An Econometric Look at the Double Dividend Hypothesis

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Abstract

In its strongest and most controversial form the double dividend hypothesis states that that there may be efficiency gains from shifting taxation away from existing distortionary taxes to new environmental taxes, even in the absence of improvements in the environment. In this paper we take an econometric approach to evaluating this hypothesis. We use a time-series database of US input-output tables to estimate the parameters of a small general equilibrium model. We then use the model to estimate the welfare effect of revenue-neutral shifts of taxes from labor and capital to energy. Where our study differs from previous work, however, is that we then use the covariance matrix of the parameter estimates to construct confidence intervals for our results. The advantage of this approach is that it recognizes and incorporates the uncertainty inherent in the parameters and explicitly acknowledges that the actual effect of the tax shift cannot be predicted precisely.

1 Introduction

Many market-based policies for controlling environmental problems, such as taxes or auctioned permits, have the potential to raise large amounts of revenue. The idea that this revenue could be used to lower distorting taxes elsewhere in the economy, hence producing a welfare gain beyond the environmental benefits of the policy, has become known as the "double dividend hypothesis". The hypothesis has appeared in the literature in several forms.[1] The weakest form simply states that using the revenue to lower a distorting tax would be superior to returning the revenue as a lump sum rebate. In this form, the hypothesis is true by construction and generates little controversy.

The strongest form of the hypothesis has been far more controversial. It states that taxing goods that produce externalities (such as fossil fuels) and using the revenue to reduce other taxes (particular those on primary factors) can improve economic welfare even before environmental benefits are considered. In other words, the strong form is really an assertion that the economy would benefit from tax reform.[2] Advocates of stronger environmental regulation have used the strong form to argue that both the economy and the environment would benefit from shifting the tax system toward environmental taxes.[3] The extreme version of this view is that tighter regulations can be a "no regrets" policy – one that can be justified even if its environmental benefits are modest or impossible to quantify. At the same time, however, a large theoretical literature has sprung up challenging the hypothesis and arguing that environmental taxes often exacerbate existing distortions, particularly in the labor market.[4]

Although this theoretical work has made a number of important contributions, it will never completely resolve the debate over the strong double dividend hypothesis because the hypothesis itself is fundamentally empirical rather than theoretical.[5] A simple example makes it clear why. Suppose an economy has two primary factors: capital and labor, and that the supply of capital is elastic while the supply of labor is perfectly inelastic. Now consider what happens under a revenue-neutral shift in taxation that reduces income taxes, which fall on both labor and capital, and increases the tax on energy. Much of the burden of the energy tax will be passed back to the primary factors used in energy production. If energy is more labor-intensive than the rest of the economy, therefore, the shift in taxes would be equivalent to a policy that reduced taxes on capital income while raising taxes on labor income. Since capital is supplied elastically while labor is not, this would stimulate capital formation, raising GDP and producing a strong double dividend. On the other hand, if energy production is more capital-intensive than average, the effect would work in the other direction: the shift would increase the effective tax burden on capital which would reduce capital formation, lower GDP and would fail to generate a double dividend. Finally, if energy production used the two factors in the same proportions they are used in the overall economy, the shift in taxes would have no effect on GDP.

Because the strong form of the hypothesis is an empirical question it must be tested econometrically. In order to do so it is necessary to estimate the mean equivalent variation (EV) for the tax shift *and* its standard error. This would allow the hypothesis to be subjected to standard statistical tests. We could reject the strong double dividend hypothesis if the mean EV is negative and its 95% confidence interval does not include zero. On the other hand, if the estimated EV is positive and its confidence interval again does not include zero we could reject the hypothesis that there is *not* a double dividend. Finally, if the confidence interval includes zero it would be clear why different authors have come to different conclusions: the data simply does not allow us to reject either hypothesis. In that situation, different but equally reasonable choices of parameters would lead to different double dividend results.

In this paper we use a small econometric general equilibrium model of the United States to demonstrate how the mean equivalent variation and its standard error can be calculated for a representative shift from income to energy taxes.[6] This allows us to construct a confidence interval for the equivalent variation, which we can then use to test the strong form of the double dividend hypothesis. Further empirical work is needed but our preliminary results suggest that there is, in fact, a modest double dividend from raising energy taxes in order to cut taxes on capital.

2 A Small Econometric General Equilibrium Model

For transparency we represent the U.S. economy using the smallest possible general equilibrium model that still has enough detail to capture the important features of the double-dividend hypothesis. We divide the production side of the economy into three industries: energy, E, materials, M, and new capital goods, G. Each industry produces its output, Q_i, according to a constant elasticity of substitution (CES) production function which takes inputs of capital services, X_{iK}, labor, X_{iL}, energy, X_{iE}, and materials, X_{iM}:

$$(1) \qquad Q_i = A_i \left(\sum_{j \in \{K,L,E,M\}} \gamma_{ij}^{\sigma_i}{}_{ij} X_{ij}^{\frac{\sigma_i - 1}{\sigma_i}} \right)^{\frac{\sigma_i}{\sigma_i - 1}} \quad i \in \{E, M, G\}$$

where σ_i, A_i and γ_{ij} are parameters with σ_i being the elasticity of substitution. There are six parameters per industry for a total of eighteen in the production model overall.

We represent household behavior using a single infinitely-lived representative agent. The household supplies all of the economy's labor and capital services. In addition, it demands labor, capital services, energy and materials. The household maximizes the intertemporal utility function:

(2) $$U = \int \ln(u) e^{-\rho t} dt$$

where ρ is the time preference rate. The instantaneous utility index, *u*, is given by a Stone-Geary utility function :

(3) $$u = \prod_{i \in \{K,L,E,M\}} (c_i - \mu_i)^{\alpha_i}$$

where c_i is consumption of good *i* and μ_i and α_i are parameters. Without loss of generality, the α parameters are constrained to sum to one. The total number of parameters in the household model is thus eight.

The household's maximization of (2) is subject to the constraint that the present value of expenditures be equal to the household's wealth:

(4) $$\int \left(qc_k + wc_l + P_e(1+\tau_e)c_e + P_m(1+\tau_m)c_m + P_g I\right) e^{-rt} dt = W$$

where *q* is the rental price of capital services, *w* is the wage rate, P_e, P_m and P_g are the prices of energy, materials and new capital goods, τ_e and τ_m are sales tax rates, *I* is the quantity of new capital goods purchased by the household, *r* is the interest rate and *W* is total wealth. Wealth is given by the present value of all earnings on labor and capital:

(5) $$W = \int \left(wL(1-\tau_l) + qK(1-\tau_k) + S\right) e^{-rt} dt$$

where L is the supply of labor and K is the supply of capital services; τ_l and τ_k are tax rates; and S is a lump sum subsidy. The household's stock of capital evolves according to the accumulation equation:

(6) $$\dot{K} = I - \delta K$$

where δ is the rate of depreciation.

In order to keep our model as transparent as possible we model the government as doing nothing more than collecting taxes and returning the revenue as a lump sum rebate. Taxes are imposed on capital services, labor, and sales of energy and materials. The government's budget constraint is thus:

(7) $$S = \tau_l wL + \tau_k qK + \tau_e P_e c_e + \tau_m P_m c_m$$

3 Parameter Estimates

To estimate the model's parameters we assembled a time-series database of input-output tables for the United States spanning the period 1947-1985. We then estimated the complete production model – all three sectors – as a single system of simultaneous equations. The resulting estimates are showing in Table 1 along with standard errors. On the household side, we take the values of the time preference rate, ρ, and the depreciation rate, δ, from Jorgenson and Wilcoxen (1990); the time preference rate is equal to 2.9% and the depreciation rate is equal to 4.6%. The remaining household parameters were obtained by estimating the household demand functions as system of simultaneous equations. The results shown in Table 2.

4 Confidence Intervals for Results

Using the estimates in Table 1 and Table 2 we solved the model for its steady state equilibrium. We then calculated confidence intervals for the model's endogenous variables using two techniques: the delta method and Monte Carlo simulation.[7] The results for the two techniques were essentially identical and are shown in Table 3, which gives 95% confidence intervals expressed as percentages of the corresponding variable's base case value.[8] Some of the confidence intervals are quite narrow: the capital stock, for example, is determined within 0.5%.[9] Many of the variables are less precisely determined. The rental price of capital, q, and the price of new capital goods, P_g, for example, have confidence intervals of 6.5%. The quantity of energy is the least precise of all with a confidence interval of 11.2%.

5 The Effects of a Shift Toward Energy Taxes

In order to examine the double dividend hypothesis we simulated a shift in tax policy that increased the tax on energy to 10% from an initial value of zero. Simultaneously, the tax rate on capital was reduced (from an initial value of 10%) by exactly enough to leave the lump sum subsidy unchanged.[10]

Figure 1 shows the distribution of new capital tax rates resulting from a Monte Carlo simulation using 10,000 draws from the distribution of parameter estimates. The mean of the distribution is 8.46% and the 95% confidence interval runs from 8.11% to 8.81%. Raising the energy tax to 10%, in other words, would allow the capital tax rate to be cut by about 1 to 2 percentage points, with 1.5 being the most likely.

More interesting is the distribution of equivalent variations, shown in Figure 2. The mean equivalent variation is 0.24% and the 95% confidence interval runs from 0.14% to 0.33%. The key result is that the confidence interval does not include zero. Conditional on the assumptions underlying the model, therefore, it is possible to reject the hypothesis that shifting to energy taxes would not produce a double dividend.

6 Conclusion

In this paper we have proposed and implemented an econometric approach for evaluating the strong form of the double dividend hypothesis for an energy tax in the United States. In particular, we examine the effect of a ten percent increase in tax rate on energy in the U.S. accompanied by a revenue-neutral reduction in the rate of tax on capital. Our preliminary results suggest that there is, indeed, a double dividend. Accounting for uncertainty in the model's estimated parameters, we find that the mean equivalent variation of the policy is positive and that the 95% confidence interval does not include zero. Put less technically, we find that shifting taxation toward energy would indeed improve welfare, even before accounting for the environmental benefits of lower energy use, and that the probability is very low that this is an artifact of our parameter estimates.

Our results are suggestive but should be regarded as preliminary in several respects. First, our model only represents the economy at the steady state. To the extent that the change in policy causes welfare losses along the transition to the new steady state, our equivalent variation will overstate the benefit of the reform. Second, labor supply is fixed in our model. If the energy tax significantly exacerbates distortions in the labor market, our results will also overstate the equivalent variation of the policy. Third, by our choice of utility function we have imposed a unitary intertemporal elasticity of substitution. This will have little effect on the steady state but would have important effects during the transition period in a full intertemporal solution.

Finally, we have examined only the effect of uncertainty in the parameter estimates; it would be useful and straightforward to extend our approach to examine the effect of the residual uncertainty in the estimated equations.

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Table 1: Production Parameter Estimates with Standard Errors

Parameter	Estimate	Std Error	Parameter	Estimate	Std Error	Parameter	Estimate	Std Error
σ_E	1.048	0.0031	σ_M	0.764	0.0048	σ_I	0.990	0.0029
A_E	1.187	0.0183	A_M	0.999	0.0010	A_I	0.871	0.0199
γ_{KE}	0.285	0.0040	γ_{KM}	0.176	0.0012	γ_{KI}	0.041	0.0011
γ_{LE}	0.160	0.0024	γ_{LM}	0.356	0.0013	γ_{LI}	0.179	0.0028
γ_{EE}	0.393	0.0081	γ_{EM}	0.025	0.0008	γ_{EI}	0.012	0.0013
γ_{ME}	0.159	0.0020	γ_{MM}	0.441	0.0016	γ_{MI}	0.767	0.0029

Table 2: Household Parameter Estimates and Standard Errors

Parameter	Estimate	Std Error
μ_K	55430	20469
μ_L	110104	20174
μ_E	52760	23259
μ_M	670442	79937
α_K	0.205	0.0043
α_L	0.125	0.0046
α_E	0.044	0.0111
α_M	0.623	0.0073

Table 3: Base Case Confidence Intervals as Percentages

Variable	%	Variable	%	Variable	%
q	6.5	K	0.5	c_K	6.1
P_G	6.5	Q_E	11.2	c_L	2.1
P_E	4.2	Q_M	1.1	c_E	17.5
P_M	2.2	I	0.5	c_M	1.3

Figure 1: Distribution of Capital Tax Rates

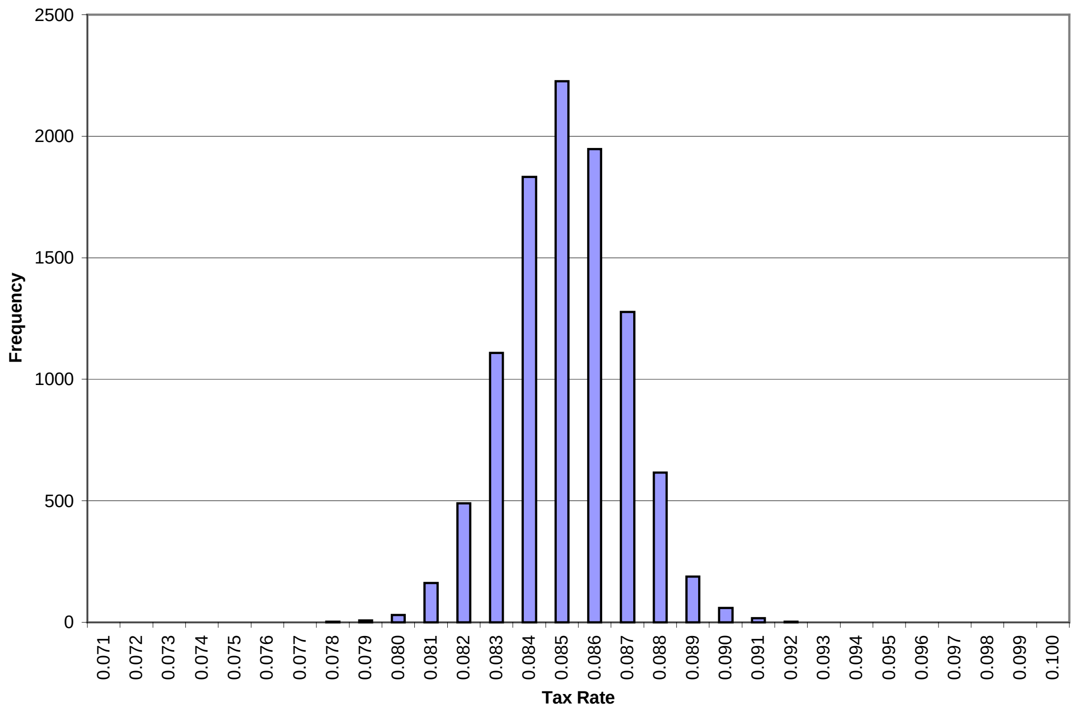
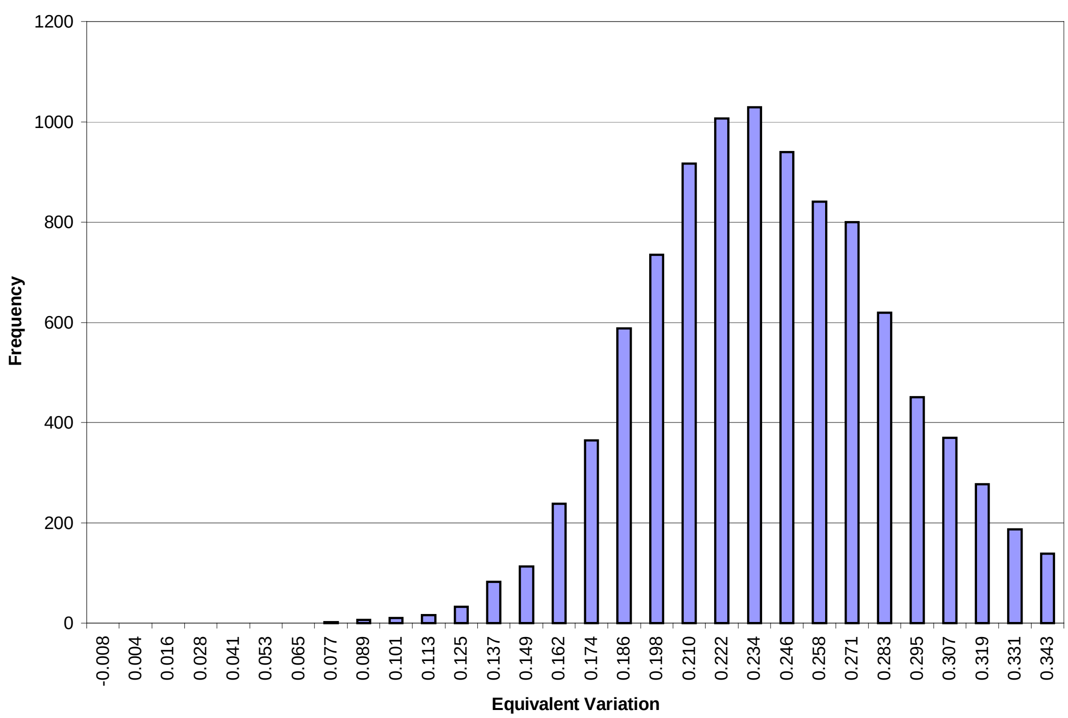


Figure 2: Distribution of Equivalent Variations



Endnotes

[1] For a clear description of the different forms the hypothesis has taken, see Goulder (1995).

[2] To put the double dividend debate into terms familiar to tax policy analysts, the strong form asserts that the excess burden of taxation is relatively low on externality-producing goods.

[3] Prominent examples include Repetto, et. al (1992) and Hammond, et al. (1997).

[4] See, for example, Bovenberg and de Mooij (1994).

[5] A few studies have attempted to test the strong double dividend hypothesis using computational general equilibrium models; see Jorgenson and Wilcoxen (1993), Ballard and Medema (1993), or Bovenberg and Goulder (1996), for example. These papers have calculated point estimates of the effect of revenue neutral shifts of taxation from primary factors to energy goods. Our work builds on this approach but extends it to allow confidence intervals to be calculated instead of point estimates.

[6] Many general equilibrium studies include some degree of sensitivity analysis but only a few studies have gone beyond examining the effects of fairly arbitrary perturbations a handful of parameters. Pagan and Shannon (1985) suggest one approach for systematic sensitivity analysis when the covariance matrix of parameter estimates is unavailable. Harrison, et. al (1993), propose using a Monte Carlo approach based on drawing parameters from a prior (but not estimated) distribution. Arndt (1996) and Arndt and Pearson (1998) propose a method of sensitivity analysis based on gaussian quadrature that has much in common with our approach.

[7] These techniques are necessary because the endogenous variables are, in general, nonlinear functions of the parameters. In the delta method, confidence intervals are calculated from the

covariance matrix of the parameter estimates using a linear approximation to the nonlinear system of equations. This approach is commonly used by econometric software packages. In our Monte Carlo simulation we solved the model for 10,000 draws from the joint distribution of the parameter estimates.

[8] These confidence intervals take into account the standard errors of the parameter estimates but not the residual variance of the estimated equations. Including the latter would make the confidence intervals considerably larger.

[9] This is an interesting result but it should not be taken too literally since we imposed the time preference rate, ρ. Had it been estimated, the confidence interval for K would be considerably larger.

[10] These are only very rough approximations to the actual tax rates.