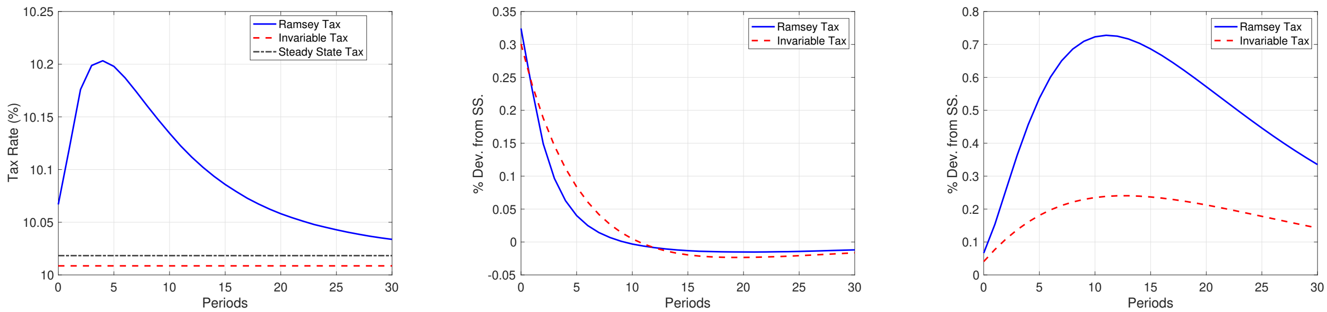
To understand the above finding further, we plot key impulse response functions to a positive TFP shock in Figure 2. The solid blue line represents the economy with the Ramsey tax, while the dotted red line denotes the economy with fixed τ^E where the tax rate is set to the mean of the Ramsey tax.

First, the optimal environmental tax rate is procyclical (Figure 2-(a)), consistent with the existing environmental RBC literature (Heutel, 2012; Angelopoulos, Economides, and Philippopoulos, 2013). In response to rising production, labor input surges (Figure 2-(b)), and the Ramsey government heightens

[5] We multiply the number of population in the US (about 330 million in 2021) and the individual gain ($4).

Table 2: Welfare Cost with Ramsey Taxation

Tax rate	Welfare cost (%)	Description
0%	-0.0435	RBC model without environment
7%	-0.0422	Maximum welfare gain with time-invariant rate
Time-varying	-0.0315	Ramsey taxation



(a) Ramsey Optimal Tax (b) Labor Input (c) Quality of environment

Figure 2: Impulse Response Functions

Note: The solid blue line (resp. dotted red line) represents impulse responses with the Ramsey tax rate (resp. the invariable tax rate (tax rate equal to the mean of Ramsey tax)).

the tax rate to deal with the aggravated environmental quality. As more tax is collected, the improvement of environmental quality is greater, compared to the economy with the fixed tax rate (Figure 2-(c)), resulting in lower welfare cost of business cycles.

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A.1 Optimality Conditions

Household

$$\frac{1}{C_t} = \beta E_t \left[\frac{1}{C_{t+1}} (r_{t+1} + 1 - \delta) \right] \quad \text{(Euler Equation)}$$

$$\theta N_t^{\eta} = \frac{W_t}{C_t} \quad \text{(Labor Supply)}$$

$$C_t + K_{t+1} - (1-\delta)K_t = W_t N_t + r_t K_t \quad \text{(Household's Budget Constraint)}$$

$$\lim_{t\to\infty} \beta^t K_{t+1} \frac{1}{C_t} = 0 \quad \text{(Transversality Condition)}$$

Firm

$$W_t = (1-\tau^E)(1-\alpha)\frac{Y_t}{N_t} \quad \text{(Labor Demand)}$$

$$r_t = (1-\tau^E)\alpha \frac{Y_t}{K_t} \quad \text{(Capital Demand)}$$

$$Y_t = A_t K_t^{\alpha} N_t^{1-\alpha} \quad \text{(Production Function)}$$

Government

$$G_t = \tau^E Y_t \quad \text{(Government's Budget Constraint)}$$

Environmental Conditions

$$Q_{t+1} = (1-\delta^q)\bar{Q} + \delta^q Q_t - P_t + \nu G_t \quad \text{(Environmental Quality)}$$

$$P_t = \phi Y_t \quad \text{(Pollution Generation)}$$

A.2 Calculating Compensating Variations (short-run)

Note that the representative household's utility is additively separable and has log utility over consumption. Under this utility setting and from the definition of the value function in the fluctuating economy from the equation (10), we can derive :

$$\begin{aligned}
V^f((1-\lambda^{SR})\mathbf{C}_t, \mathbf{N}_t, \mathbf{Q}_t) &= U((1-\lambda^{SR})C_t, N_t, Q_t) + \beta\mathbb{E}_t V^f((1-\lambda^{SR})\mathbf{C}_{t+1}, \mathbf{N}_{t+1}, \mathbf{Q}_{t+1}) \\
&= \ln(1-\lambda^{SR}) + U(C_t, N_t, Q_t) + \Sigma_{\tau=1}^{\infty}\beta(1-\lambda^{SR}) + \mathbb{E}_t V^f(\mathbf{C}_{t+1}, \mathbf{N}_{t+1}, \mathbf{Q}_{t+1}) \\
&= V^f(\mathbf{C}_t, \mathbf{N}_t, \mathbf{Q}_t) + \frac{1}{1-\beta}\ln(1-\lambda^{SR})
\end{aligned}$$

From the above relationship and the equation (11), we can derive λ^{SR} :

$$\begin{aligned}
V^s(C, N, Q) &= V^f((1-\lambda^{SR})\mathbf{C}_t, \mathbf{N}_t, \mathbf{Q}_t) \\
&= V^f(\mathbf{C}_t, \mathbf{N}_t, \mathbf{Q}_t) + \frac{1}{1-\beta}\ln(1-\lambda^{SR}) \\
\Leftrightarrow \lambda^{SR} &= 1 - \exp\{(1-\beta)(V^s(C, N, Q) - V^f(\mathbf{C}_t, \mathbf{N}_t, \mathbf{Q}_t))\}
\end{aligned}$$

A.3 Calculating Compensating Variations (Long-run)

We can derive λ^{LR} similarly with the appendix A.2. From the equation (9), we get the relationship:

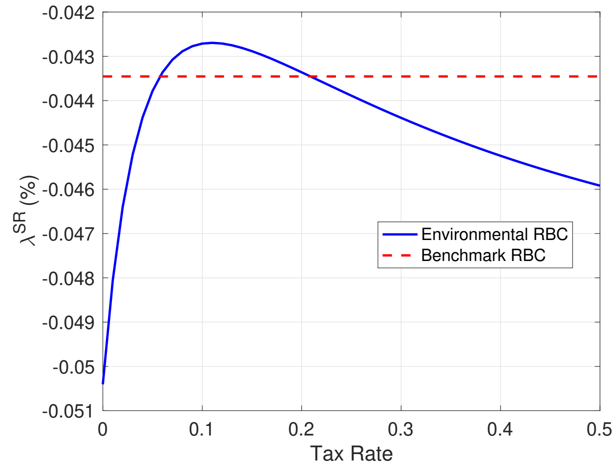
$$\begin{aligned} V^s((1-\lambda^{LR})C, N, Q; \tau^E) &= \frac{1}{1-\beta} U((1-\lambda^{LR})C, N, Q; \tau^E) \\ &= \frac{1}{1-\beta} \left[U(C, N, Q; \tau^E) + \ln(1-\lambda^{LR}) \right] \\ &= V^s(C, N, Q; \tau^E) + \frac{1}{1-\beta} \ln(1-\lambda^{LR}) \end{aligned}$$

From this relationship and the equation (12),

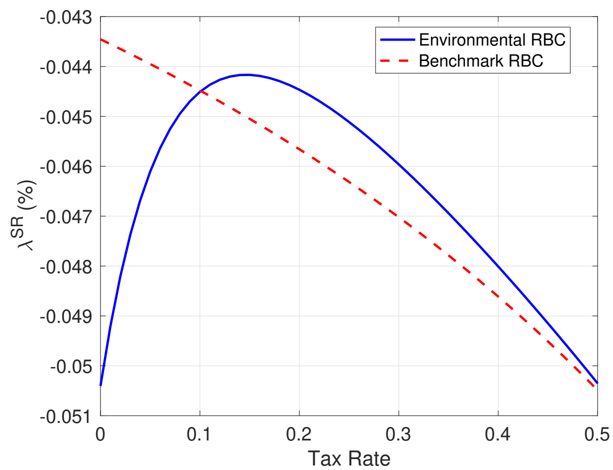
$$\begin{aligned} V^s(C, N, Q; \tau^E = 0) &= V^s((1-\lambda^{LR})C, N, Q; \tau^E) \\ &= V^s(C, N, Q; \tau^E) + \frac{1}{1-\beta} \ln(1-\lambda^{LR}) \\ \Leftrightarrow \lambda^{LR} &= 1 - \exp\{(1-\beta)(V^s(C, N, Q; \tau^E = 0) - V^s(C, N, Q; \tau^E))\} \end{aligned}$$

A.4 Robustness Checks

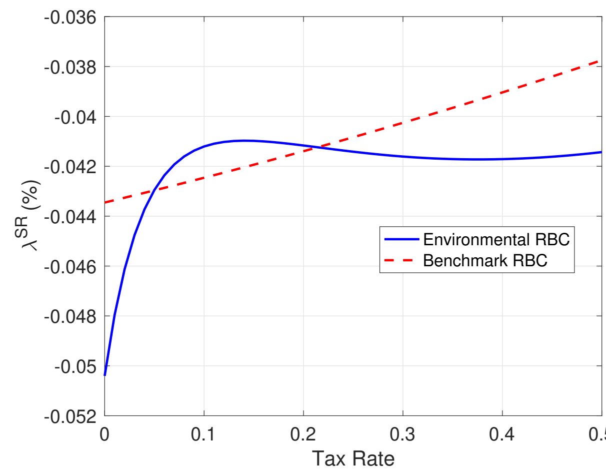
In this section, we present findings from two robustness checks.



(a) Household Consumption Tax



(b) Household Capital Income Tax



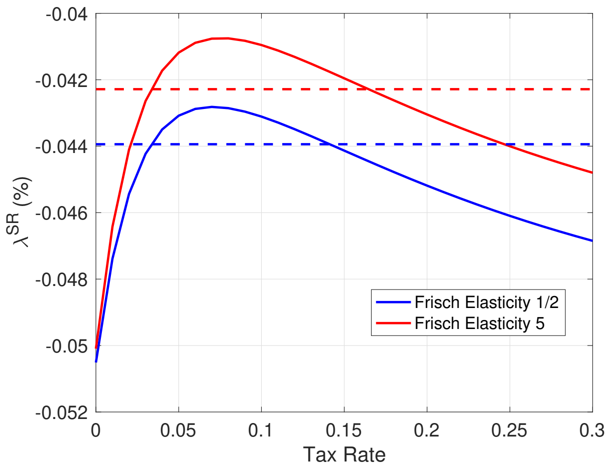
(c) Household Labor Income Tax

Figure A.4.1: Robustness Check: Alternative Tax Schemes

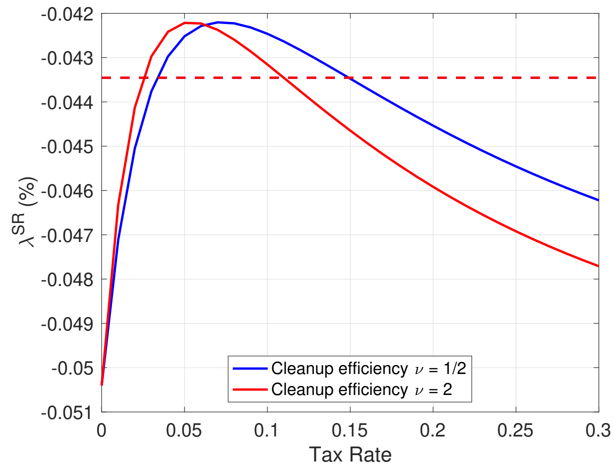
Note: A positive λ^{SR} value means welfare-improvement from the benchmark. The x-axis is the environmental tax rate levied on the firm or household. The red dotted line represents a model without the environmental sector (Q=1).

Alternative tax schemes. We first check the robustness of our finding to alternative tax schemes (consumption tax, capital income tax, and labor income tax). Figure A.4.1 presents the welfare cost under different sources of taxation: Regardless of how the tax is imposed, the finding that there is a short-run welfare gain from the environmental policy (within certain tax rate ranges) is preserved.

Changing parameter values. We then change values for the parameters of Frisch labor supply elasticity (Figure A.4.2-(a)) and cleanup efficiency (Figure A.4.2-(b)). These two parameters are considered, since (1) endogenous labor supply is a key to understand the welfare cost of business cycles (Cho, Cooley, and Kim 2015) and (2) the efficiency of the government policy is imperative for understanding the role of government in environment-augmented models. The main finding remain little changed.[6]



(a) Short-Run Welfare Gain with different η



(b) Short-Run Welfare Gain with different ν

Figure A.4.2: Robustness Check: Alternative Parameter Values

Note: A negative λ value means welfare-diminishment from the benchmark. The x-axis is the environmental tax rate levied on the firm or household. The dotted lines represent a model without the environmental sector (Q=1).

[6] Of note, there is no welfare gain from the environmental policy when $\mu = 0$. This is because (1) welfare is not affected by the environmental quality and (2) the tax rate is constant over time, with which the degree of fluctuations around the steady-state is independent from the tax rate.