# An Overlapping Generation Model Analysis of Enviromental Tax and Double Dividend Hypothesis

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# Outline

- Introduction
- The Model
- The Specification of the Environmental Fiscal Reform
- A Simple CES utility Example
- Conclusion

# Introduction

- Why Environmental Tax?
  - Could be cost-effective compared to command-and-control (mandates) and other policies
  - Require less information on the abatement costs, flexible to reach given abatement targets through trial-and-error
  - Provide sustained incentives for technology innovation and diffusion
  - Government's revenue incentives
  - In the 2nd best setting, environmental tax revenue can be used to substitute for more distorted taxes , such as capital tax, labor taxes, may result positive effects

# Why OLG Model?

- Possibly long time horizon, such as carbon tax for global climate change
- Debates in both theoretical and numerical literature on environmental tax reform, mostly focused on short-term one generation
- However, environmental tax (in particular carbon tax) have an impact on the welfare of both current and future generations, since environmental quality is a public good shared by both generations.
- Thus, OLG model is very appropriate to consider the inter-generational equity issues

# Previous Literature on OLG Model and Externality

- Dasgupta and Heal(1979), Pearce and Turner (1990): Environmental Modeling should focus on Intertemporal issues and externalities
- Solow(1986): "discrete time overlapping generations models are the natural habitat for these issues"
- Marini and Scaramozzino (1994): Sets forth a continuous-time OLG model to analyze intertemporal trade-offs in the use of environmental resources
- Chiroleu-Assouline and Fodha (2006): use a discrete time OLG model to examine the effect of swapping labor tax with environmental tax, characterize the conditions for double dividend
  - *However, Chiroleu-Assouline and Fodha ignores in many countries in particular developing countries, capital tax is more readily for revenue recycling than small labor tax, which may result different effects*

# Previous Literature on OLG Model and Externality

- In the one-generation model, Goulder (1995, 1996), Parry (1995) and other 2nd best environmental tax literature suggest: if revenue recycling through labor tax, environmental tax is more distorted, no double dividend
- However, Wilcoxen and Jorgenson(1997) suggest if use environmental tax revenue to reduce capital tax, then "double dividend" is possible
- All above are debates for the single-generation model. We take Chiroleu-Assouline and Fodha (2006) as our starting point, the objective of this paper is to experiment with recycling with capital tax, and then compare in the OLG model how would different channel revenue recycling result in different results in terms of "double dividend" hypothesis.
- Another difference that we make here is we consider different pollution emission for different age groups.

# Model
## Household

- 2 overlapping generations at each period and each can only live for 2 periods.
- Population grows at a constant rate $n$
- Each individual supplies one unit of labor when young and supplies 0 when old.
- $c_t^y$ : generation $t$'s consumption when young at period $t$;
- $c_t^o$ : generation $t-1$'s consumption when old at period $t$.
- Young's consumption leads to pollution emission with a proportion of $a$.
- The government imposes pollution taxes on young's consumption $\tau_t^e$.
- An individual's welfare is measured by the intertemporal separable utility function

$$\max_{\{c_t^y, c_{t+1}^o, s_t\}} \quad u(c_t^y) - \gamma v(\pi_t) + \beta[u(c_{t+1}^o) - \gamma v(\pi_{t+1})],$$
$$s.t. \qquad p_t^y c_t^y + p_{t+1}^o c_{t+1}^o = w_t.$$

- Assume many identical firms, each is characterized by the same production function $f$ which has constant returns to scale and satisfies the Inada condition.
- In this economy, the pre-existing tax is assumed to be imposed on capital income
- Thus, the firm is modeled to maximize its profit

$$\max_{k_t} f(k_t) - w_t - R_t(1+\tau_t^r)k_t$$
$$f'(k_t) = R_t(1+\tau_t^r)$$
$$f(k_t) - f'(k_t)k_t = w_t$$

- We assume the natural absorption of pollution is $h$. So in the 2nd period the per capita pollution stock from the previous period is $\frac{1-h}{1+n}\pi_t$, the new pollution stock is the sum of the previous stock in period $t$ and the new pollution flow in period $t+1$ (pollution example: carbon dioxide, can be absorbed by trees)

$$\pi_{t+1} = \frac{1-h}{1+n}\pi_t + ac^y_{t+1}$$

- The government's budget constraint suggest that its purchase $g_t$ is entirely financed by current capital income tax and environmental tax
- Therefore, per capita government's purchase is:

$$g_t = a\tau_t^e c_t^y + R_t \tau_t^r k_t.$$

- Solving household's problem, we derive the optimal consumptions for both periods and the savings:

$$c_t^y = c^y\left(w_t, p_t^y, \frac{p_t^y}{p_{t+1}^o}\right)$$
$$c_{t+1}^o = c^o\left(w_t, p_{t+1}^o, \frac{p_t^y}{p_{t+1}^o}\right)$$
$$s_t = s\left(w_t, \frac{p_t^y}{p_{t+1}^o}\right)$$

# Equilibrium

- In equilibrium, the law of motion for per capita capital stock is derived as follows:

$$k_{t+1} = \frac{1}{1+n} s_t$$

- The output good market in equilibrium is expressed as:

$$y_t = c_t^y + \frac{1}{1+n} c_t^o + (1+n) k_{t+1} + g_t$$

# Steady State Equilibrium

- In steady state, $\tau_t^e = \tau^e$, $k_{t+1} = k_t = k^*$. So, we first have

$$\frac{p_t^y}{p_{t+1}^o} = (1 + a\tau^e)R$$

- The solution of the steady state can be expressed by:

$$\begin{gathered}
c^y = c^y(w(k^*), p^y(\tau^e), R(\tau^r, k^*)) = c^y[w(k^*), R(k^*, \tau^r), \tau^e] \\
c^o = c^o(w(k^*), p^o(\tau^e, R), R(\tau^r, k^*)) = c^o[w(k^*), R(k^*, \tau^r), \tau^e] \\
s^* = s[w(k^*), R(k^*, \tau^r), \tau^e] \\
w^* = w(k^*) \\
R^* = R(k^*, \tau^r)
\end{gathered}$$

# Steady State Equilibrium (continued)

- In the 2nd period, the amount of capital stock is the amount saved by young individuals in period $t$, and determined by $w(k^*), r(\tau^r, k^*)$

$$(1+n)k^* = s[w(k^*), \frac{p^y}{p^o}] = s[w(k^*), R(\tau^r, k^*), \tau^e]$$

- Per capita capital stock in the steady state is a function of $\tau^r$ and $\tau^e$:

$$k^* = k(\tau^r, \tau^e)$$

# The Specification of the Fiscal Reform

- At the steady state equilibrium, the government's budget constrait can be written as:

$$g^* = \underbrace{a\tau^e c^y(w(k^*), \tau^e, R(\tau^r, k^*))}_{PT} + \underbrace{R(\tau^r, k^*)\tau^r k^*}_{CT}$$

$PT$ denotes the pollution tax revenue collected from households
$CT$ denotes the capital tax revenue.

# Balanced fiscal reform

- Consider the effect of raising pollution tax $\tau^e$ while keeping $g$ constant.
- Any balanced fiscal reform is characterized by the following relationship between $d\tau^e$ and $d\tau^r$:

$$d\tau^r = \Pi d\tau^e$$

where $\Pi$ *is the balanced fiscal reform multiplier.*

- A potential double dividend if $\Pi < 0$: a less distortionary tax system.

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        - IE<SE: $s$ increases, implying a higher labor income and a lower capital return.
    - $w$ increasing means a higher $c^y$;
    - $R$ falling means a higher $c^y$.
- Same logic follows for $\tau^r$.

# Example: CES Utility

- CES utility function

$$u(c_t^y, c_{t+1}^o, \pi_t, \pi_{t+1}) = \frac{(c_t^y)^{1-\sigma}}{1-\sigma} - \gamma \log \pi_t + \beta \frac{(c_{t+1}^o)^{1-\sigma}}{1-\sigma} - \gamma \log \pi_{t+1},$$

- Cobb-Douglas production function

$$f(k) = Ak^\alpha.$$

- Household's solution:

$$\begin{aligned} c_t^y &= \frac{\beta^{-1/\sigma} R_{t+1}^{1-1/\sigma} (1+a\tau^e)^{-1/\sigma}}{1+\beta^{-1/\sigma} R_{t+1}^{1-1/\sigma} (1+a\tau^e)^{1-1/\sigma}} w_t, \\ c_{t+1}^o &= \frac{R_{t+1}}{1+\beta^{-1/\sigma} R_{t+1}^{1-1/\sigma} (1+a\tau^e)^{1-1/\sigma}} w_t, \\ s_t &= \frac{1}{1+\beta^{-1/\sigma} R_{t+1}^{1-1/\sigma} (1+a\tau^e)^{1-1/\sigma}} w_t. \end{aligned}$$

# Example: CES

## Direct effect

- $\frac{1}{\sigma}$: intertemporal substitution elasticity between consumptions in two periods.
- $\frac{dc_t^y}{d\tau^e} < 0$.
- If $\sigma < 1$, then $\frac{ds_t}{d\tau^e} > 0$; $< 0$ otherwise.

# Example: CES
## Firm's problem

$$w_t = A(1-\alpha)k_t^{\alpha},$$

$$R_t = \frac{A\alpha k_t^{\alpha-1}}{1+\tau^r}$$

# Example: CES
## Steady state

In equilibrium, we have

$$k_{t+1} = \frac{1}{1+n} s_t$$

and the steady state per capita capital is determined by the follows

$$(1+n)(k^*)^{1-\alpha} = A(1-\alpha) - (1+n)\beta^{-1/\sigma}\left(\frac{A\alpha(1+a\tau^e)}{1+\tau^r}\right)^{1-1/\sigma}(k^*)^{\frac{1-\alpha}{\sigma}}. \tag{1}$$

**Lemma**

*There exists one unique steady state per capita capital stock $k^*$ which is determined by the equation (1).*

**Lemma**

*If $\sigma < 1$, $\frac{dk^*}{d\tau^e} > 0$ and $\frac{dk^*}{d\tau^r} < 0$; if $\sigma > 1$, then $\frac{dk^*}{d\tau^e} < 0$ and $\frac{dk^*}{d\tau^r} > 0$.*

Consider the case where $\sigma < 1$.

Conjecture: The sign of $\Pi$ depends on the initial value of $g$, $\tau^e$ and $\tau^r$. If the initial $g$ is small, $\Pi < 0$; if $g$ is large, then $\Pi > 0$.

$$
\begin{aligned}
g &= a\tau^e c^y + \tau^r Rk^* \\
&= a\tau^e c^y + \frac{\tau^r}{1+\tau^r}\alpha f(k^*). \\
&\equiv H(\tau^e, \tau^r)
\end{aligned}
$$

The first and the second terms can be both viewed to have a laffer curve effect.

$$\frac{dH}{d\tau^e} ? 0$$

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## Conjecture (continued)

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- $\frac{\tau^r}{1+\tau^r}\alpha f(k^*)$
  - keeping $\tau^r$ fixed, this part of revenue also goes up with a higher $\tau^e$, since $\frac{dk^*}{d\tau^e} > 0$.

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- $\frac{dH}{d\tau^e} > 0$.

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  - Laffer curve effect.

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- As $\tau^r$ is small, the negative effect of $k^*$ is small, implying $\frac{dH}{d\tau^r} > 0$.

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- As $\tau^r$ is small, the negative effect of $k^*$ is small, implying $\frac{dH}{d\tau^r} > 0$.
- As $\tau^e$ is large, the rate effect may be dominated by the negative effects, implying $\frac{dH}{d\tau^r} < 0$.

- Combining the signs of $\frac{dH}{d\tau^e}$, $\frac{dH}{d\tau^r}$, we can see that when $\tau^r$ is small, a higher $\tau^e \longrightarrow g$ increases.

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- In order to hold $g$ constant, we need to decrease $\tau^r$ since $\frac{dH}{d\tau^r} > 0$.
- When $\tau^r$ is large, to hold $g$ constant, we need to increase $\tau^r$ because of $\frac{dH}{d\tau^r} < 0$.

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- Guess: depends on parameters ($\alpha$, $g$, etc).

- A better environment quality as we raise $\tau^e$?
  - Uncertain.
  - $\tau^e \nearrow$, $c^y \searrow$; but $k^* \nearrow$, i.e., $c^y \nearrow$; and $\tau^r \searrow$ in order to keep government budget sheet balanced, causing $k^* \nearrow$ and $c^y \nearrow$.
- The welfare effects of the fiscal reform is uncertain.
- Guess: depends on parameters ($\alpha$, $g$, etc).
- Will need to do simulation.

# Conclusion

- If $\sigma < 1$ (a higher intertemporal substitution elasticity), a higher pollution tax may cause a less distortionary capital tax if the initial $g$ is small.
- However, the "double dividend" hypothesis is unverified:
  - depends on many parameters
  - Intertemporal elasticity of substitution ($\sigma$)
  - Capital intensity ($\alpha$)
  - Initial government expenditure ($g$)
- Future exploration:
  - Work on the numerical simulation using OLG-CGE method.
  - Compare the difference between recycling by capital tax vs. labor tax.
  - Consider the effect on the social security tax.

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