Impact of Urban Policies on CO_2 Emissions with Particular Regard to Demand Elasticity of Floor Space

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CO_2 emissions caused by urban residents' energy consumption arise from transportation and housing energy consumption. The current study quantitatively examines the effect of congestion tolls and carbon tax on urban structure, benefits, and CO_2 emissions in cities with multiple income elasticities of housing consumption. The results are as follows. When the income elasticity of housing consumption is 1, the benefit of the congestion tax is equivalent to about 56% of the first-best, and the benefit of the carbon tax is about 42%. Regarding CO_2 emissions, our simulations show that, among each urban activity (residential energy consumption, commuting, and composite goods consumption), the composite goods consumption has the largest CO_2 emissions per yen. The CO_2 emissions from composite goods consumption are larger with income elasticity of 1 than with those of 0 and 0.45. In total, CO_2 emissions are similarly larger with income elasticity of 1 than with those of 0 and 0.45. We find that price elasticity of housing consumption also affects CO_2 emissions.

Key words: *CO2 emissions, congestion, Pigovian tax, income elasticity, price elasticity*

1. Introduction

Global warming is a worldwide problem which can cause various unpredictable disasters. CO2 emissions caused by urban residents' energy consumption arise from 1) transportation and 2) residential energy consumption. Pigovian tax is a solution to congestion as well as CO2 emissions. Carbon tax and congestion tolls can decrease individual energy consumption.

Domon et al. (2021) quantitatively examines the effectiveness of 1) congestion tolls, 2) carbon tax on the social welfare and reduction of urban CO2 emissions. Results show that the distribution of the tax revenue generates a large amount of CO2 emissions, which exceeds the saving in the CO2 emissions in housing energy and commuting in congestion tolls. This is because, total return of tax revenue and land rent income was used exclusively for consumption of composite goods due to there being no income effect on housing space. If the policy is conducted in cities with a large income elasticity of housing, and if the policy increases incomes, the amount of CO2 emissions increases owing to increased housing energy consumption rather than increased composite consumption.

With this background, we study the externalities of congestion and CO_2 emissions and numerically evaluate the impact of urban policies on urban structure, social welfare, and CO_2 emissions in cities with multiple income elasticities of housing consumption. We quantitatively examine the effectiveness of 1) congestion tolls and 2) carbon tax.

2. Model

The model introduces environmentally-related factors such as temperature and energy use into a spatial general equilibrium model of a congested monocentric city. The residential area in the city expands from at the edge of the central business district (CBD) to at the urban boundary. The model city we target is Sendai in Japan. A household can choose one location within the city to resident. The annual utility of a household is assumed to be composed of a partial utility function of housing space, denoted by q and numeraire composite goods, denoted by z, and another partial utility of temperatures in summer and winter, denoted $t_c(m)$ for $m \in summer$ and $t_h(m)$ for $m \in winter$. The utility function is given by

$$v = g(q,z) + h(t_c(m)_{m \in summer}, t_h(m)_{m \in winter}). \quad (1)$$

$g(q,z)$ is a Stone-Geary type utility function of housing space and composite goods. The reason for using this utility function is that the income elasticity of demand with respect to floor area can be set lower than 1.

$h(t_c(m)_{m \in summer}, t_h(m)_{m \in winter})$ is a concave function of monthly room temperatures with air-conditioning. The household utility is maximized subject to the budget constraint given by

$$(1+\tau_2 c_z)z + q(p+\phi) + \varphi = y - k(x) + I_L + I_T. \quad (2)$$

Here, τ_2 is carbon tax per unit of CO_2 emissions, and c_z is the amount of CO_2 arising from per-amount production of composite goods. y is the household income per year. $k(x)$ is the round-trip commuting cost from x to the workplace in the CBD. I_L and I_T are the returns from the land rent revenue and the tax revenue, respectively. I_L and I_T will be formulated after the definition of land rents and tax revenues. x is distance from the edge of the CBD.

We use equivalent variation (EV) as a benefit index. The total of EVs of urban residents constitutes the benefits of each policy. In addition, the global environmental externalities due to CO_2.emissions arising from the target city changes according to the policies. So, we consider the change from no policy in the environmental externalities, $E_{no\,policy} - E_{Regime}$. The benefit of a policy is described as,

$$B_{Regime} = \int_0^{\bar{x}} n(x)EV(x)dx \quad + E_{no\,policy} - E_{Regime}. \quad (3)$$

The EV of a resident in the current model is defined by the minimum amount required for achieving the utility with no policy after a policy is implemented.

The global environmental externalities due to CO_2 emissions is defined by

$$E = e\int_0^{\bar{x}} 2\pi x \rho_h D(x)\{E^z(x) + E^r(x) + E^c(x) + E^H\}dx \quad (4)$$

$E^z(x)$ expresses the CO_2 emissions indirectly arising from consumption of the composite goods. $E^r(x)$ is the amount of CO_2 emissions arising from electricity at home. $E^c(x)$ is the CO_2 emissions arising from the residents' commuting. We set the effect of CO_2 emissions on the global welfare as an identical value, e in eq. (4).

3. Numerical Simulations

We present four numerical results: (i) the laissez faire (baseline), (ii) congestion toll regime, (iii) carbon tax, (iv) congestion toll regime and carbon tax (first best). we set carbon tax (price) is 2,500 yen/tC.

First, we show the results for income elasticity of 1. The numerical results are presented in Table 1. Benefit in congestion toll regime (ii) is the second largest. The radius of the city decreases from the equilibrium boundary in regimes that include a congestion tax. In the four regimes, the amount of total CO2 emissions is the smallest in the carbon tax regime (iii). Congestion toll regime would (ii) increase CO2 emissions. The CO_2 emissions arising from the urban activities (housing energy consumption and commuting) are drastically decreased in regime (ii) and (iv).

Next, We show the results for income elasticity of 0.45. The numerical results are presented in Table 2. The benefit in congestion toll regime (ii) is the second largest. CO_2 emissions decrease in all regimes. Among them, the case of the first best regime (iv) had the smallest CO_2 emissions. CO_2 emissions in regime (ii) is the second largest. The smallest reduction was in the carbon tax regime. The difference between income elasticities of 1 and 0.45 is whether total CO_2 emissions decrease when a congestion tax is imposed. This difference can be explained by the price elasticity of housing space. In regimes (ii) and (iv), the city becomes more compact and the housing rent near the CBD increases. When the income elasticity and price elasticity of 1 is 1, this increase in floor rents results in spending on housing decreases. That decrease in budget increases the consumption of composite goods through budget constraints. CO_2 emissions per yen for the consumption of composite goods are larger than the energy consumption in a house. Therefore, CO_2 emissions decrease when a congestion tax is imposed when income elasticity is 0.45.

Table 1. numerical results
(income elasticity and price elasticity of 1)

Regime		(i)	(ii)	(iii)	(iv)
Benefit	(10^10 yen)		1.42	1.07	2.54
Benefit gains	(%)		56	42	100
Urban boundary	(km)	10.0	9.0	10.0	9.0
CO2 emissions					
Total	(10^6 tCO2)	6.28	6.28	6.26	6.26
Difference	(%)		0.036	-0.35	-0.34
Housing energy (without distribution)	(10^6 tCO2)	1.60	1.47	1.60	1.48
Difference	(%)		-7.8	0.32	-7.5
Commuting	(10^6 tCO2)	0.342	0.272	0.341	0.272
Difference	(%)		-20	-0.06	-20
Composite goods	(10^6 tCO2)	4.30	4.41	4.26	4.37
	(%)		2.5	-0.87	1.6

Finally, we show the CO_2 emissions per yen for each urban activity (i) the laissez faire for an income elasticity of 1. The CO_2 emissions per yen from composite goods are largest.

Table 2. numerical results
(income elasticity and price elasticity of 0.45)

Regime		(i)	(ii)	(iii)	(iv)
Benefit	(10^10 yen)		1.33	1.23	2.52
Benefit gains	(%)		53	49	100
Urban boundary	(km)	10.0	9.0	10.0	9.0
CO2 emissions					
Total	(10^6 tCO2)	6.36	6.34	6.35	6.33
Difference	(%)		-0.29	-0.23	-0.53
Composite goods	(10^6 tCO2)	4.51	4.58	4.49	4.55
	(%)		1.4	-0.48	0.92

Table 3. numerical results (income elasticity of 1)

Regime	(Unit: 10^-6 tCO2/yen)			
	(i)	(ii)	(iii)	(iv)
Housing energy	2.12	2.02	2.10	2.00
Commuting	2.05	1.06	2.04	1.05
Composite goods	2.53	2.53	2.51	2.51

4. Concluding Comments

One of our findings is that the CO_2 emissions from consumption of composite goods increase when income elasticity is 1 compared to when income elasticity is 0 and 0.45. In addition, our simulations show that it is important to consider both price elasticity and income elasticity to estimate the amount of CO_2 emissions.

References

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