What to Expect from an International System of Tradable Permits for Carbon Emissions*

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ABSTRACT

We use an econometrically-estimated multi-region, multi-sector general equilibrium model of the world economy to examine the effects of using a system of internationally-tradable emissions permits to control world carbon dioxide emissions. We focus, in particular, on the effects of the system on flows of trade and international capital. Our results show that international trade and capital flows significantly alter projections of the domestic effects of emissions mitigation policy, compared with analyses that ignore international capital flows, and that under some systems of international permit trading the United States is likely to become a significant permit *seller*, the opposite of the conventional wisdom

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1 Introduction

One of the leading proposals for controlling global climate change is an international system of tradable permits for carbon dioxide emissions. In fact, the Kyoto Protocol to the United Nations Framework Convention on Climate Change, signed in Kyoto in December 1997, includes provisions for setting up just such a system among industrial ("Annex I") countries. The theoretical attraction of permit trading is that it is efficient: it guarantees that emissions reductions will be obtained at minimum cost. As a political matter, especially in the United States, an equally important virtue of a permit system is that it does not involve new taxes.

Despite the enthusiasm for international permit trading, little empirical work has been done on the short-term dynamics of such a policy in a world of highly integrated financial markets and numerous short-term rigidities. In this paper we attempt to fill that gap by using a multi-region, multi-sector intertemporal general equilibrium model of the world economy called "G-Cubed".[1]

In order to explore the main issues in permit trading as a general proposition, we abstract from the actual regimes proposed in the Kyoto Protocol and instead examine three more transparent policies: (1) unilateral stabilization of U.S. carbon emissions at 1990 levels, (2) stabilization of OECD emissions at 1990 levels on a country by country basis without international permit trading, and (3) joint stabilization of OECD emissions with full international permit trading. We focus particularly on the effects of the policies on output, exchange rates and

[1] G-Cubed stands for "Global General Equilibrium Growth Model". An earlier draft of this paper used version 31 of the model. This draft uses version 39, which includes significant data updates and has emission coefficients on gas and oil separately rather than on the crude oil and gas extraction sector.

international flows of goods and financial capital. In addition, by comparing the second and third simulations we are able to calculate the gains from allowing international permit trading.

It is worth repeating that these are not simulations of the trading regime proposed in the Kyoto Protocol signed in December 1997. We focus on stabilization at 1990 emissions rather than the more stringent cuts in the Kyoto agreement. Also, we examine trading within the OECD rather than within the Kyoto agreement's broader "Annex I" group which includes Eastern Europe and the states of the former Soviet Union. The reason for this is that our goal is to measure the efficiency gains from trading and examine the key mechanisms affecting this calculation. In order to do that we need the overall level of abatement to be the same with or without trading. That would not be the case if we examined Annex I trading because the former Soviet Union is currently about 300 million metric tons below its 1990 emissions. Moving from the no-trading case to Annex I trading, therefore, would essentially relax the emissions constraint by 300 million tons and make it impossible to measure the efficiency gains obtained purely from trading.[2] Because our analysis does not involve the quantitative targets of the Kyoto Protocol, our results should not be interpreted as estimates of the costs of the Protocol.

2 Model Structure

In this section we give a brief overview of the key features of the model, G-Cubed, underlying this study. Space constraints make it necessary for us to focus only on the details that are most important for understanding the results. For more complete documentation, please see

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[2] See McKibbin, Ross, Shackleton and Wilcoxen (1998) for simulations of the Kyoto Protocol that include these complicating factors.

McKibbin and Wilcoxen (forthcoming).[3]

At the most abstract level, the G-Cubed model consists of a set of eight general equilibrium models, each corresponding to a geographic region, linked by international flows of goods and assets. We assume the regions each consist of a representative household, a government sector, a financial sector, twelve industries, and a sector producing capital goods. The regions and sectors are listed in Table 1. Although the regions are similar in structure (that is, they consist of similar agents solving similar problems), they differ in endowments, behavioral parameters and government policy variables.[4] In the remainder of this section we present the key features of the regional models. To keep the notation from becoming cumbersome, we will generally not subscript variables by country. The complete model, however, consists of eight regional modules linked by trade and asset flows.

2.1 Producer Behavior

Within a region, each producing sector is represented by a single firm which chooses it inputs and its level of investment in order to maximize its stock market value subject to a multiple-input production function and a vector of prices it takes to be exogenous. We assume that output can be represented by a constant elasticity of substitution (CES) function of inputs of capital, labor, energy and materials:

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[3] This and other papers describing the model are also available at http:\www.msgpl.com.au.

[4] This is enough to allow the regions to be quite different from one another. For example, even though all of the regions consist of the twelve industries in Table 2 we do not impose any requirement that the output of a particular industry in one country be identical to that of another country. The industries are themselves aggregates of smaller sectors and the aggregation weights can be very different across countries: the output of the durable goods sector in Japan will not be identical to that of the United States. The fact that these goods are not identical is reflected in the assumption (discussed further below) that foreign and domestic goods are generally imperfect substitutes.

(1) $$Q_i = A_{iO}\left(\sum_{j=K,L,E,M} \delta_{ij}^{1/\sigma_{iO}} X_{ij}^{(\sigma_{iO}-1)/\sigma_{iO}}\right)^{\frac{\sigma_{iO}}{(\sigma_{iO}-1)}}$$

where Q_i is output, X_{ij} is industry i's use of input j (i.e. K, L, E and M), and A_{iO}, δ_{ij}, and σ_{io} are parameters. Energy and materials, in turn, are CES aggregates of inputs of intermediate goods: energy is composed of the first five goods in Table 1 and materials is composed of the remaining seven:

(2) $$X_{iE} = A_{iE}\left(\sum_{j=1}^{5} \delta_{ij}^{1/\sigma_{iE}} X_{ij}^{(\sigma_{iE}-1)/\sigma_{iE}}\right)^{\frac{\sigma_{iE}}{(\sigma_{iE}-1)}}$$

(3) $$X_{iM} = A_{iM}\left(\sum_{j=6}^{12} \delta_{ij}^{1/\sigma_{iM}} X_{ij}^{(\sigma_{iM}-1)/\sigma_{iM}}\right)^{\frac{\sigma_{iM}}{(\sigma_{iM}-1)}}$$

Intermediate goods are, in turn, functions of domestically produced and imported goods.

We used a nested system of CES equations rather than a more flexible functional form because data limitations make even the CES model a challenge to estimate. In principle we need price and quantity data for 14 inputs (twelve goods plus capital and labor) in each of 96 industries (12 industries in 8 regions). Moreover, data on intermediate inputs (which is published in the form of input-output tables) is not collected annually in any major country and is collected infrequently, if at all, in developing countries. For many of our regions we had access to only a single input-output table. There is simply too little data for a more flexible specification to be feasible.

In fact, the scarcity of input-output data requires us to restrict the model further by imposing the assumption that the substitution elasticities for each industry be identical across countries (although they may differ across industries). In other words, we assume that each industry has the same energy, materials and KLEM substitution elasticities no matter where it is located. This is consistent with the econometric evidence of Kim and Lau in a number of papers (see for example Kim and Lau, 1994).

Although the substitution elasticities are identical across countries, the overall production models are not identical because we obtain the CES input weights from the latest available input-output data for each country or region.[5] Thus, the durable goods sectors in the United States and Japan, for example, have identical substitution elasticities but different sets of input weights. The consequence of this is that the cost shares of inputs to a given industry are based on data for the country in which the industry operates, but the industry's response to price changes is identical across countries.

In effect we are assuming that all regions share production methods that differ in first-order properties but have identical second-order characteristics. This is intermediate between one extreme of assuming that the regions share common technologies and the other extreme of allowing the technologies to differ across regions in arbitrary ways. The regions also differ in their endowments of primary factors, their government policies, and patterns of final demands, so although they some common parameters they are not simple replicas of one another.

To estimate the elasticities we constructed time-series data on prices, industry inputs, outputs and value-added for the country for which we were able to obtain the longest series of input-output tables: the United States. The following is a sketch of the approach we have followed; complete details are contained in McKibbin and Wilcoxen (forthcoming).

[5] Input-output tables were not available for the regions in the model larger than individual countries. The input weights for those regions were based on data for the United States.

We began with the benchmark input-output transactions tables produced by the Bureau of Economic Analysis (BEA) for years 1958, 1963, 1967, 1972, 1977 and 1982.[6] The conventions used by the BEA have changed over time, so the raw tables are not completely comparable. We transformed the tables to make them consistent and aggregated them to twelve sectors. We then shifted consumer durables out of final consumption and into fixed investment.[7] We also increased the capital services element of final consumption to account for imputed service flows from durables and owner-occupied housing. Finally, we used a data set constructed by Dale Jorgenson and his colleagues to decompose the value added rows of the tables,[8] and a data set produced by the Office of Employment Projections at the Bureau of Labor Statistics to provide product prices.

Table 2 presents estimates of the substitution elasticities for each industry; standard errors are shown in parentheses.[9] The elasticity of substitution between capital, labor, energy and materials (KLEM) for each sector, parameter σ_{iO} in (1), is shown in the column labeled "Output"; the columns labeled "Energy" and "Materials" give the elasticities of substitution within the energy and materials node, σ_{iE} and σ_{iM}. Standard errors are shown in parentheses.

A number of the estimates had the wrong sign or could not be estimated (the estimation procedure failed to converge). In such cases we examined the data and imposed elasticities that

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[6] A benchmark table also exists for 1947 but it has inadequate final demand detail for our purposes. Subsequent to our estimation work a 1987 table has become available.

[7] The National Income and Product Accounts (and the benchmark input-output tables as well) treat purchases of consumer durables as consumption rather than investment.

[8] This data set is the work of several people over many years. In addition to Dale Jorgenson, some of the contributors were Lau Christiansen, Barbara Fraumeni, Mun Sing Ho and Dae Keun Park. The original source of data is the Fourteen Components of Income Tape produced by the Bureau of Economic Analysis. See Ho (1989) for more information.

seemed appropriate; these values are shown in the table without standard errors.[10] For most of the imposed parameters, the data suggest complementarities among inputs, which is incompatible with the CES specification. If more data were available, it would be worthwhile to use a more flexible functional form.

Finally, in order to improve the model's ability to match physical flows of energy we have imposed lower energy and output elasticities in a few sectors. These are show in the columns labeled "Imposed." For example, the estimated KLEM elasticity in the electric sector was 0.763 but we have imposed an elasticity of 0.2 in order to help the model more accurately track the physical quantities of energy inputs and outputs to the sector.

Maximizing the firm's short run profit subject to its capital stock and the production functions above gives the firm's factor demand equations. At this point we add two further levels of detail: we assume that domestic and imported inputs of a given commodity are imperfect substitutes, and that imported products from different countries are imperfect substitutes for each other. As noted earlier, given the model's level of aggregation these are more a simple acknowledgment of reality than an assumption.[11] Thus, the final decision the firm must make is the fraction of each of its inputs to buy from each region in the model (including the firm's home country). Due to data constraints we represent this decision using a Cobb-Douglas function.[12] Moreover, we assume that all agents in the economy have identical preferences over foreign and

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[9] The parameters were estimated using systems of factor demand equations derived from the KLEM portion of the production function and the dual versions of the energy and materials tiers.

[10] For this study we also imposed lower KLEM substitution elasticities on a few of the energy industries where it seemed that the estimated elasticities might overstate the true ability of the industry to shift factors of production.

[11] This approach is based on the work of Armington (1969).

[12] This assumption is far from ideal and some sensitivity analysis is presented later in this paper.

domestic varieties of each particular commodity.[13] We parameterize this decision using trade shares based on aggregations of the United Nations international trade data for 1987.[14] The result is a system of demand equations for domestic output and imports from each other region.

In addition to buying inputs and producing output, each sector must also choose its level of investment. We assume that capital is specific to each sector, it depreciates geometrically at rate δ, and that firms choose their investment paths in order to maximize their market value. Following the cost of adjustment models of Lucas (1967), Treadway (1969) and Uzawa (1969) we assume that the investment process is subject to rising marginal costs of installation. To formalize this we adopt Uzawa's approach by assuming that in order to install J units of capital the firm must buy a larger quantity, I, that depends on its rate of investment (J/K) as follows:

$$I = \left(1 + \frac{\phi}{2}\frac{J}{K}\right)J \tag{4}$$

where ϕ is a non-negative parameter and the factor of two is included purely for algebraic convenience. The difference between J and I may be interpreted many ways; we will view it as installation services provided by the capital vendor.

Setting up and solving the firm's investment problem yields the following expression for investment in terms of parameters, the current capital stock, and marginal *q* (the ratio of the marginal value of a unit of capital to its purchase price):

$$I = \frac{1}{2\phi}\left(q^2 - 1\right)K \tag{5}$$

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[13] Anything else would require time-series data on imports of products from each country of origin to each industry, which is not only unavailable but difficult to imagine collecting.

[14] Specifically, we aggregate up from data at the 4-digit level of the Standard International Trade Classification.

Following Hayashi (1979), and building on large body of empirical evidence suggesting that a nested investment function fits the data much better than a pure q-theory model, we extend (5) and write I as a function not only of q, but also of the firm's current profit π:

(6) $$I = \alpha_2 \frac{1}{2\phi}\left(q^2 - 1\right)K + \left(1-\alpha_2\right)\frac{\pi}{\left(1-\tau_4\right)P^I}$$

This improves the empirical behavior of the specification and is consistent with the existence of firms that are unable to borrow and therefore invest purely out of retained earnings. The parameter a_2 was taken to be 0.3 based on a range of empirical estimates reported by McKibbin and Sachs (1991).

In addition to the twelve industries discussed above, the model also includes a special sector that produces capital goods. This sector supplies the new investment goods demanded by other industries. Like other industries, the investment sector demands labor and capital services as well as intermediate inputs. We represent its behavior using a nested CES production function with the same structure as that used for the other sectors, and we estimate the parameters using price and quantity data for the final demand column for investment. As before, we use U.S. data to estimate the substitution elasticities and country or region data to determine the γ parameters.

2.2 Households

Households consume goods and services in every period and also demand labor and capital services. Household capital services consist of the service flows of consumer durables plus residential housing. Households receive income by providing labor services to firms and the government, and from holding financial assets. In addition, they receive imputed income from ownership of durables and housing, and they also may receive transfers from their region's government.

Within each region we assume household behavior can be modeled by a representative agent with an intertemporal utility function of the form:

(7) $$U_t = \int_t^{\infty} (\ln C(s) + \ln G(s))\, e^{-\theta(s-t)}\, ds$$

where $C(s)$ is the household's aggregate consumption of goods at time s, $G(s)$ is government consumption, which we take to be a measure of public goods supply, and θ is the rate of time preference and is equal to 2.5 percent.[15] The household maximizes its utility subject to the constraint that the present value of consumption be equal to human wealth plus initial financial assets. Human wealth, *H*, is the present value of the future stream of after-tax labor income and transfer payments received by households. Financial wealth, *F*, is the sum of real money balances, real government bonds in the hands of the public (Ricardian neutrality does not hold in this model because some consumers are liquidity-constrained; more on this below), net holdings of claims against foreign residents and the value of capital in each sector. A full derivation can be found in McKibbin and Sachs (1991) and McKibbin and Wilcoxen (forthcoming).

Under this specification, it is easy to show that the desired value of each period's consumption is equal to the product of the time preference rate and household wealth:

(8) $$P^C C = \theta (F + H)$$

There has, however, been considerable debate about whether the actual behavior of

[15] This specification imposes the restriction that household decisions on the allocations of expenditure among different goods at different points in time be separable. Also, since utility is additive in the logs of private and government consumption, changes in government consumption will have no effect on private consumption decisions.

aggregate consumption is consistent with the permanent income model.[16] Based on a wide range of empirical evidence in the macroeconomics literature (see Campbell and Mankiw, 1990), we impose that only a fraction β of all consumers choose their consumption to satisfy (8) and that the remainder consume based entirely on current after-tax income. It is important to emphasize that this is not capricious or arbitrary assumption. Rather, we have deliberately chosen to depart from the theoretical elegance of (8) because we are evaluating real-world policy and it is absolutely clear from empirical data that (8) alone is not a satisfactory model of aggregate consumption. This is an important difference between our approach and many of the other models used to study climate change policy. Whenever we have had to choose between theoretical elegance and empirical relevance, we have chosen the latter.[17]

The empirical finding that pure permanent income models such as (8) are rejected by the data while nested functions that include a large weight on current income fit much better could be interpreted in various ways, including the presence of liquidity-constrained households or households with myopic expectations. For the purposes of this paper we will not adopt any particular explanation but simply take β to be an exogenous constant.[18] This produces the final consumption function shown below:

(9) $$P^C C = \beta\theta(F_t + H_t) + (1-\beta)\gamma INC$$

[16] Some of the key papers in this debate are Hall (1978), Flavin (1981), Hayashi (1982), and Campbell and Mankiw (1990).

[17] One complication of introducing a nested specification for consumption is that traditional welfare evaluations are difficult. However, we view it as far more important to take empirical facts into account than for it to be easy to calculate equivalent variations.

[18] One side effect of this specification is that it will prevent us from using equivalent variation or other welfare measures derived from the expenditure function. Since the behavior of some of the households is implicitly inconsistent with (8), either because the households are at corner solutions or for some other reason, aggregate

where γ is the marginal propensity to consume for the households consuming out of current income. Following McKibbin and Sachs (1991) we take β to be 0.3 in all regions.[19]

Within each period, the household allocates expenditure among goods and services in order to maximize *C*(*s*), its intratemporal utility index. In this version of the model we assume that *C*(*s*) may be represented by a nested CES function. At the top tier, consumption is composed of inputs of capital services, labor, energy and materials. Energy and materials, in turn, are CES aggregates of inputs of individual goods.[20] The elasticities of substitution at the energy and materials tiers were estimated to be 0.8 and 1.0, respectively. In this version of the model the top tier elasticity has been imposed to be unity.

Finally, the supply of household capital services is determined by consumers themselves who invest in household capital. We assume households choose the level of investment to maximize the present value of future service flows (taken to be proportional to the household capital stock), and that investment in household capital is subject to adjustment costs. In other words, the household investment decision is symmetrical with that of the firms.

2.3 Labor Market Equilibrium

We assume that labor is perfectly mobile among sectors within each region but is immobile between regions. Thus, within each region wages will be equal across sectors. The nominal wage is assumed to adjust slowly according to an overlapping contracts model (adjusted for different labor market institutional structures in different economies) where nominal wages

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behavior is inconsistent with the expenditure function derived from our utility function.

[19] Our value is somewhat lower than Campbell and Mankiw's estimate of 0.5.

[20] This specification has the undesirable effect of imposing unitary income and price elasticities. There is abundant

are set based on current and expected inflation and on economy-wide labor demand relative to labor supply. In the long run, labor supply is given by the exogenous rate of population growth, but in the short run the hours worked can fluctuate depending on the demand for labor. For a given nominal wage, the demand for labor will determine short-run unemployment.

Relative to other general equilibrium models, this specification is unusual in allowing for involuntary unemployment. We adopted this approach because we are particularly interested in the transition dynamics of the world economy. The alternative of assuming that all economies are always at full employment, which might be fine for a long-run model, is clearly inappropriate during the first few years after a shock. This plays a crucial role in the adjustment in the global economy over the coming few decades because when the policy is announced, resources can't be automatically relocated. Again the model attempts to explain observed empirical phenomena such as unemployment. This is important for several reasons. Firstly initial conditions whether it be pre-existing taxes or other price distortions can be important for simulation results. Secondly the causes of unemployment due to short run stickiness in labor markets are likely to also be important for the dynamic adjustment of model. This is not a new idea but is rare to find in general equilibrium model despite the long and empirically robust tradition in mainstream macroeconomics.

2.4 Government

We take each region's real government spending on goods and services to be exogenous and assume that it is allocated among final goods, services and labor in fixed proportions, which

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empirical evidence against this assumption and we intend to generalize it in future work.

we set to 1987 values for each region. Total government spending includes purchases of goods and services plus interest payments on government debt, investment tax credits and transfers to households. Government revenue comes from sales, corporate, and personal income taxes, and by issuing government debt. In addition, there can be taxes on externalities such as carbon dioxide emissions.

The difference between revenues and total spending gives the budget deficit, which is endogenous. Deficits are financed by sales of government bonds. We assume that agents will not hold bonds unless they expect the bonds to be serviced, and accordingly impose a transversality condition on the accumulation of public debt in each region that has the effect of causing the stock of debt at each point in time to be equal to the present value of all future budget surpluses from that time forward. This condition alone, however, is insufficient to determine the time path of future surpluses: the government could pay off the debt by briefly raising taxes a lot; it could permanently raise taxes a small amount; or it could use some other policy. We assume that the government levies a lump sum tax in each period equal to the value of interest payments on the outstanding debt. In effect, therefore, any increase in government debt is financed by consols, and future taxes are raised enough to accommodate the increased interest costs. Thus, any increase in the debt will be matched by an equal present value increase in future budget surpluses. Other fiscal closure rules are possible such as always returning to the original ratio of government debt to GDP. These closures have interesting implications but are beyond the scope of this paper.

Finally, because we our wage equation depends on the rate of expected inflation, we need to include money supply and demand in the model. The supply of money is determined by the balance sheet of the central bank and is exogenous. We assume that money demand arises from the need to carry out transactions and takes the following form:

(10) $$M = PY\, i^{\varepsilon}$$

where M is money, P is the price level, Y is aggregate output, i is the interest rate and ε is the interest elasticity of money demand. Following McKibbin and Sachs (1991) we take ε to be -0.6.

2.5 International Trade and Asset Flows

The eight regions in the model are linked by flows of goods and assets. Each region may import each of the 12 goods from potentially all of the other seven regions. In terms of the way international trade data is often expressed, our model endogenously generates a set of twelve 8x8 bilateral trade matrices, one for each good. The values in these matrices are determined by the import demands generated within each region.

The trade balance in each economy is the result of intertemporal saving and investment decisions of households, firms and governments. The composition of the trade balance depends on the relative prices of goods and services and relative incomes of economies. Trade imbalances are financed by flows of assets between countries.

The role of financial capital flows and financial market adjustment is crucial to the results of the model. International capital flows are assumed to be composed of portfolio investment, direct investment and other capital flows. These alternative forms of capital flows are perfectly substitutable ex ante, adjusting to the expected rates of return across economies and across sectors. Within an economy, the expected return to each type of asset (i.e. bonds of all maturities, equity for each sector etc) are arbitraged, taking into account the costs of adjusting physical capital stock and allowing for exogenous risk premia. Because physical capital is costly to adjust, any inflow of financial capital that is invested in physical capital (i.e. direct investment) will also be costly to shift once it is in place. The decision to invest in physical assets is also based on expected rates of return. However, if there is an unanticipated shock then ex-post returns could vary significantly. Total net capital flows for each economy in which there are open capital markets are equal to the current account position of that country. The global net flows of private capital are constrained to zero.

2.6 Constructing the Base Case

To solve the model, we first normalize all quantity variables by the economy's endowment of effective labor units. This means that in the steady state all real variables are constant in these units although the actual levels of the variables will be growing at the underlying rate of growth of population plus productivity. Next, we must make base-case assumptions about the future path of the model's exogenous variables in each region. In all regions we assume that the long run real interest rate is 5 percent, tax rates are held at their 1990 levels and that fiscal spending is allocated according to 1990 shares. Population growth rates vary across regions as shown in Table 3.

A crucial group of exogenous variables are productivity growth rates by sector and country. The baseline assumption in G-Cubed is that the pattern of technical change at the sector level is similar to the historical record for the United States (where data is available). In regions other than the United States, however, the sector-level rates of technical change are scaled up or down in order to match the region’s observed rate of aggregate productivity growth. This approach attempts to capture the fact that the rate of technical change varies considerably across industries while reconciling it with regional differences in overall growth. This is clearly a rough approximation; if appropriate data were available it would be better to estimate productivity growth for each sector in each region.

Given these assumptions, we solve for the model's perfect-foresight equilibrium growth path over the period 1990-2050. This a formidable task: the endogenous variables in *each* of the sixty periods number over 6,000 and include, among other things: the equilibrium prices and quantities of each good in each region, intermediate demands for each commodity by each industry in each region, asset prices by region and sector, regional interest rates, bilateral exchange rates, incomes, investment rates and capital stocks by industry and region, international flows of goods and assets, labor demanded in each industry in each region, wage rates, current and capital account balances, final demands by consumers in all regions, and government deficits.[21] At the solution, the budget constraints for all agents are satisfied, including both intratemporal and intertemporal constraints.

3 The Effects of Tradable Emissions Permits

We now explore the effects of international trading in carbon permits by considering three scenarios. As a benchmark for comparison, we begin by examining the effects of unilateral stabilization by the United States. In this scenario, the U.S. government holds annual auctions of carbon emissions permits in each of the years from 2010 to 2020.[22] The permits are required for the use of primary fossil fuels (coal and crude oil and gas) and the quantity is set equal to U.S.

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[21] Since the model is solved for a perfect-foresight equilibrium over a 60 year period, the numerical complexity of the problem is on the order of 60 times what the single-period set of variables would suggest. We use software developed by McKibbin (1992) for solving large models with rational expectations on a personal computer.

[22] Beyond 2020 the supply of permits is allowed to increase at such a rate as to leave the real permit price at its 2020 value. Thus the scenarios involve policies that are considerably less stringent than *permanent* emisison stabilization.

emissions in 1990. Revenues from the permit sales are returned to households via a deficit-neutral lump sum rebate.[23] The policy is announced in 2000 so that agents have a decade to anticipate the policy and adapt to it.

In the second scenario, all countries in the OECD follow similar policies. Each country auctions permits equal to its 1990 emissions and returns the revenue to its citizens as a lump sum rebate. The permits can be traded within countries but not from one country to another.[24] This simulation allows us to measure the heterogeneity of the OECD regions. Differences in baseline emissions growth and initial fossil fuel prices mean that the regions face substantially different costs of achieving stabilization. This will be reflected in the pattern of permit prices (which will indicate the cost of stabilization at the margin) and GDP losses across regions.

The third scenario is identical to the second except that we allow international trading in emissions permits among OECD countries. Allowing trading will cause the price of a permit to be equal throughout the OECD because of arbitrage. This will ensure that marginal costs of carbon abatement will be equal across countries and that OECD stabilization will be achieved at minimum cost. Countries with relatively low abatement costs will sell permits and abate more than in the previous scenario; countries with high costs will buy permits and do less abatement.

Instead, they involve a levelling off of the constraint, a levelling that is reflected in the 2020 results.

[23] The rebate is chosen to leave the deficit unchanged. It is not necessarily equal to the revenue raised by permit sales because other changes in the economy may raise or lower tax revenue. This formulation is not equivalent to free distribution of permits ("grandfathering") – that would be represented in a similar fashion in the model but the rebate would be set to the gross revenue raised by permit sales. Other uses of the revenue, such as cutting income taxes or reducing the fiscal deficit, would change a some of the results substantially, although the gains from trade are robust to revenue recycling policies. For a discussion of deficit reduction, see McKibbin, Ross, Shackleton and Wilcoxen (1998).

[24] Even though there is no trading *between* regions, trading is implicitly allowed between the countries *within* a region. In particular, the "Other OECD" region lumps together the European Union, Canada and New Zealand, so trading is implicitly allowed between these countries.

Comparing scenarios 2 and 3 will allow us to estimate the gains to be had from international permit trading.

3.1 Unilateral Emissions Stabilization by the United States

Key macroeconomic results for the United States in the case of unilateral action by the United States are shown in Table 4. The figures shown are either percent deviation from 'business as usual' or deviations in units of $1995 as indicated. Results are presented for a snapshot at representative years even though the model is annual. We focus on the year 2000 when the policy is announced; the year 2005, just before the policy is implemented; the year 2010 when the policy that was announced in 2000 becomes effective and the year 2020 when the trading regime has been in place for a decade.

In order to achieve stabilization, emissions would need to drop by 24 percent relative to the baseline in 2010 and 37 percent in 2020.[25] The resulting price of carbon emissions permits would be $74 per tonne in 2010 rising to $85 per tonne in 2020.[26] Most of the drop in emissions comes about through a decline in coal consumption as total energy use drops and the fuel mix shifts toward natural gas, the least carbon-intensive fuel. This is reflected in the industry-level results shown in Table 5: the after-tax price of coal rises by more than 175 percent and coal output declines by nearly 33 percent in 2010 and by close to 50 percent by 2020. The crude oil and gas sector is also strongly affected: output declines by 7.5 to 17.4 percent over the period.

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[25] Some of the emissions eliminated within the United States – roughly 10% in 2010 – are offset by increases in emissions elsewhere. Initially, over half of this "leakage" is due to the fact that other countries buy and burn the oil that the U.S. stops importing. This effect diminishes over time: by 2020 about two-thirds of the leakage is due to higher energy demand resulting from greater economic activity.

[26] Throughout the paper carbon will be measured in metric tons (tonnes) and prices will be in 1995 U.S. dollars.

Outside the energy industries prices and output are affected very little. The only noteworthy result is that investment rises by about one percent during the period before the policy is implemented (2000-2009). This stems from the fact that the demand for services increases slightly when households and firms substitute away from energy. As a result, investment by the service industry increases as well. The increase in investment is financed by an inflow of foreign capital, which causes the exchange rate to appreciate by about 1.6 percent during that time. The exchange rate appreciation reduces exports, primarily of durable goods and enables the capital inflow to be reflected in a worsening of the current account.

The international effects of the policy vary across regions. Most OECD countries experience mild decreases in GDP on the order of -0.1 percent, mild exchange rate depreciations, and increases in their net investment positions. The exception is Australia, which benefits from taking up the slack in U.S. coal exports. China and the former Soviet Union are almost completely unaffected. Other developing countries receive minor capital inflows after 2010, experience slight exchange rate appreciation and slightly higher GDP, but also have lower production and exports of durable goods due to the change in exchange rates.

3.2 OECD Emissions Stabilization Without Permit Trading

The results for OECD stabilization without permit trading are shown in Table 6. This table shows key results for 2005, 2010 and 2020 for the four OECD regions in the model: United States, Japan, Australia and other OECD (hereafter referred to as ROECD).

The effects of the policy differ substantially across the regions: in 2010, permit prices range from a low of $83 in the United States to a high of $240 in the ROECD region. The effect on GDP follows a similar pattern: U.S. GDP is 0.3% and Japanese GDP is 0.2% below baseline values while GDP in Australia is 2.6% below and ROECD 1.3% below baseline levels, respectively. These results show that both marginal and average costs of abating carbon emissions differ substantially across countries. The differences among regions stem in part from differences in their fuel mixes, but also depend importantly on (1) the extent to which emissions are forecast to rise above the stabilization target in the baseline, and (2) the availability of alternative fuels. Thus Australia finds it relatively costly to reach the 1990 stabilization target, partly because it has a high baseline emission trajectory (due to reasonably high population growth and strong productivity growth), and partly because it has relatively few substitution possibilities. On the other hand, the United States finds it relatively cheap to change the composition of energy inputs because it has relatively low energy prices, a high baseline reliance on coal, and abundant alternative fuels.

However, an assessment of the income losses due to the policy must also account for the fact that investors can shift financial capital overseas to maintain rates of return when returns are reduced in a domestic economy that is severely impacted by a policy. In a world in which agents in any region can invest in any of the others, the GDP losses mentioned above are a poor proxy for welfare changes because they are a measure of where production occurs rather than who earns income from that production. In contrast, gross national product (GNP) is a measure of the total income the residents of a country and includes net income transfers to and from factors of production located abroad.

For an OECD stabilization policy without permit trading, regions' GNP losses are roughly comparable to their GDP losses. However, the dispersion of loss is reduced when considered in terms of GNP rather than GDP because of the ability to shift financial capital and eventually real investment into higher return activities abroad.

Comparing this simulation with the previous simulation in which the United States stabilizes alone, it is apparent that the United States is significantly better off under the OECD-wide policy than it is when it stabilizes emissions on its own. In 2010, U.S. GDP falls by only 0.3 percent, while under the unilateral policy it would have fallen by 0.6 percent. In 2020, U.S. GDP is 0.5 percent below baseline; under the unilateral policy it would have fallen by 0.7 percent. One fairly obvious reason for the lower costs is that the competitiveness loss relative to other OECD economies in fossil fuel intensive exports is reduced when more countries reduce emissions and thus raise their domestic fossil fuel prices. Another reason for the reduction in GDP loss lies in the fact that the United States has substantially lower marginal costs of abating carbon emissions than other OECD economies. The stabilization of emissions requires less of a price rise in the US relative to other countries. This further mitigates the effects of the policy on competitiveness.

However, there is an additional, somewhat more subtle reason for the reduction in US GDP losses under OECD stabilization. The policy directly reduces rates of return in each economy and relatively more so in sectors that are relatively carbon intensive. The lower abatement costs in the United States yield smaller relative effects on US rates of return to capital, compared with returns in other OECD countries. This shift in relative rates of return induces investors to shift their portfolios toward U.S. assets, leading to an increase in U.S. investment. Thus production tends to fall less in the US relative to other OECD economies. The effect is particularly apparent in the years immediately before the policy takes effect: U.S. investment is 2.4 percent above baseline in 2005. In addition, the U.S. also benefits from lower world oil prices as OECD oil demand falls. The boost in investment and lower oil prices both tend to raise energy demand and cause permit prices to rise relative to the unilateral stabilization scenario – from $74 to $83 in 2010 and from $85 to $90 in 2020.

Examining the effect of the policy on different regions raises a number of interesting results that tend to be ignored in popular discussion of the impacts of emission permit trading. Those countries that have the largest relative abatement costs, such as Australia, have large capital outflows because of the fall in the rate of return to capital in high abatement cost countries. Most of this capital outflow goes to the United States, although some to developing countries, which are not controlling emissions at all. However, capital flows to developing countries are limited by adjustment costs: the cost of expanding a region's physical capital stock is inversely related to the size of the region's capital stock. It is thus expensive for a region with a relatively small capital stock to absorb a large flow of new capital; and the LDCs, even taken as a group, are simply quite small economies in relative terms. In contrast, it is relatively cheap for a large country with a large capital stock, such as the United States, to absorb capital. Thus the arbitrage of expected financial rates of return is directly affected by the size of physical capital stocks and capacity to build physical capital over time. A relatively small capital inflow can exhaust arbitrage opportunities in developing economies. This is an important insight from the model because there is a popular perception that greenhouse abatement policies will lead to wholesale short- to medium-term migration of industries out of abating countries to non-abating developing countries. In fact the model gives a plausible story that suggest this is unlikely: most of the financial capital reallocation is between OECD economies.

Capital flows cause the exchange rates of countries receiving financial capital, such as the Untied States and developing countries, to appreciate, and the Japanese, Australian and ROECD currencies to depreciate. These exchange rate adjustments, induced by financial capital flows, lead directly to changes in export patterns on top of the changes induced by the relative changes in the cost of carbon inputs into production. Between 2010 and 2020, Japanese and ROECD exports of durable goods increase by about 1% and 6%, respectively, over baseline; U.S. exports of durables fall by 9% to 11%, while exports from developing countries fall by 8% to 13%.[27] At the same time, capital flows to higher rate of return activities overseas cause Japanese, Australian and ROECD GNP to fall by less than the fall in GDP.

Overall, the effect of stabilization on countries with high abatement costs – Australia and ROECD – is to reduce GDP, cause an outflow of capital, depreciate the exchange rate and stimulate overall exports although carbon intensive exports are relative worse off. The effect on low cost countries is the opposite: capital inflows tend to raise GDP by reducing real interest rate and stimulating domestic demand in the short run and a higher capital stock in the medium to long run; appreciate the exchange rate and diminish exports. Australia is substantially hurt directly through high abatement costs but also indirectly by the impact of Japanese carbon controls on Australian coal exports. Finally, oil exports from OPEC countries decline by about 8 percent in 2010 and world oil prices decline by about 15 percent.

[27] Even though capital inflows to developing countries raise overall economic activity, the durables sector declines slightly because exports are adversely affected by exchange rate appreciation. This effect limits the "leakage" of emissions arising from redirection of trade away from emissions-controlling regions to developing countries.

3.3 OECD Emissions Stabilization With Permit Trading

Results for the scenario in which trading in emission permits are allowed are shown in Table 7. In this case countries are given allocations of permits equal to their 1990 carbon emissions, allocations which they can use or sell as they wish. Countries can thus also choose to reduce emissions or buy permits on an international market if they wish to raise emissions above their 1990 levels.

In contrast to independent stabilization, international permit trading leads to a uniform OECD-wide permit price that rises from about $116 per tonne in 2010 to $132 per tonne in 2020. Because the United States has the lowest abatement costs, US emission reductions are larger than in the no-trading scenario. This is because the United States finds it beneficial to sell permits on the world market while the permit price is above the marginal cost of reducing a unit of carbon in the domestic US economy. As more abatement is done, the marginal cost rises to the world permit price. U.S. carbon emissions decline by over 35%, significantly more than the 24.3% reduction needed to return U.S. emissions to their 1990 levels. Annual permit sales exceed 189 million tonnes ($22 billion) in 2010 and reach over 430 million tonnes ($51.7 billion) in 2020. The largest purchaser of permits by far is the ROECD region, although Australia's purchases are a larger share of GDP in value terms.

Because energy prices are substantially higher in the U.S. than in the no trade case, GDP during the 2010-2020 period is reduced only marginally less in the trading case than in the unilateral US stabilization case. Nonetheless in terms of GNP the US is better off with a permit trading regime than under either unilateral action or multilateral action with no trading.[28]

Exchange rate changes are similar in sign but generally larger in magnitude in the trading scenario relative to the no trading scenario. The Japanese and RO currencies, in particular, depreciate somewhat more. One aspect of the changes in exchange rates is the improvement in the terms of trade of the United States and a deterioration in the terms of trade of other countries because the US is endowed with more permits than it requires. In addition to this effect, there is the crucial, and overlooked issue of the real transfer of resources between countries necessary to support the value of the permit trading that is being undertaken. When a country buys a permit, it not only gives money to the country selling the permit, but it gives a claim over the future exports of the country which give the permit its underlying value. The current account must change to reflect the permit transaction and this requires changes in the trade balance. These adjustments are brought about through changes in real and nominal exchange rates which respond to the permit trade. This entire issue of resources shifting between economies due to changes in property claims is the classic 'transfer problem' that has a long tradition in international economics.

The real currency depreciation in permit-buying regions causes non-permit exports from the United States to contract and exports from Japan, Australia and the ROECD to expand more under the permit trading scenario. In fact, the Japanese and RO trade surpluses grow by amounts

[28] This result differs from that reported in earlier papers drawing on earlier versions of the model, and is dependent mainly on differences in the baseline emission trajectories, as well as differences in key assumptions about substitution elasticities and carbon emission coefficients. For the same reasons, the following relative exchange rate results differ from previously reported results as well.

roughly comparable to what each country spends on emissions permits. Because most international trade involves manufactured products, these countries in effect pay for their emissions permits with exports of durables. This leaves the pattern and magnitude of net international capital flows similar between the trading and no trading scenarios.

The overall real GDP gains from emissions trading total about $28 billion in 2010 and around $50 billion in 2020. These gains reduce total OECD GDP losses from about $222 billion (0.8%) to about $193 billion (0.7%) in 2010, and from $336 billion (1.0%) to $286 billion (0.9%) in 2020. Trading thus reduces overall OECD GDP losses by 13% to 15%. In contrast, the real GNP gains from trade are about $34 billion in 2010 and $55 billion in 2020.[29] Discounted to 2000, the total GDP gains from trade over the 2010-2020 period – $205 billion – reduce overall OECD costs of stabilization 14%, from a discounted total of about $1.47 trillion (0.9% of total discounted GDP) to $1.27 trillion (0.8%). Similarly, the GNP discounted gains of $233 billion reduce overall costs 16%, from $1.45 trillion (0.9% of total discounted GDP) to $1.22 trillion (0.8%).

Large though these gains are, they are very unevenly distributed among regions. In 2010, ROECD gains about $46 billion in GDP from trading ($40 billion in GNP); Australia gains about $7 billion ($4 billion in GNP), Japan loses about $10 billion ($11 billion in GNP), and the U.S. loses about $14 billion ($1 billion gain in GNP). By 2020, the U.S. GDP is about $34 billion lower from trading (GNP, however, is higher by $14 billion); Japan loses $1.3 billion in GDP (GNP is essentially unchanged from the baseline), Australia gains $6.2 billion in GDP (GNP is

[29] Gross domestic product (GDP) measures the output that occurs in a country; while gross national product (GNP) measures the income to citizens of that country.

essentially unchanged), and RO gains about $78 billion in GDP ($40 billion in GNP). In discounted GNP terms, all regions gain from permit trading except for Japan, which loses about $16 billion. The ROECD region enjoys nearly all of the gains.

4 Sensitivity Analysis

The results above are clearly conditional on the assumptions and parameters built into the model. In another paper that focuses on the Kyoto Protocol (McKibbin, Ross, Shackleton and Wilcoxen, 1998), we undertake a range of sensitivity analysis to check on the robustness of the insights from the G-Cubed model. In this section we undertake sensitivity analysis of the trade price elasticities, to see if the values of these parameters change the qualitative as well as quantitative results. Space is the major consideration for limiting this analysis to one alternative set of parameters.

In this section we present results for a version of the model in which the elasticities of substitution between domestic and foreign goods and between alternative sources of foreign goods (Armington elasticities) are both raised from 1 to 2. The results for the no trade scenario are contained in Table 9, and for the permit trading scenario in Table 10. A direct comparison is somewhat complicated because we use the model with higher Armington elasticities to generate both a new baseline projection and policy cases, and the new baseline differs rather significantly from the baseline in which Armington elasticities are assumed to be equal to unity. Thus the two versions differ not only in how the world's economies respond to a carbon policy, but also in how they evolve in the absence of one. In particular, in a world with higher trade elasticities, it is easier to run the trade deficits and surpluses required to move a given amount of financial capital between regions, and as a consequence there are greater baseline international financial capital flows from developed regions of the world, which have relatively modest investment prospects, to developing regions, which have relatively greater investment prospects.

Despite these difficulties, a key result emerges from a comparison of Table 9 with Table 6. The exchange rate change required to generate the resource shift behind each permit sale is substantially smaller when trade elasticities are larger. This is not surprising because a given change in the exchange rate can double the change in exports in the case of the high elasticities. The effect is not linear on trade balances because the exchange rate change acts on both imports and exports. Thus, all else being equal a doubling of the Armington elasticity changes the exchange rate outcome by roughly a factor of four.

Furthermore, the net foreign asset flows are smaller when trade elasticities rise. This is also not surprising, because the more easily trade flows can adjust, the less physical capital has to be relocated across economies in response to the shock. Thus a loosening on the restriction of trade flows means that less adjustment of capital is required.

Another interesting difference between the two no trade scenarios is that with higher Armington elasticities, Japan’s real exchange rate is not reduced as much by capital outflows. A higher exchange rate, in turn, makes fossil fuel imports cheaper, and thus leads to higher Japanese carbon emissions in the baseline. Higher carbon emissions, finally, require a higher permit price to achieve stabilization in Japan.

Comparing the effects of international permit trading under the two sets of assumptions about Armington elasticities in Tables 10 and 7, many results appear similar, including permit prices and annual permit sales; but the exchange rate outcomes are again dramatically different, as are the magnitudes of capital flows. In comparing the moves from no trading to trading under the two alternative parameter sets, it is clear that the changes are also largely occurring in the exchange rate and international capital flow results. Thus the key insights of the G-Cubed model remain under the two sets of parameters considered here. It is clear however that trade price elasticities are important determinants of the magnitudes of capital flow and exchange rate responses to a permit trading regime.

5 Conclusion

The theoretical appeal of an international permits program is strongest if participating countries have very different marginal costs of abating carbon emissions – in that situation, the potential gains from trade are largest. Our results show that within the OECD, abatement costs are indeed quite heterogeneous: the marginal cost of stabilizing emissions in Australia and the "Rest of the OECD" region are nearly three times that of stabilizing emissions in the United States. These differences in abatement costs are caused by a range of factors, including different carbon intensities of energy use, different substitution possibilities, and different baseline projections of future carbon emissions. Because of these differences in marginal abatement costs, under an OECD-only permit trading regime the U.S. emerges as a large seller of emissions permits and ends up doing far more abatement than if it had stabilized its emissions unilaterally. The shift of abatement to the United States provides total gains to the OECD as a group of 13% to 15% – $30 billion to $50 billion a year. Given heterogeneous marginal abatement costs, international trading provides significant gains in efficiency.

Because the United States can reduce carbon emissions at relatively low cost, under an OECD stabilization policy – with or without trading – it will benefit from a significant inflow of international financial capital. This will cause the dollar to appreciate, and will tend to reduce exports of durable goods. Australia, Japan and the "Rest of the OECD", as high cost countries, will see capital outflows, exchange rate depreciation, and increased exports of durables. Total flows of capital could be substantial, accumulating as much as half a trillion 1990 dollars over the period between 2000 and 2020. The extent to which the exchange rate needs to move depends importantly on how sensitive trade flows are to exchange rate changes. The key issue here is how resources, that are implicit in the trading of emission permits, will move between economies.

Finally, it is important to note that the OECD trading regime examined in this paper has only a relatively modest effect on the costs of stabilizing emissions. Furthermore, in this case permit trading causes the United States to undertake more abatement than it would otherwise. Our results suggest that in order for U.S. abatement to fall under a trading regime (that is, for the U.S. to be come an importer of permits), permits would have to be available at a price below $83 per tonne and in sufficiently large quantity (substantially more than 190 million tonnes) as to be able to supply the demands of Europe, Japan and Australia as well as the United States. This will only be possible if China, Brazil and other developing countries join the trading program *and* they are given very large allotments of permits, or if the countries of the former Soviet Union are allowed to sell their 300 million tonnes of unneeded permits.

Sensitivity analysis also presented in this paper suggests that many of the qualitative insights are robust to the size of trade elasticities, although the swings in exchange rates and the extent of movements in current account balances as a result of the trading of permits are quite different. With higher price sensitivity of trade flows, the more easily trade movements rather than capital movements can achieve the desired global allocation of emissions rights. This result is not surprising since in a completely flexible world the emission permit system would not really present a challenge for policy. The fact that reality is substantially less frictionless than usually assumed in theoretical economic models, implies greater volatility of variables that are flexible in response to policy reforms. Therefore flexible variables such as asset prices and international financial flows will likely respond significantly more when other variables are subject to stickiness. The model underlying this study attempts to plausibly incorporate many of the empirical regularities excluded from many theoretical models. This makes for a much richer analysis and illustrates how important empirically observed rigidities (whether it be costs of adjustment in physical investment, sticky labor markets due to institutional structures, or liquidity constraints) should be to the insights we formulate about policy. It also highlights just how important further empirical estimation of key relationships are for relevant policy analysis of something as potentially large and important as a multi-country system of emission permit trading.

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Table 1: Regions and Sectors in G-Cubed

Regions	Sectors
1. United States 2. Japan 3. Australia 4. Other OECD countries 5. China 6. Former Soviet Union 7. Oil exporting developing countries 8. Other developing countries	1. Electric utilities 2. Gas utilities 3. Petroleum refining 4. Coal mining 5. Crude oil and gas extraction 6. Other mining 7. Agriculture 8. Forestry and wood products 9. Durable goods 10. Nondurables 11. Transportation 12. Services

Table 2: Production Elasticities

Sector	Output		Energy		Materials
	Estimated	Imposed	Estimated	Imposed	
Electricity	0.763 (0.076)	0.200	0.200		1.000
Natural Gas	0.810 (0.039)	0.200	0.933 (0.347)	0.200	0.200
Petroleum Refining	0.543 (0.039)	0.200	0.200		0.200
Coal Mining	1.703 (0.038)	0.200	0.159 (0.121)		0.529 (0.018)
Crude Oil & Gas	0.493 (0.031)		0.137 (0.034)		0.200
Other Mining	1.001 (0.315)		1.147 (0.136)	0.500	2.765 (0.028)
Agriculture	1.283 (0.047)		0.628 (0.051)		1.732 (0.105)
Forestry & Wood	0.935 (0.080)		0.938 (0.138)	0.400	0.176 (0.000)
Durables	0.410 (0.019)		0.804 (0.058)	0.500	0.200
Nondurables	1.004 (0.012)	0.410	1.000	0.400	0.057 (0.000)
Transportation	0.537 (0.070)		0.200		0.200
Services	0.256 (0.027)		0.321 (0.045)		3.006 (0.073)

Table 3: Population Growth Rates

Region	Population Growth Rate
United States	0.5
Japan	0.0
Australia	0.8
Other OECD	0.7
China	1.5
Former Soviet Union	0.5
Other developing countries	1.0

Table 4: Aggregate Effects of Unilateral U.S. Stabilization

	2000	2005	2010	2020
Permit price ($95)	--	--	$74	$85
Carbon emissions	0.4%	0.5%	-24.3%	-37.1%
Coal consumption	0.1%	0.1%	-40.2%	-57.7%
Oil consumption	0.6%	0.8%	-15.6%	-24.0%
Gas consumption	0.3%	0.5%	-9.7%	-20.4%
GDP	0.0%	0.1%	-0.6%	-0.7%
Consumption	0.3%	0.6%	-0.6%	-0.1%
Investment	1.1%	0.8%	-0.8%	-0.6%
Exchange rate	2.9%	2.9%	2.2%	4.4%
Exports	-2.3%	-2.4%	-2.2%	-4.5%
Imports	-0.5%	-0.6%	-3.0%	-4.2%
Net foreign assets (Bil. $95)	$0	-$64	-$165	-$58
GNP	0.0%	0.1%	-0.6%	-0.7%

Table 5: Industry Effects of Unilateral U.S. Stabilization

	2005		2010		2020	
	Price	Qty	Price	Qty	Price	Qty
Energy Industries						
Electric utilities	-0.1%	0.3%	4.7%	-4.5%	10.9%	-8.4%
Gas utilities	-0.2%	0.4%	8.2%	-9.3%	22.4%	-20.1%
Petroleum refining	-0.4%	0.4%	15.6%	-12.9%	24.2%	-21.8%
Coal mining	0.0%	-0.1%	175.8%	-32.7%	302.9%	-49.9%
Oil and gas extraction	-0.2%	0.0%	-8.1%	-7.5%	-6.6%	-17.4%
Other Sectors						
Other mining	-0.3%	-0.3%	0.8%	-2.1%	0.7%	-3.0%
Agriculture	-0.2%	0.1%	0.1%	-1.2%	-0.6%	-0.8%
Forestry and wood	-0.3%	0.1%	0.0%	-1.0%	-0.7%	-1.0%
Durable goods	-0.5%	-0.2%	-0.1%	-1.1%	-1.0%	-1.3%
Nondurables	-0.3%	0.2%	-0.3%	-1.0%	-0.7%	-0.7%
Transportation	-0.2%	0.3%	0.2%	-1.6%	-0.4%	-1.3%
Services	-0.2%	0.3%	-0.7%	-0.3%	-1.2%	0.3%

Table 6: OECD Stabilization Without Permit Trading

	United States	Japan	Australia	Other OECD
2005				
Permit price ($95)	--	--	--	--
Carbon emissions	1.6%	-2.0%	0.0%	-1.5%
Coal consumption	0.6%	-0.8%	-0.3%	-0.5%
Oil consumption	2.6%	-2.7%	0.0%	-2.0%
Gas consumption	1.6%	-0.6%	0.0%	-1.3%
GDP	0.3%	-0.2%	0.1%	-0.2%
Investment	2.4%	-0.4%	0.5%	-1.7%
Exchange rate	8.9%	-5.5%	1.0%	-11.1%
Net foreign assets (Bil. $95)	-$204	-$40	$12	$156
GNP	0.2%	-0.2%	0.1%	0.0%
2010				
Permit price ($95)	$83	$105	$219	$240
Carbon emissions	-24.3%	-15.6%	-42.2%	-27.1%
Coal consumption	-43.9%	-32.6%	-59.6%	-41.9%
Oil consumption	-12.5%	-11.0%	-23.7%	-24.6%
Gas consumption	-8.3%	-3.2%	-22.7%	-13.7%
GDP	-0.3%	-0.2%	-2.6%	-1.3%
Investment	1.2%	-1.1%	-0.7%	-2.9%
Exchange rate	8.2%	-3.5%	-2.0%	-12.3%
Net foreign assets (Bil. $95)	-$504	-$31	$16	$319
GNP	-0.5%	-0.1%	-2.2%	-1.2%
2020				
Permit price ($95)	$90	$143	$248	$286
Carbon emissions	-30.9%	-23.0%	-48.2%	-34.0%
Coal consumption	-52.0%	-47.9%	-70.6%	-51.2%
Oil consumption	-17.1%	-16.0%	-23.6%	-30.5%
Gas consumption	-15.0%	-5.4%	-25.5%	-20.4%
GDP	-0.5%	-0.6%	-2.2%	-1.4%
Investment	0.6%	-1.2%	0.0%	-3.2%
Exchange rate	9.0%	-5.8%	5.1%	-11.3%
Net foreign assets (Bil. $95)	-$526	-$71	$42	$474
GNP	-0.7%	-0.6%	-1.8%	-1.2%

Table 7: OECD Stabilization With Permit Trading

	United States	Japan	Australia	Other OECD
2005				
Permit price ($95)	--	--	--	--
Annual Permit sales (Bil. $95)	--	--	--	--
Carbon emissions	2.3%	-3.0%	-0.4%	-2.3%
Coal consumption	0.8%	-0.8%	-0.3%	-0.7%
Oil consumption	3.7%	-4.3%	-0.7%	-3.2%
Gas consumption	2.3%	-0.8%	-0.8%	-2.0%
GDP	0.5%	-0.3%	0.0%	-0.3%
Investment	3.4%	-0.7%	-0.3%	-2.6%
Exchange rate	13.0%	-8.3%	-0.5%	-17.2%
Net foreign assets (Bil. $95)	-$280	-$56	$27	$248
GNP	0.3%	-0.2%	0.1%	-0.1%
2010				
Permit price ($95)	$116	$116	$116	$116
Annual Permit sales (Bil. $95)	$22.0	$1.6	-$3.0	-$20.6
Carbon emissions	-35.2%	-19.9%	-21.8%	-14.3%
Coal consumption	-61.6%	-39.0%	-30.2%	-20.6%
Oil consumption	-20.0%	-15.1%	-12.7%	-13.5%
Gas consumption	-12.6%	-4.1%	-12.2%	-7.9%
GDP	-0.5%	-0.5%	-1.5%	-0.9%
Investment	1.1%	-1.4%	-0.6%	-2.7%
Exchange rate	11.5%	-6.8%	-2.4%	-17.9%
Net foreign assets (Bil. $95)	-$693	-$42	$44	$521
GNP	-0.5%	-0.3%	-1.5%	-0.9%
2020				
Permit price ($95)	$132	$132	$132	$132
Annual Permit sales (Bil. $95)	$51.7	-$0.3	-$5.1	-$46.3
Carbon emissions	-45.6%	-25.0%	-25.4%	-17.3%
Coal consumption	-75.0%	-48.5%	-37.2%	-24.3%
Oil consumption	-26.8%	-18.9%	-12.5%	-16.1%
Gas consumption	-22.5%	-6.0%	-13.9%	-10.9%
GDP	-0.7%	-0.7%	-1.2%	-1.0%
Investment	0.6%	-1.4%	-0.2%	-3.0%
Exchange rate	13.4%	-8.6%	0.9%	-18.2%
Net foreign assets (Bil. $95)	-$695	-$72	$58	$647
GNP	-0.7%	-0.6%	-1.5%	-0.9%

Table 8: Gains From Permit Trading, $90 Billion (* - 2010-20 Discounted @ 5%)

	GDP ($95)			GNP ($95)		
	2010	**2020**	**2010-20***	**2010**	**2020**	**2010-20***
United States	$ -13.9	$ -34.2	$ -129.4	$ 1.0	$ 14.1	$ 6.9
Japan	$ -10.4	$ -1.3	$ -27.5	$ -10.6	$ 0.5	$ -16.1
Australia	$ 6.9	$ 6.2	$ 31.1	$ 4.0	$ 0.1	$ 10.5
Other OECD	$ 45.8	$ 78.3	$ 331.4	$ 39.5	$ 40.4	$ 232.1
Total OECD	$ 28.4	$ 49.0	$ 205.5	$ 33.9	$ 54.9	$ 233.4

Table 9: OECD Stabilization Without Permit Trading (Armington Elasticity = 2)

	United States	Japan	Australia	Other OECD
2005				
Permit price ($95)	--	--	--	--
Carbon emissions	0.2%	0.1%	-0.1%	-0.2%
Coal consumption	0.0%	0.1%	0.3%	-0.1%
Oil consumption	0.5%	0.1%	-0.2%	-0.3%
Gas consumption	0.2%	0.0%	0.0%	-0.2%
GDP	0.1%	0.0%	0.0%	0.0%
Investment	0.6%	0.0%	-0.3%	-0.3%
Exchange rate	1.1%	0.4%	-1.0%	-0.8%
Net foreign assets (Bil. $95)	-$90	-$18	$9	$47
GNP	0.0%	0.0%	0.0%	0.0%
2010				
Permit price ($95)	$78	$150	$222	$221
Carbon emissions	-24.1%	-20.8%	-42.8%	-24.4%
Coal consumption	-42.1%	-48.6%	-59.8%	-38.6%
Oil consumption	-13.5%	-13.0%	-24.5%	-21.8%
Gas consumption	-9.2%	-4.0%	-23.9%	-11.9%
GDP	-0.6%	-0.3%	-2.7%	-1.0%
Investment	-0.4%	-0.9%	-2.4%	-1.9%
Exchange rate	1.0%	1.9%	-2.1%	-1.1%
Net foreign assets (Bil. $95)	-$232	-$33	$20	$116
GNP	-0.6%	-0.3%	-2.4%	-1.0%
2020				
Permit price ($95)	$83	$168	$248	$253
Carbon emissions	-30.2%	-27.0%	-48.9%	-30.9%
Coal consumption	-49.4%	-60.6%	-70.5%	-46.8%
Oil consumption	-17.8%	-17.2%	-24.5%	-27.4%
Gas consumption	-15.5%	-6.4%	-27.0%	-17.9%
GDP	-0.7%	-0.6%	-2.5%	-1.1%
Investment	-0.7%	-1.0%	-0.7%	-2.0%
Exchange rate	1.9%	0.2%	3.0%	-0.5%
Net foreign assets (Bil. $95)	-$76	-$121	$68	$205
GNP	-0.7%	-0.7%	-1.9%	-1.0%

Table 10: OECD Stabilization With Permit Trading (Armington Elasticity = 2)

	United States	Japan	Australia	Other OECD
2005				
Permit price ($95)	--	--	--	--
Annual Permit sales (Bil. $95)	--	--	--	--
Carbon emissions	0.4%	0.0%	-0.3%	-0.3%
Coal consumption	0.0%	0.1%	0.0%	-0.1%
Oil consumption	0.8%	0.0%	-0.5%	-0.5%
Gas consumption	0.4%	0.0%	0.0%	-0.3%
GDP	0.1%	0.0%	-0.1%	0.0%
Investment	1.0%	0.0%	-0.8%	-0.5%
Exchange rate	1.8%	0.1%	-1.5%	-1.6%
Net foreign assets (Bil. $95)	-$133	-$13	$15	$94
GNP	0.0%	0.0%	0.0%	0.0%
2010				
Permit price ($95)	$112	$112	$112	$112
Annual Permit sales (Bil. $95)	$24.8	-$2.2	-$3.2	-$19.4
Carbon emissions	-36.3%	-15.4%	-21.1%	-12.0%
Coal consumption	-61.0%	-36.3%	-29.4%	-19.5%
Oil consumption	-22.5%	-9.5%	-12.1%	-10.4%
Gas consumption	-14.5%	-3.0%	-12.0%	-5.8%
GDP	-0.9%	-0.3%	-1.5%	-0.5%
Investment	-1.3%	-0.6%	-1.6%	-0.9%
Exchange rate	1.7%	1.2%	-2.2%	-1.8%
Net foreign assets (Bil. $95)	-$343	-$15	$33	$234
GNP	-0.7%	-0.3%	-1.6%	-0.6%
2020				
Permit price ($95)	$123	$123	$123	$123
Annual Permit sales (Bil. $95)	$48.8	-$4.6	-$5.4	-$38.8
Carbon emissions	-45.8%	-19.9%	-24.1%	-14.9%
Coal consumption	-72.8%	-44.8%	-34.9%	-23.0%
Oil consumption	-28.7%	-12.7%	-11.9%	-13.1%
Gas consumption	-23.8%	-4.7%	-13.0%	-8.7%
GDP	-1.2%	-0.4%	-1.3%	-0.6%
Investment	-1.3%	-0.8%	-0.8%	-1.2%
Exchange rate	3.5%	-0.1%	-0.1%	-2.1%
Net foreign assets (Bil. $95)	-$69	-$105	$51	$217
GNP	-0.8%	-0.6%	-1.6%	-0.7%