Who bears the burden of a tax on carbon emissions in Japan?

By: Don Fullerton and Garth Heutel

"Who Bears the Burden of a Tax on Carbon Emissions in Japan?" (with Don Fullerton), *Environmental Economics and Policy Studies*, Vol. 8, No. 4 (2007), 255-270.

Abstract:
We develop a simple general equilibrium model in the style of Harberger to analyze the distributional effects of the proposed "environment tax" on carbon in Japan. We derive closed-form equations that show how a change in the tax rate affects the economy-wide return to capital, wage, and output prices. The two main features of the economy that determine the sources-side incidence of the tax are the factor intensities of the polluting and nonpolluting industries and the elasticity of substitution in production between polluting inputs and labor or capital. The input that is a better substitute for pollution usually bears a lower burden of the tax than the other input, although we find conditions under which this is not true. If the polluting sector is relatively capital intensive, then capital can bear a higher burden of the tax. Calibrating this model to the Japanese economy, we find a trade-off between these two effects. Polluting industries are more capital intensive, but capital is likely to be a better substitute for pollution than is labor.
Key words: Tax incidence, Pollution, Carbon tax, Kyoto Protocol, Japan

Article:
1 Introduction
Much debate surrounds the proposed introduction in Japan of an "environmental tax" on carbon emissions. A great deal of this debate centers on the question of who will ultimately have to pay the costs of the tax and who will reap the benefits. While estimates indicate that the average family will have to pay about 3000 Japanese Yen (about $30 US) per year due to the tax, some families will bear a higher burden than others. A careful analysis of the proposed policy must contain a discussion of the incidence of the tax. While the tax may be successful at its primary goal of helping Japan meet its obligations under the 1997 Kyoto Protocols, it may carry some unintended and unwanted distributional side effects. If the tax is too regressive, it may not be the most preferred policy choice to reach the desired reduction in carbon emissions. Indeed, one of the four long-term objectives of Japan's 1994 Basic Environmental Plan is to ensure that all parties share the burden of environmental policy fairly.

Many articles focus on tax incidence, using both analytical models and numerical simulations. We use as our starting point the quintessential analytical model of the general equilibrium incidence of a tax on capital, the Harberger model (Harberger 1962). It provides a simple two-sector, two-input model that can be linearized and solved to see how a tax on one factor in one sector affects the prices of both factors in both sectors. The change in the prices of labor and capital shows how owners of those two factors are burdened by the tax as it passes through the economy via general equilibrium effects. The Harberger model is simple, which can be both an advantage and a liability. It is easy to see how the results are affected by certain parameters, such as factor intensities and substitution elasticities. However, a large number of simplifying assumptions are employed, and one should use caution in interpreting any numerical estimates derived from the model.

In this article, we solve for the incidence of the proposed Japanese environment tax by applying an extension of the Harberger model. This extension has previously been used to analyze a broad range of environmental taxes and other policies in the United States (Fullerton and Heutel 2005, 2007). We find explicit analytical expressions for the changes in the wage rate and the capital rental rate due to the tax. These expressions show

how economic parameters determine the distribution of the burden of the tax. Then, we use the model to generate numerical estimates of the size of these price changes. By using a range of reasonable parameter values, we can see the sensitivity of these estimates to the assumptions in the model.

Many studies investigate environmental taxation, but the main focus is usually on efficiency, for example, solving for the optimal pollution tax or determining how pollution taxes affect labor supply. Fewer studies have considered the distributional effects of taxes, and most of those use a partial equilibrium model or a computable general equilibrium (CGE) model. Robison (1985) solves for the effect of policy on output prices; West and Williams (2004) empirically estimate the distribution of the burden of a gasoline tax; and Metcalf (1999) studies how the return of tax revenue affects the regressivity of a tax. Unlike those articles, ours contains a simple and interpretable analytical general equilibrium model that can provide intuition for results reached by more complex models.

Our main analytical results concern how factor intensities and substitution elasticities affect the incidence of the tax. Intuitively, we expect that if the taxed sector (the "dirty" sector) is capital intensive, then a pollution tax would hurt capital more than labor. We find that this outcome is likely, but we give a condition under which it does not hold. Likewise, intuition suggests that the factor that is a better substitute for pollution is hurt less than the other factor, but we find a condition under which this intuition fails as well. Applying reasonable parameter values to the model, we find a trade-off between these two effects on the burden of the environment tax in Japan. The heaviest emitting industries are capital intensive, but capital is likely to be a better substitute for emissions than labor.

Section 2 briefly discusses the history of Japanese environmental policy and the environment tax. In Sect. 3, we present the model and summarize some analytical results. Section 4 provides numerical estimates of the distributional impacts of the environment tax, and Sect. 5 concludes.

2 Japanese environmental policy and the environment tax

The Environmental Agency of Japan, founded in 1971 to address ecological and environmental issues, was restructured into the Japanese Ministry of the Environment (MOE) in 2001. The centerpiece of environmental legislation in Japan is the Basic Environment Law, which passed in 1993. Before this law was passed, most Japanese environmental policies were based on two laws: the Basic Law for Environmental Pollution (1967) and the Nature Conservation Law (1972). The Basic Environment Law outlines the direction for Japanese environmental policy. Essential to the law is Article 15, the Basic Environment Plan (BEP), established on December 16, 1994.

Forecasting through the middle of the twenty-first century, the BEP establishes objectives and sets out expectations for local governments, corporations, citizens, and private organizations. The BEP sets four long-term objectives: sound material cycle, harmonious coexistence, participation, and international activities. The third of these long-term objectives, participation, demonstrates the importance of distributional issues to policy makers in Japan. In describing the purpose behind the objective, the BEP reads:

> Each sector of society, each party, must assume its fair share of burden, according to the environmental load they generate, the benefits they enjoy, and the capability they have to contribute to environmental conservation. In so doing, it is indispensable that all parties recognize they generate environmental load, either directly or indirectly, through daily business activities or everyday living.[1]

This wording, taken from the introduction to a section describing one of the four main pillars of Japan's major environmental policy, explicitly states the importance of distributional concerns. Demanding that each sector pay a "fair" share of the burden of environmental policy underscores the need for research such as the tax incidence analysis presented here. Although we make no claim about what share of the burden is "fair," we take an important first step toward that policy objective by solving for the burden on different parties, including investors, laborers, and different types of consumers.

While the BEP remains the central piece of domestic environmental legislation, another main policy focus is the Kyoto Protocol, the international agreement to reduce global emissions of greenhouse gases. Because Japan was the host country of the forum in which the agreement was drafted in December 1997, the MOE desires to take the lead among countries in ensuring its implementation. A main element of the Kyoto Protocol is the national goals in carbon emissions reductions. Japan is required to reduce its carbon emissions by 6% from its 1990 levels between 2008 and 2012. However, emissions grew 17% from 1990 to 2001, meaning that a reduction of 20% from 2001 levels is necessary to meet the Kyoto goal. While Japan has demonstrated and declared commitment to the Kyoto Protocol, it remains a major emitter. As of 2001, Japan was the world's fourth largest energy consumer, accounting for 5.4% of the world's total, and 4.8% of the world's energy-related carbon emissions. Its per capita energy consumption, however, is lower than most G7 nations and is about one half that of the United States.[2]

Emissions standards have long been a part of Japanese environmental policy and were last amended in 1998. While SO_2 emissions have steadily decreased since the 1960s, NO levels have been stagnant. The effect of stricter environmental regulation is offset by the increased number of vehicle-miles driven. To strengthen regulation enough to meet the Kyoto standards, the Japanese government has announced that it will levy a tax on carbon emissions, dubbed the "environment tax," at a rate of 2400 yen per one ton of carbon emissions. The Japanese people will have to pay higher taxes on gasoline, light oil, home oil, electricity, and natural gas. It is estimated that the average family will pay 3000 yen annually, yielding government revenue of 490 billion yen. The majority of this revenue, 340 billion yen, is earmarked for use in emissions-reducing programs, and the rest will be used for social insurance.

The implementation of the tax will not come without controversy. Although complaints have been raised about the portion of revenue being used on the state's pension system, the main opposition comes from business groups. At a September 17, 2004 news conference, Akio Mimura, chairman of the Japan Iron and Steel Federation, warned that the tax would force steelmakers to move their plants abroad, estimating that the steel industry would have to pay an additional 150 billion yen per year. The Petroleum Association of Japan accused the government of dumping its responsibility onto industry, and Nippon Keidanren (Japanese Business Federation) endorses voluntary agreements to reduce greenhouse gas emissions.[3] Japan's Industry Minister and Finance Minister have both been reluctant to support the measure, and Hiromitsu Ishi, chairman of the government's Tax Commission, has questioned whether the tax will even be implemented. While the MOE supports the environment tax, claiming that it will reduce carbon emissions by 4%, the Economy, Trade, and Industry Ministry opposes the tax. A more lukewarm reaction was provided by an official at the Finance Ministry, who suggested renaming it rather than rescinding it: "If the aim is to reduce greenhouse gases, it shouldn't be called a tax. It should be called a surcharge, for example." The opposition to the tax may be working, because it appears that the government is backtracking its support of the tax. A draft plan compiled in March 2005 by the Global Warming Prevention Headquarters, a group headed by the then Japanese Prime Minister Junichiro Koizumi, said merely that the tax would be considered "with sincerity."[4] The responses to the tax listed above underscore the political importance of distributional issues. Even if the law did not mandate that all parties assume a "fair share of the burden" of policy, charges of an unfair distribution threaten the policy's solvency.

Few studies of the Japanese environment tax appear in the economics literature. Park (2004) notably examines the possibility of a "double dividend" in the context of the tax using a computable general equilibrium analysis with 16 production sectors. Some analyses of other Japanese environmental policies are available.[5] Kochi et al. (2001) perform a cost—benefit analysis on Japan's SO_2 emissions control policy. They conclude that the benefit—cost ratio has decreased from 5.39 (in 1968-1973) to 1.18 (1974-1983) to 0.41 (1984-1993), indicating that the policy has become less efficient over time. As the policy includes mainly command and control (CAC) regulations, the authors interpret this finding as a tacit endorsement of using economic incentives such as taxes. Popp (2006) examines the innovation and diffusion of pollution control technologies across nations, focusing on Japan, Germany, and the United States. He finds evidence that a tightening of environmental regulations led to increased domestic innovation of abatement technologies in Japan. A number of case studies examine specific Japanese policies or environmental problems. Welch and Hibiki (2003) analyze the voluntary agreements of a

Japanese city, Kita Kyushu. Hayami et al. (2003) examine international cooperation for clean development mechanisms (CDMs), particularly the relationship between China and Japan for developing biocoal briquette (biobriquette) to replace coal. Yoshida et al. (1999) study the itai-itai disease case, an infamous example of cadmium poisoning at the Kamioka mine.

3 Model

The model presented here is very similar to the one found in Fullerton and Heutel (2007). As in the original Harberger (1962) model, this economy consists of two sectors producing two different goods, the "clean" good *(X)* and the "dirty" good (Y). The clean sector uses only capital and labor in production, while the dirty sector uses capital, labor, and pollution:

$$X = X(K_x, L_X)$$
$$Y = -Y(K_\gamma, L_\gamma, Z)$$

In these two production functions, K_x and L_x represent the capital and labor used by sector X, with K_γ and L_γ defined similarly. Pollution us denoted by Z and is modeled as an input to production rather than as a joint byproduct. The production function could be rewritten so that both output and pollution appear on the left-hand side. We keep pollution as an input to allow a simple representation of producers' ability to substitute among capital, labor, and pollution.

We assume that capital and labor are both fully employed, in fixed total quantity, and perfectly mobile between sectors. That is,

$$K_X + K_Y = \bar{K}$$
$$L_X + L_Y = \bar{L},$$

where $\bar{K}$ and $\bar{L}$ are the fixed total amounts of capital and labor in the economy. We totally differentiate the capital constraint to get:

$$\hat{K}_X\lambda_{KX} + \hat{K}_Y\lambda_{KY} = 0, \quad (1)$$

where $\lambda_{KX} \equiv \frac{K_X}{\bar{K}}$ is the share of capital in the economy that is employed in sector X, and λ_{KY} is defined analogously. A hat represents a proportional change (e.g., $\hat{K}_X \equiv \frac{dK_X}{K_X}$). Applying the same technique to the labor constraint yields:

$$\hat{L}_X\lambda_{LX} + \hat{L}_Y\lambda_{LY} = 0, \quad (2)$$

with all variables defined analogously. Pollution is used only by the dirty sector and is not in fixed supply, so the model has no pollution constraint.

Each sector faces the same price of capital, *r*, and price of labor, w. In the clean sector, the decision between those inputs is described by σ_x, the elasticity of substitution in production between capital and labor:

$$\widehat{K}_x - \hat{L}_x = \sigma_x(\widehat{w} - \hat{r}). \quad (3)$$

Again, $\widehat{w}$ and $\hat{r}$ are defined as proportional changes in the input prices. In the dirty sector, the choice of inputs is more complicated because firms choose among three inputs rather than two. While firms face no private price for pollution, they do have to pay a specific tax on their emissions, τ_z. We follow Mieszkowski (1972) in modeling this choice of inputs. Details of this method are available in Fullerton and Heutel (2005a). Two equations are needed to describe the dirty sector's input choices:

$$\hat{K}_Y - \hat{Z} = (a_{KK} - a_{ZK})\hat{r} + (a_{KL} - a_{ZL})\hat{w} + (a_{KZ} - a_{ZZ})\hat{\tau}_Z, \quad (4)$$

$$\hat{L}_Y - \hat{Z} = (a_{LK} - a_{ZK})\hat{r} + (a_{LL} - a_{ZL})\hat{w} + (a_{LZ} - a_{ZZ})\hat{\tau}_Z. \quad (5)$$

The parameter a_{ij} represents the input demand elasticity of input *i* with respect to the price of input *j*. It is shown that this elasticity equals $e_{ij}\Theta_{Yj}$, the Allen elasticity of substitution (e_{ij}) times the share of factor *j* in total costs (Θ_{Yj}) (Allen 1938). Under this specification, the model allows both capital and labor to be either a substitute or a complement to pollution, and the magnitudes of the elasticities indicate which input is a better substitute for pollution.

By assuming constant returns to scale production technologies and perfect competition in both sectors, we get two zero-profit conditions. We differentiate these, along with the production functions themselves, and substitute in firms' first-order profit-maximizing conditions, to yield:

$$\hat{p}_X + \hat{X} = \theta_{XK}(\hat{r} + \hat{K}_X) + \theta_{XL}(\hat{w} + \hat{L}_X) \quad (6)$$

$$\hat{p}_Y + \hat{Y} = \theta_{YK}(\hat{r} + \hat{K}_Y) + \theta_{YL}(\hat{w} + \hat{L}_Y) + \theta_{YZ}(\hat{p}_Z + \hat{Z}) \quad (7)$$

$$\hat{X} = \theta_{XK}\hat{K}_X + \theta_{XL}\hat{L}_X \quad (8)$$

$$\hat{Y} = \theta_{YK}\hat{K}_Y + \theta_{YL}\hat{L}_Y + \theta_{YZ}\hat{Z} \quad (9)$$

where θ_{ij} is the share of factor *j* in sector *i* (e.g., $\theta_{YK} \equiv \frac{rK_Y}{p_Y Y}$). Finally, consumer utility is modeled by an elasticity of substitution in consumption σ_u. The relationship between output prices p_X and p_Y and the quantity of each final good demanded is

$$\hat{X} - \hat{Y} = \sigma_u(\hat{p}_Y - \hat{p}_X). \quad (10)$$

Equations 1-10 show all of the endogenous changes to prices and quantities due to an exogenous change in the pollution tax τ_Z. The system of equations has 11 unknowns, so it cannot be solved without choice of a numeraire. We set $\hat{p}_x$, = 0, so that good *X* is numeraire, and all price changes are relative to this price.[6] Because we are primarily concerned with the *relative* burden of the tax, this choice of numeraire does not alter our results.

The solutions are expressed in terms of changes in prices relative to the numeraire. The main conclusions are about which factor bears a disproportionate burden of the tax. If we find that the wage rate falls and the capital rental rate rises, for example, it does not mean that capital owners are absolutely better off. Rather, it means that laborers bear a fraction of the tax that is higher than their share in national income. Although the return to capital relative to the numeraire rises, in real terms this return may still fall. Throughout the article, we express our incidence results relative to the numeraire, because our concern is the relative burden of the tax. Our choice of numeraire implies that the change in the wage and the change in the rental rate are always of opposite sign (relative to the numeraire),[7] but this does not mean that one factor is better off and one is worse off after the policy change. It means that one factor is relatively worse off than the other factor.

The Appendix lists the general solutions to this system for the changes in the wage, the capital rental rate, the price of the dirty good, and the amount of pollution emitted. Because of their length and the difficulty in interpretation, we choose to isolate specific effects, like substitution effects and output effects, by focusing on special cases. In the first special case, we assume equal factor intensities. That is, we set $L_Y/L_X = K_Y/K_X$. Under this condition we can isolate the effect of substitution elasticities.[8] The solutions for the endogenous price changes are:

$$\hat{p}_Y = \theta_{YZ}\hat{\tau}_Z$$

$$\hat{w} = \frac{-\theta_{XK}\theta_{YZ}\gamma(e_{KZ} - e_{LZ})}{D_1}\hat{\tau}_Z$$

$$\hat{r} = \frac{\theta_{XL}\theta_{YZ}\gamma(e_{KZ} - e_{LZ})}{D_1}\hat{\tau}_Z$$

where $D_1 \equiv \sigma_X - \theta_{XL}\theta_{YK}\gamma(e_{KK} - e_{KL}) - \theta_{XK}\theta_{YL}\gamma(e_{LL} - e_{KL})$ and $\gamma \equiv \frac{L_Y}{L_X} = \frac{K_Y}{K_X}$. The expression tor $\hat{p}_y$ gives the uses-sloe incidence, which is unambiguous: the price of the dirty good rises relative to the price of the clean good. Hence, consumers who spend more than average on the dirty good bear a disproportionately high burden. On the sources side, the sign of the changes in the factor prices is determined by the sign of $e_{KZ} - e_{LZ}$.This term is positive whenever capital is a better substitute for pollution than is labor. From Eqs. 4 and 5, if $e_{LZ} > e_{KZ}$, then when the price of pollution increases, the quantity demanded of labor increases more than the quantity demanded of capital, that is, labor is a better substitute for pollution than is capital.[9] Suppose for now that $D_1 > 0$. If $e_{LZ} > e_{KZ}$, then the wage rate increases and the rental rate decreases after an increase in the pollution tax. This result matches intuition.

However, this result is reversed when $D_1 < 0$. It can be shown that this inequality holds under the following condition:

$$e_{KL} < \frac{-\sigma_X + \theta_{XL}\theta_{YK}\gamma e_{KK} + \theta_{XK}\theta_{YL}\gamma e_{LL}}{\gamma(\theta_{XL}\theta_{YK} + \theta_{XK}\theta_{YL})}.$$

The right-hand side of this inequality is negative. Therefore, D_1 can be negative only if e_{KL} is even more negative, that is, if capital and labor are sufficiently complementary inputs (Allen 1938). When D_1 is negative, the factor that is a better substitute for pollution is actually worse off after an increase in the pollution tax.

The explanation for this surprising result is as follows. Suppose that capital and labor are sufficiently complementary, and suppose that capital is a better substitute for pollution. When the pollution tax is increased, firms in the dirty sector demand more capital and more labor, but the substitution effect means that their increase in demand for capital is greater than their increase in demand for labor. However, because labor is a complement to capital, the increased use of capital increases their demand for labor. If this second effect dominates the primary effect, then labor demanded increases more than capital demanded. The price of labor in general equilibrium rises relative to the price of capital. Therefore, capital is hurt more than labor, even though it is a better substitute for pollution.

The second special case that we focus on eliminates any substitution effects and focuses only on output effects caused by differential factor intensity. We drop the assumption of equal factor intensity, but instead we assume that all of the Allen elasticities of substitution for the dirty sector are equal to zero. This implies that $a_{ij} = 0$ for all i,j, or that firms in the dirty sector must use all three inputs in the same proportion, regardless of any change in relative prices. Under this assumption, the solutions for the effect of a change in the pollution tax on prices are:

$$\hat{p}_Y = \frac{C\sigma_X\theta_{YZ}}{D_2}\hat{\tau}_Z$$

$$\hat{w} = \frac{(\gamma_K - \gamma_L)\theta_{XK}\theta_{YZ}\sigma_u}{D_2}\hat{\tau}_Z$$

$$\hat{r} = \frac{-(\gamma_K - \gamma_L)\theta_{XL}\theta_{YZ}\sigma_u}{D_2}\hat{\tau}_Z$$

Here $D_2 = C\sigma_X - (\gamma_K - \gamma_L)\sigma_u(\theta_{XK}\theta_{YL} - \theta_{XL}\theta_{YK})$, $\gamma_K \equiv \frac{K_Y}{K_X}$, $\gamma_L \equiv \frac{L_Y}{L_X}$, and $C - \theta_{XK}\lambda_{KY}/$

$\Lambda_{KX} + \Theta_{XL}\lambda_{LY}/\lambda_{LY} + 1$. It can be shown that D_2 and C must be positive. On the uses side we reach the same result; the price of the dirty good increases. On the sources side, the input that bears a higher burden is determined by the sign of $\gamma_K — \gamma_L$. The sign of this term indicates factor intensity; it is positive if the dirty sector is capital intensive. Then, according to the equations above, an increase in the pollution tax hurts capital disproportionately more than labor. The intuition is as follows. An increase in the price of pollution would normally cause the dirty sector to substitute into other inputs, but in this special case that is impossible (all a_{ij} = 0). All that the dirty sector can do is to reduce demand for all inputs by the same proportion. If the dirty sector uses relatively more capital than the clean sector, then its decreased demand for capital counts more in general equilibrium than its decreased demand for labor, and the price of capital falls. This is a pure output effect, because any possibility of substitution has been assumed away.[10]

4 Numerical analysis

We calibrate the model's parameters to quantify the results described above. While the main results of the article are in the theoretical section above, this simulation exercise helps to determine how the magnitudes of the results are affected by the parameters. The numerical results we present below are not meant to be predictions of the full impact of the environment tax, because the model is not rich enough to capture all possible responses to the policy. Instead, the simulations merely attach numbers to the theoretical results proven above.

4.1 Calibration

To calibrate this model to the Japanese economy, we must first choose which industries are "dirty" and which are "clean." According to the model, only dirty industries emit pollution. More generally, it can be interpreted that only dirty industries must pay for the pollution they emit. The clean sector may still emit pollution, but if it pays no price for pollution, then its choice of capital and labor inputs is based only on the relative price of the two inputs. While the environment tax applies to most carbon emissions from all industries,[11] we define the dirty sector to include the following 11 industries: electricity, gas, and heat supply; chemical products; iron and steel; petroleum and coal products; foods; mining; nonferrous metals; pulp, paper, and wooden products; metal products; transportation equipment; and ceramic, stone, and clay products. In the United States, these industries account for a significant portion of the total economy-wide carbon emissions. Because they emit the most carbon, they will face the largest direct impact from the tax.

Table 1. Factor intensity from Japanese data

	1995	2000	Average
Parameter			
K_Y	13941211	13729137	13835174
K_X	85765020	82794597	84279809
L_Y	28508414	28905617	28707016
L_X	244652088	246683531	245667810
Factor intensity parameters			
λ_{KY}	0.1398229	0.1422359	0.1410098
λ_{KX}	0.8601771	0.8577641	0.8589902
λ_{LY}	0.1043651	0.1048866	0.104627
λ_{LX}	0.8956349	0.8951134	0.895373
θ_{XK}	0.2595659	0.2512901	0.2554339
θ_{XL}	0.7404341	0.7487099	0.7445661
θ_{YK}	0.2627342	0.257614	0.2601685
θ_{YL}	0.5372658	0.542386	0.5398315

Data given in million yen (nominal)

Data on the employment of labor and capital in each industry in Japan are available for 1995 and 2000 from the Statistics Bureau of the Ministry of Internal Affairs and Communication.[12] These data include total labor compensation by each sector and total "operating surplus," which we use for the return to capital. This value includes corporate profits, and it may be sensitive to economic fluctuations. Thus, it imperfectly represents the true value of capital stock. To smooth out possible errors, we use the data from both 1995 and 2000, as well as the mean values of both years. Summary statistics from these data appear in Table 1. Here, the dirty sector represents about 11 % of the economy, whereas a previous policy simulation using this model applied to the US economy sets the dirty sector equal to 20% of the entire economy.[13] The dirty sector here is relatively capital intensive, consistent with previous research.[14]

From these data we calibrate the factor intensity parameters Θ_{ij} and λ_{ij} by normalizing all initial input prices to one[15] and supposing that the fraction of the dirty sector's revenue that is paid in pollution taxes is 20%.[16] These parameters are also presented in Table 1. The dirty sector is small but relatively capital intensive. Note that $\gamma_K - \gamma_L = K_Y/K_X - L_Y/L_X = 0.0473 > 0$, indicating the capital intensity of the Y sector.

We assign a value of unity to both σ_x the elasticity of substitution in production in the clean sector, and σ_u, the elasticity of substitution in consumption, consistent with previous estimations and simulations.[17] The last piece of information needed is the set of values of the input demand elasticities for the dirty sector, the a_{ij} parameters. While nine of these parameters appear in the model, they are fully determined by the factor share parameters and the six Allen elasticities. Furthermore, for any factor i, $a_{iL} + a_{iK} + a_{iZ} = 0$, which reduces the degrees of freedom to three. Therefore, all of the input demand elasticities are determined by the three cross-price Allen elasticities e_{KL}, e_{KZ}, and e_{LZ}. Unfortunately, as far as we know, these parameters have never been estimated where the three inputs are capital, labor, and pollution. Allen elasticities have been estimated with inputs of capital, labor, and *energy*. DeMooij and Bovenberg (1998) use estimates of these parameters from previous studies in their simulations. We use the same values they use in our base case: $e_{KL} = 0.5$, e_{KZ}, $= 0.5$, and $e_{LZ} = 0.3$. In this base case, then, capital is a slightly better substitute for pollution than is labor.[18]

The estimates of the Allen elasticities cited above suffer from two possible misspecifications. First, the third input is energy, not pollution. If these two inputs were used with a fixed ratio, so that every unit of energy used resulted in the same amount of emissions, then these elasticities would be identical. However, producers have some freedom to alter the ratio of energy inputs to carbon emissions. For example, they may use cleaner burning coal or install scrubbers to reduce emissions. The second misspecification of the Allen elasticities is that they were estimated using data from Western European countries, not Japan.[19] We allow these elasticities to vary in our simulations to accommodate the fact that they may provide only rough estimates of the true values in Japan.[20]

Table 2. Numerical analysis results of a 10% pollution tax increase

e_{LZ}	$\hat{w}$ (%)	$\hat{r}$ (%)	$\hat{p}_Y$ (%)	$\hat{Z}$ (%)
1995 factor intensities				
0	−0.0192	0.0547	2.0041	−3.1196
0.3	−0.0017	0.0050	2.0004	−4.8710
0.6	0.0156	−0.0446	1.9967	−6.4366
2000 factor intensities				
0	−0.0182	0.0543	2.0041	−3.0923
0.3	−0.0012	0.0037	2.0003	−4.7695
0.6	0.0157	−0.0467	1.9965	−6.4412
Average factor intensities				
0	−0.0187	0.0545	2.0041	−3.1059
0.3	−0.0015	0.0044	2.0003	−4.7753
0.6	0.0156	−0.0456	1.9966	−6.4389
Dirty sector capital twice as high				
0	0.0107	−0.0312	1.9921	−3.7426
0.3	0.0284	−0.0827	1.9791	−5.0050
0.6	0.0460	−0.1340	1.9661	−6.2630
Dirty sector capital half as much				
0	−0.0356	0.1039	1.9932	−2.5863
0.3	−0.0188	0.0549	1.9964	−4.5779
0.6	−0.0021	0.0061	1.9996	−6.5629

($e_{KZ} = e_{LZ} = 0.5$, $\sigma_X = \sigma_u = 1$, factor intensities listed in Table 1)

4.2 Simulations

Table 2 presents our numerical sensitivity analysis of the incidence results. The policy experiment is a 10% increase in the pollution tax.[21] We find solutions for the three sets of factor intensity parameters and for three different values of e_{LZ}, holding constant e_{KL} and e_{KZ}. Because the three sets of factor intensity parameters above do not vary much, we also provide two additional sets of those parameters with larger deviations from the average. First, we assume that the value of capital employed in the dirty sector is twice as high as it is in the average column in Table 1 and all other input values are the same as their values from that column. This greatly increases the capital intensity of the dirty sector. Second, we assume that the value of the dirty sector's capital is half as much as it is in Table 1. Under this scenario, the dirty sector is actually labor intensive.

Before turning to the incidence results in the $\hat{w}$ and $\hat{r}$ columns, consider the two other columns. The results for $\hat{p}_y$, the proportional change in the price of the dirty good, is about 2% in each calibration. This reflects the 10% tax increase on a factor that is 20% of a sector's expenses (10% x 20% = 2%). On the uses side, then, the incidence result is clear: consumers of the dirty industries' goods are hurt more than other consumers. The final column in Table 2, $\hat{Z}$, presents the effect of the tax on emissions. This value increases with e_{LZ}. Because a larger value of e_{LZ} implies easier substitution within the dirty sector, firms can more easily substitute out of pollution. As that elasticity varies from 0 to 0.6, a 10% tax increase decreases pollution by anywhere from 2% to 7%. The elasticity values are important not only for incidence results, but also for gauging the policy's impact on environmental quality. They also determine how much this tax will help to meet Japan's target reductions in carbon to meet the Kyoto Protocol.

The main results involve the changes to the wage and rental rate brought about by the environment tax. In the three sets of estimates under the calibrated factor intensity parameters for 1995, 2000, and the average, the wage decreases and the capital rental rate increases whenever e_{LZ} equals 0 or 0.3, but the opposite result holds when e_{LZ} equals 0.6. This shows how the variance in that substitution elasticity affects the magnitude of the burden of the tax that falls on each factor. As e_{LZ} increases, $\hat{w}$ rises and $\hat{r}$ falls, demonstrating the impact of factor substitutability on incidence. As labor becomes a better substitute for pollution, firms can more easily substitute away from pollution and into labor. The dirty sector therefore demands more labor as e_{LZ} increases, and, in general equilibrium, its price increases to meet this increased demand.

Under the last two sets of factor intensity parameters, the direction of incidence is independent of the substitution elasticity e_{LZ}; the wage falls when the dirty sector is labor intensive, and the wage rises when the dirty sector is capital intensive. Although labor is becoming a better substitute for pollution than is capital as e_{LZ} increases, in these simulations that effect is dominated by the effect of factor intensities.

The values in the $\hat{w}$ and $\hat{r}$ columns are quite small; neither factor's price changes by more than 0.06% in the simulations with the calibrated factor intensity parameters. This is expected, because we define the dirty sector to constitute only about 11% of the entire economy. Pollution accounts for 20% of their expenditure, and the tax rate is increasing by 10%, suggesting an impact in the order of 0.1% (11% x 20% x 10% = 0.22%). Our simple model clearly demonstrates how factor intensities and substitution elasticities impact the incidence of the tax.

5 Conclusions

We use a two-sector general equilibrium analytical model in the style of Harberger to analyze the impact of 1 he proposed Japanese "environment tax" on carbon emissions. The analytical model shows that if the polluting sector is capital intensive, the tax tends to fall more heavily on capital, and if capital is a better substitute for pollution than is labor, the tax tends to fall more heavily on labor. Data and previous estimates suggest that in the case of the Japanese economy, both of those conditions seem likely to hold, although numerical sensitivity analysis is imprecise due to the simplicity of the model. We show how altering the substitution elasticity or the factor intensity parameters alters the distribution of the burden of the tax.

The assumptions that we employ make the model much more tractable and interpretable, but they make it less likely to capture all of the determinants of tax incidence. For example, full employment and perfect mobility of capital and labor are more suitable assumptions to make when considering a closed economy or a large economy, such as the United States where external macroeconomic variables have no impact internally. If capital is perfectly mobile *internationally,* and if Japan is small, then a world price for capital is fixed, and capital in Japan bears *none* of the burden of the tax. Similarly, if dirty industries in Japan wield market power, then the zero-profit condition does not hold and the model yields incorrect results. However, the model is an important first step toward a more thorough analysis of the distributional impacts of the environment tax. Like the original Harberger (1962) model, this model can be significantly extended without abandoning the two-sector framework.[22] Extending the model to more than two sectors, and possibly creating a computable general equilibrium (CGE) model may yield other insights.

Japanese business leaders and Ministry officials have criticized the environment tax, claiming it will hurt business profits. The central piece of Japanese environmental legislation calls for all factors to bear a "fair" share of the burden of environmental policy. Our results are not to be interpreted as claiming that capital will be forced to bear an "unfair" share of the tax. The fair burden on capital may indeed make it relatively worse off than labor; that judgment is not within the scope of this research. It is, however, up to policymakers at some level to determine what these fair levels are, and this research into tax incidence is necessary to making an informed decision.

Notes:

[1] Ministry of the Environment (1994), part III, Chap. 3, Basic direction (Introduction).

[2] From US Energy Information Administration, available online at: http://www.eia.doe.gov/ emeu/cabs/japanenv.html.

[3] Welch and Hibiki (2003) point out that Japan offers the longest experiment on voluntary policy in the world, the Voluntary Pollution Prevention Agreements.

[4] Information on the environment tax is taken from articles in Japan Today, Asahi Shimbun, and Yomiuri Shimbun, available at: http://www.japantoday.com/e/?content=shukan&id=255, http://www.climateark.org/articles/reader.asp?linkid=35422, http://www.climateark.org/articles/ reader.asp?linkid=36343, and http://www.asahi.com/english/Herald-asahi/TKY200503310170. html.

[5] Cansier and Krumm (1997) summarize a number of other environmental taxes in various nations, including the SO, tax in Japan introduced in 1974. Carbon taxes from other countries are discussed, and the authors conclude that inefficiencies arise because not all CO, units are taxed at the same rate.

[6] Many choices for numeraire exist. In Harberger (1962), the wage rate is chosen as numeraire.

[7] To see why, subtract Eq. 8 from Eq. 6, and set the change in the numeraire price equal to zero.

[8] As Mieszkowski (1967) observes of the original Harberger (1962) model, no output effect exists when the two sectors have equal factor intensities.

[9] Because $a_{ij}= \Theta_{Yj}e_{ij}$, $e_{LZ} > e_{KZ}$ whenever $a_{LZ} > a_{KZ}$.

[10] A counterintuitive result is found in Fullerton and Heutel (2007), where substitution elasticities are equal, but not all equal to zero. In that more general case, labor can be hurt more than capital if the dirty sector is capital intensive.

[11] Some carbon emissions are not taxed. For example, coal used for power generation is exempted.

[12] See http://www.stat.go.jp/english/data/io/.

[13] Fullerton and Heutel (2007). The dirty sector in that simulation consists of the top 13 chemical-emitting industries in the United States. The 11 industries represented here in the dirty sector are those that most closely compare with those in the US; because the industry definitions and categories are different between the two countries, the mapping is not perfect.

[14] See Antweiler et al. (2001, p. 879).

15 This unit convention merely defines a unit of labor as the amount that earns 1 yen, and a unit of capital as the amount that rents for 1 yen.

[16] As in previous studies, this parameter is somewhat arbitrarily set. It could be estimated from emissions permit markets or by estimating the shadow value of emissions.

[17] See Claro (2003) and Babiker et al. (2003) for a_x and Fullerton and Metcalf (2001) for a,,. While these parameters are estimated from or used in simulations of the US economy, we have little reason to believe them to be significantly different for the Japanese economy.

[18] Because the substitution elasticities are nonzero and the factor intensities are not equal across the two sectors, the numerical results do not correspond to either of the special cases listed in Sect. 3. Rather, they come from the general solution presented in the Appendix.

[19] Labor markets are more tightly regulated in Europe than in Japan, so firms in Europe may be less able to substitute into or out of labor when prices change, even with technologies identical to those in Japan. This may imply that Japan's *e,,* is greater than Europe's *e,,*.

[20] Tokutsu (1994) estimates Allen elasticities of substitution for production in the Japanese economy. These estimates are provided for each of 23 industries. The production function used contains four inputs: capital, labor, energy, and materials; as opposed to our three inputs of capital, labor, and pollution. Even if energy is used in a fixed ratio to pollution, the presence of materials as an input means that the estimates in Tokutsu do not correspond to ours. Simply comparing his estimates of e_{KE} and e_{LE} (where E is energy) for the two dirty sectors as defined here, in both industries these two elasticities are equal to each other. For the electricity, gas, and city water sector e_{KE} = *eLE* = 0.1988, and for the chemical products industry e_{KE} = *eLE* 0.4875. Saito and Tokutsu (2001) estimate the Allen elasticity of substitution between capital and energy for several manufacturing sectors in the Japanese economy. For chemicals, they find an elasticity of —0.349, indicating complementarity of those two inputs.
[21] This figure is somewhat arbitrary. The solution is linear in the tax increase, so any larger tax increase results in proportionally larger changes in all endogenous values. For example, a 20% tax increase would double all of the values in Table 2. However, the log-linearization method employed is appropriate only for considering small changes in the tax rate. Furthermore, while the actual policy proposal is the introduction of a carbon tax, our model can only solve for small changes in a preexisting tax.
[22] See McLure (1975) for a summary of these extensions.

References

Allen RGD (1938) Mathematical analysis for economists. St. Martin's, New York

Antweiler W, Copeland BR, Taylor MS (2001) Is free trade good for the environment? American Economic Review 91:877-908

Babiker MH, Metcalf GE, Reilly J (2003) Tax distortions and global climate policy. Journal of Environmental Economics and Management 46:269-287

Cansier D, Krumm R (1997) Air pollution taxation: an empirical survey. Ecological Economics 23:59-70

Claro S (2003) A cross-country estimation of the elasticity of substitution between labor and capital in manufacturing industries. Cuadernos de Economia 40:239-257

DeMooij RA, Bovenberg AL (1998) Environmental taxes, international capital mobility and inefficient tax systems: tax burden vs. tax shifting. International Tax and Public Finance 5:7-39 Fullerton D, Heutel G (2005) The general equilibrium incidence of environmental mandates. Working Paper, University of Texas at Austin

Fullerton D, Heutel G (2007) The general equilibrium incidence of environmental taxes. Journal of Public Economics 91:571-591

Fullerton D, Metcalf GE (2001) Environmental controls, scarcity rents, and pre-existing distortions. Journal of Public Economics 80:249-267

Harberger AC (1962) The incidence of the corporation income tax. Journal of Political Economy 70:215-240

Hayami H, Nakamura M, Yoshioka K (2003) A joint Japan—China research project for reducing pollution in China in the context of the Kyoto Protocol clean development mechanism (CDM): case study of the desulfurized bio-coal briquette experiments in Shenyang and Chendu. Managerial and Decision Economics 24:213-229

Kochi I, Matsuoka S, Memon MA, Shirakawa H (2001) Cost—benefit analysis of the sulfur dioxide emissions control policy in Japan. Environmental Economics and Policy Studies 4:219-233

McLure C (1975) General equilibrium incidence analysis: the Harberger model after ten years. Journal of Public Economics 4:125-161

Metcalf GE (1999) A distributional analysis of green tax reforms. National Tax Journal 52:655-681

Mieszkowski P (1972) The property tax: an excise tax or a profits tax? Journal of Public Economics 1:73-96

Mieszkowski P (1967) On the theory of tax incidence. Journal of Political Economy 75:250-262 Ministry of the Environment (1994) Basic environment plan. http://www.env.go.jp/en/policy/plan/ basic/

Park S-J (2004) The double dividend of an environmental tax reform in Japan. Acta Humanistica et Scientifica Universitatis Sangio Kyotiensis, Social Science Series No. 21, Kyoto Sangyo University, pp 137-159

Popp D (2006) International innovation and diffusion of air pollution control technologies: the effects of NO_x and SO_2 regulations in the U.S., Japan, and Germany. Journal of Environmental Economics and Management 51:46-71

Robison HD (1985) Who pays for industrial pollution abatement? Review of Economics and Statistics 67:702-706
Saito M, Tokutsu I (2001) An international comparison of the input—output structure: Europe, the U.S.A, and East Asia. Journal of Applied Input—Output Analysis 7:35-60
Tokutsu I (1994) Econometric analysis of the structure of production. Sobunsha, Tokyo
Welch E, Hibiki A (2003) An institutional framework for analysis of voluntary policy: the case of voluntary environmental agreements in Kita Kyushu, Japan. Journal of Environmental Planning and Management 46:523-543
West SE, Williams RC III (2004) Estimates from a consumer demand system: implications for the incidence of environmental taxes. Journal of Environmental Economics and Management 47:535-558
Yoshida F, Hata A, Tonegawa H (1999) Itai-itai disease and the countermeasures against cadmium pollution by the Kamioka Mine. Environmental Economics and Policy Studies 2:215-229

Appendix

The general solution to the model's system of equations is

$$\hat{p}_Y = \frac{(\theta_{YL}\theta_{XK} - \theta_{YK}\theta_{XL})\theta_{YZ}}{D} \times [A(e_{ZZ} - e_{KZ}) - B(e_{ZZ} - e_{LZ}) + (\gamma_K - \gamma_L)\sigma_u]\hat{\tau}_Z + \theta_{YZ}\hat{\tau}_Z \tag{11}$$

$$\hat{w} = \frac{\theta_{XK}\theta_{YZ}}{D}[A(e_{ZZ} - e_{KZ}) - B(e_{ZZ} - e_{LZ}) + (\gamma_K - \gamma_L)\sigma_u]\hat{\tau}_Z, \tag{12}$$

$$\hat{r} = \frac{\theta_{XL}\theta_{YZ}}{D}[A(e_{KZ} - e_{ZZ}) - B(e_{LZ} - e_{ZZ}) - (\gamma_K - \gamma_L)\sigma_u]\hat{\tau}_Z, \tag{13}$$

$$\begin{aligned}\hat{Z} = -\frac{1}{C}[&\theta_{YK}(\beta_K(e_{KK} - e_{ZK}) + \beta_L(e_{LK} - e_{ZK}) + \sigma_u)\hat{r} \\ &+ \theta_{YL}(\beta_K(e_{KL} - e_{ZL}) + \beta_L(e_{LL} - e_{ZL}) + \sigma_u)\hat{w} \\ &+ \theta_{YZ}(\beta_K(e_{KZ} - e_{ZZ}) + \beta_L(e_{LZ} - e_{ZZ}) + \sigma_u)\hat{\tau}_Z]\end{aligned} \tag{14}$$

where

$$\gamma_K \equiv \frac{\lambda_{KY}}{\lambda_{KX}} = \frac{K_Y}{K_X} \quad \text{and} \quad \gamma_L \equiv \frac{\lambda_{LY}}{\lambda_{LX}} = \frac{L_Y}{L_X}.$$

Also, for convenience, this solution combines notation into definitions where

$$\beta_K \equiv \theta_{XK}\gamma_K + \theta_{YK},$$
$$\beta_L \equiv \theta_{XL}\gamma_L + \theta_{YL},$$
$$A \equiv \gamma_L\beta_K + \gamma_K(\beta_L + \theta_{YZ}),$$
$$B \equiv \gamma_K\beta_L + \gamma_L(\beta_K + \theta_{YZ}), \text{ and}$$
$$C \equiv \beta_K + \beta_L + \theta_{YZ}.$$

It is readily apparent that $A > 0$, $B > 0$, and $C > 0$. The denominator is

$$\begin{aligned}D \equiv C\sigma_X &+ A[\theta_{XK}\theta_{YL}(e_{KL} - e_{LZ}) - \theta_{XL}\theta_{YK}(e_{KK} - e_{KZ})] - B[\theta_{XK}\theta_{YL}(e_{LL} - e_{LZ}) \\ &- \theta_{XL}\theta_{YK}(e_{KL} - e_{KZ})] - (\gamma_K - \gamma_L)\sigma_u(\theta_{XK}\theta_{YL} - \theta_{XL}\theta_{YK}).\end{aligned}$$