The Potential Effects of International Carbon Emissions Permit Trading Under the Kyoto Protocol

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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 the tradable emissions permit system proposed in the 1997 Kyoto protocol, under various assumptions about that extent of international permit trading. We focus, in particular, on the effects of the system on international trade and capital flows. Our results suggest that consideration of these flows significantly affects estimates of the domestic effects of the emissions mitigation policy, compared with analyses that ignore international capital flows.

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1. Introduction

As part of an effort to reduce global emissions of greenhouse gases (GHGs) that are expected to contribute to a significant warming of the earth's climate, the Kyoto Protocol to the United Nations Framework Convention on Climate Change, signed in Kyoto in December 1997, includes binding GHG emissions targets for the world's industrial economies ("Annex I" countries) for the period 2008-2012. The Protocol also provides for international trading of emission allowances among the countries that accept binding targets, in recognition of the theoretical efficiency benefits of allowing emission reductions to be obtained at least cost. In addition, the Protocol provides for a Clean Development Mechanism, under which agents from industrial countries can earn emission credits for certified reductions from investments in "clean development" projects in developing countries that have not taken on binding targets.

In this paper we present estimates of the potential economic effects of the Kyoto Protocol, using the G-Cubed multi-region, multi-sector intertemporal general equilibrium model of the world economy.[1] We examine and compare four potential implementations of the Protocol involving varying degrees of international permit trading, focusing particularly on the effects of the policies on output, exchange rates and international flows of goods and capital; and calculate some of the gains from allowing international permit trading.

2. Model Structure

G-Cubed consists of a set of eight regional general equilibrium models linked by consistent international flows of goods and assets. We assume that each region consists of a representative household, a government sector, a financial sector, twelve industries, and two sectors producing capital goods for the producing industries and households, respectively. The regions and sectors are listed in Table 1. The regions are similar in structure (that is, they consist of similar agents solving similar problems), but they differ in endowments, behavioral parameters and government

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[1] G-Cubed stands for "Global General Equilibrium Growth Model".

policy variables.[2] In the remainder of this section we present the key features of the regional models.[3]

2.1 Producer Behavior

Within a region, each producing sector is represented by a single firm which chooses its inputs and 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. 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.

We use a nested system of CES equations rather than a more flexible functional form because there is too little data available for a more flexible specification to be feasible. In principle, to estimate a more flexible specification we would need time-series price and quantity data for 14 inputs (twelve goods plus capital and labor) in each of 96 industries (12 industries in 8 regions). Unfortunately, no country collects annual data on intermediate inputs, and most developing countries collect almost no industry data at all.

The scarcity of input-output data requires us to restrict the model further by imposing the assumption that each industry has the same energy, materials and KLEM substitution elasticities no matter where it is located (although the elasticities differ across industries).[4] However, even though the substitution elasticities are identical across countries, the overall production models differ because the CES input weights are taken from the latest available input-output data for each

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[2] 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 1 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.

[3] A more complete description of the model is contained in McKibbin and Wilcoxen (1995b).

[4] This assumption is consistent with the available econometric evidence (see for example Kim and Lau, 1994).

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 a given percentage increase in an input price is identical across countries. Taken together, these assumptions are equivalent to assuming that all regions share production methods that differ in first-order properties but have identical second-order characteristics. This approach 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 share some common parameters they are not simple replicas of one another.

To estimate the elasticities we have 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; complete details are contained in McKibbin and Wilcoxen (1995b).

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

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[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.

[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.

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] 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 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.

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. 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 domestic varieties of each particular commodity.[13] We parameterize this decision using trade shares based on

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[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.

[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 we intend to relax it in future work.

[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.

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:

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

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):

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

Following Hayashi (1979), we expand the equation above and write *I* as a function not only of *q*, but also of the firm's current profit, π, adjusted by the investment tax credit, τ_4:

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

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

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

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 share 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 by 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:

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

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

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[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.

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

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

There has, however, been considerable debate about whether the actual behavior of aggregate consumption is consistent with the permanent income model.[16] Based on the evidence cited in Campbell and Mankiw (1990), we assume that only a fraction β of all consumers choose their consumption to satisfy the equation and that the remainder consume based entirely on current after-tax income. This 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 and will simply take β to be an exogenous constant.[17] This produces the final consumption function shown below:

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

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.[18]

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

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

[17] 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 the previous equation, either because the households are at corner solutions or for some other reason, aggregate behavior is inconsistent with the expenditure function derived from our utility function.

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

inputs of capital services, labor, energy and materials. Energy and materials, in turn, are CES aggregates of inputs of individual goods.[19] 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 where nominal wages are set based on current and expected inflation and on labor demand relative to labor supply. In the long run labor supply, which is specified in terms of labor efficiency units, 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.

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[19] This specification has the undesirable effect of imposing unitary income and price elasticities. There is abundant empirical evidence against this assumption and we intend to generalize it in future work.

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 we set to 1990 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 from 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 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:

$$M = PY\, i^{\varepsilon}$$

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 Capital 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.

Trade imbalances are financed by flows of assets between countries. We assume that asset markets are perfectly integrated and that financial capital is freely mobile.[20] Under this assumption, expected returns on loans denominated in the currencies of the various regions must be equalized period to period according to a set of interest arbitrage relations of the following form:

$$i_k + \mu_k = i_j + \mu_j + \frac{\dot{E}_k^j}{E_k^j}$$

where i_k and i_j are the interest rates in countries k and j, μ_k and μ_j are exogenous risk premiums demanded by investors (possibly zero), and E_k^j is the exchange rate between the two currencies. The risk premiums are calculated in the course of generating the model's baseline and are generally held constant in simulations. Thus, if, in the base year, capital tended not to flow into a region with relatively high interest rates, it will not do so during the simulation. Finally, we also assume that OPEC chooses its foreign lending in order to maintain a desired ratio of income to wealth subject to a fixed exchange rate with the U.S. dollar.

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[20] The mobility of international capital is a subject of considerable debate; see Gordon and Bovenberg (1994) or Feldstein and Horioka (1980). Also, this assumption should not be confused with our treatment of *physical* capital, which we assume to be specific to sectors and regions and hence completely immobile. The consequence of assuming mobile financial capital and immobile physical capital is that there can be windfall gains and losses to owners of physical capital. For example, if a shock adversely affects profits in a particular industry, the physical capital stock in that sector will initially be unaffected. Its value, however, will immediately drop by enough to bring the rate of return in that sector back to into equilibrium with that in the rest of the economy.

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.[21] 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

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[21] For a more detailed discussion of the importance of accounting for heterogeneity in sector-level productivity growth rates see Bagnoli, McKibbin and Wilcoxen (1996).

deficits.[22] At the solution, the budget constraints for all agents are satisfied, including both intratemporal and intertemporal constraints.

3. The Effects of the Kyoto Protocol

We now explore the effects of the Kyoto Protocol in five different scenarios. In the first, the United States meets its commitment under the Protocol but no other regions take action. This scenario is presented not as a practical proposition but as a benchmark against which multilateral scenarios can be compared. In the remaining four scenarios we examine the effects of the Protocol when all regions meet their commitments but the extent of international emissions permit trading varies.

Since the model only accounts for emissions of carbon dioxide from fossil fuel combustion, while the Protocol specifies targets for all GHGs in carbon equivalent units,[23] we make the simplifying assumption that 88% of each country's mitigation efforts is met through reductions in fossil-related carbon emissions, and set the carbon target accordingly. In each scenario, Annex I regions hold annual auctions of the specified quantity of carbon emissions permits in each of the years from 2008 to 2020.[24] The permits are required for the use of primary fossil fuels (coal, crude oil and gas) in proportion to the average carbon content per physical unit of each fuel. Revenues from the permit sales are assumed to be returned to households via a deficit-neutral lump sum rebate.[25] The policy is announced in 2000 so that agents have a nearly

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[22] 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.

[23] The carbon equivalent units are specified in terms of the 100-year global warming potentials (GWPs) of carbon; e.g. a ton of methane emissions are counted as the equivalent of 21 tons of carbon (or 21 times 3.67 tons of carbon dioxide), since a ton of methane contributes roughly the same amount of radiative forcing over a century as 21 tons of carbon in the form of carbon dioxide. The permits are sold and used annually; we do not allow for banking or borrowing of emissions between years within the 2008-2012 budget period although this is permitted under the Protocol.

[24] 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.

[25] 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 some of the results substantially. For a discussion of deficit reduction, see

decade to anticipate the policy and adapt to it.

Because G-Cubed represents each region as a competitive market economy in dynamic equilibrium with other regions, its representation of the former Soviet Bloc does not capture the shock associated with the institutional collapse of the formerly planned economy, the consequent dramatic decrease in emissions, or the fact that the region's emissions are likely to be well below the limit mandated by the Kyoto Protocol a decade from now. However, except for the reunification of Germany and the extensive development of parts of Eastern Europe, and the fact that crude oil and gas exports have continued, much of the region has remained substantially independent of the global economy since 1990; and it seems unlikely that international trade and capital flows between this region and the rest of the world will be large enough over the next decade to be a first-order concern. Since the region has relatively little interaction with the rest of the world in the model (as a consequence of the calibration that renders it in equilibrium in the base year), we treat the former Soviet Bloc exogenously in this analysis. (However, we account for income flows from the international sale of permits.) Taking these observations into account, in each of these scenarios, emission reductions in the former Soviet Bloc (encompassing the former Soviet Union and Eastern Europe) are specified exogenously, drawing on mitigation supply curves constructed mainly from the results of the Pacific Northwest National Laboratory's Second Generation Model (SGM). Furthermore, since former Soviet Bloc GHG emissions are expected to remain well below the targets mandated by the Kyoto Protocol, our exogenously specified supply curve for this region includes mitigation of greenhouse gases other than carbon. Thus the analysis assumes 426 MMTC of "paper tons" (emission allowances that would otherwise remain unused) available in 2010, declining to about 350 MMTC in 2015 and 290 MMTC in 2020, and roughly an additional 140 MMTC available at a cost of less than $25/MTC ($92).[26]

Taken together, the G-Cubed baseline and additional simplifying assumptions lead to reduction requirements in 2010 of 523 million metric tons of carbon (MMTC) for the United

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McKibbin, Shackleton and Wilcoxen (1998a).

[26] The SGM numbers, in turn, are based partly on the results of a joint project between the OECD, the World Bank and the Office of Policy Development at US EPA (see OECD document OECD/GD(97)154 "Environmental Implications of

States, 97 MMTC for Japan, 28 MMTC for Australia, and 401 MMTC for the Other OECD countries; with approximately 41% of those reductions potentially offset by paper tons from the former Soviet Bloc.

The remaining four scenarios involve the attainment of Annex I targets specified in the Protocol with:

1. no international permit trading between regions;
2. international permit trading permitted between all Annex I countries;
3. international permit trading permitted within the Other OECD region, and among the other Annex I regions (the U.S., Japan, Australia, and the former Soviet Bloc), but prohibited between the Other OECD region and the rest of the Annex I countries – the so-called "double umbrella" or "double bubble;" and
4. global permit trading; that is, the developing regions accept an emissions allocation consistent with their modeled baselines, and permit sales from their allowances to Annex I countries.

Graphs illustrating the most important impacts of the Protocol under different assumptions about the extent of international permit trading are provided at the end of the paper. The variables illustrated include regional emission permit prices; emission reductions; international permit sales and purchases; impacts on OPEC oil prices, sales and revenues; changes in international investment and exchange rates; and changes in regions' exports, gross domestic products and gross national products.

3.1 Unilateral Emissions Stabilization by the United States

Key results for the unilateral U.S. policy are shown in Table 4. Since neither the model's behavioral parameters nor the future values of tax rates, productivity, or other exogenous variables can be known with complete certainty, these numbers should be regarded as point estimates within a range of possible outcomes. They do, however, give a clear indication of the

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Energy and Transport Subsidies" or Chapter 6 of OECD publication "Reforming Energy and Transport Subsidies."

mechanisms that determine how the economy responds to climate change policy.

In order to achieve the Kyoto target, emissions in the United States would need to drop by 28 percent relative to the baseline in 2010 and 38 percent in 2020.[27] The resulting price of carbon emissions permits would be $56 per metric ton ($95) in 2010 rising to $64 per ton in 2020.[28] 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 135 percent and coal output declines by 45 percent in 2010 and by 57 percent in 2020. The crude oil and gas sector is also strongly affected: output declines by 16 to 28 percent over the period.

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 (2001-2007). 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, in anticipation of the increase in demand. The increase in investment is financed by an inflow of foreign capital, as aggregate national savings decline slightly. The capital inflow causes the exchange rate to appreciate by about 2 percent over that period. The exchange rate appreciation hurts exports, primarily of durable goods.

The international effects of the US policy vary across regions. Most Annex I 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

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[27] 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.

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

of durable goods due to the change in exchange rates.

3.2 Annex I Targets Met Without International Permit Trading

In the second scenario, all Annex I regions meet their commitments under the Protocol. Each region is restricted to use of their allocated emissions; the permits can be traded within regions but not from one region to another.[29] This simulation allows us to measure the heterogeneity of the Annex I regions. Differences in baseline emissions growth, endowments of fossil fuels, reliance on fossil fuels for energy generation 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.

Annex I stabilization without trading produces the results shown in Table 6. The effects of the policy differ substantially across the regions: in 2010, permit prices per metric ton of carbon range from a low of $57 in Australia to a high of $252 in the “Other OECD” region. (We’ll refer to the “Other OECD” region as “RO”, for “Rest of the OECD”, in the remainder of the text). These results show that both marginal and average costs of abating carbon emissions differ substantially across countries. Since, by assumption, all regions have access to the same technologies, the differences in permit prices reflect differences in mitigation opportunities: regions which have relatively low baseline carbon emissions per unit of output, and are thus relatively sparing in their use of fossil fuels, have relatively fewer options for reducing emissions further. The differences among regions stem in part from differences in the fuel mix: stabilization is cheapest in coal-intensive countries like the United States and Australia; in Japan and RO, stabilization requires larger cuts in oil and gas consumption. These regions therefore face higher marginal costs for achieving their targets under the Protocol.

The effect on GDP follows a pattern similar to that of mitigation costs: U.S. GDP is

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[29] 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.

slightly above its baseline value while GDP in Japan and RO falls by 1.6 and 1.5 percent, respectively. Comparing this simulation with the previous one shows that the United States is significantly better off under the Annex I policy than it is when it reduces emissions on its own. In 2010, U.S. GDP is above its baseline value while under the unilateral policy it would have fallen by 0.6 percent. The reason for this lies in the fact that the United States has substantially lower marginal costs of abating carbon emissions. This causes rates of return in the U.S. to fall less than in other OECD countries, which induces investors to shift their portfolios toward U.S. assets, leading to an increase in U.S. investment. The effect is particularly apparent in the years immediately before the policy takes effect: U.S. investment is almost 8 percent above baseline in 2005. In addition, the U.S. also benefits from lower world oil prices as Annex I 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 $56 to $63 in 2010 and from $64 to $71 in 2020. Although U.S. GDP rises slightly relative to the baseline, it would be wrong to conclude that the policy was actually good for the United States. Much of the additional resources are owned by foreigners, and the income earned by those resource accrues to them. U.S. income, as measured by GNP, falls by 0.3 percent in 2010, though this smaller than the 0.6 percent loss suffered under unilateral action.

Examining the effect of the policy on different regions, RO and Japan, which face the greatest costs of stabilizing emissions, have large capital outflows, accumulating to roughly $875 billion 1995 dollars by 2020. Most of these outflows go to the United States, although some capital flows to Australia, which also has comparatively low costs of abatement, and some to developing countries, which are not controlling emissions at all. Capital flows to developing countries are limited by adjustment costs, however: it is expensive for a region with a relatively small capital stock to absorb a large flow of new capital.

Capital flows cause the U.S., Australian and developing country exchange rates to appreciate by 13, 17 and 53 percent, respectively, and the Japanese and RO currencies to depreciate by roughly 24 and 26 percent, compared with their baseline levels. The dollar appreciates by 50 percent relative to the RO currencies, but depreciates by 25 percent relative to the developing countries. The RO currencies depreciate by 50 percent relative to the developing countries. These changes lead directly to changes in export patterns. By 2010, Japanese and RO exports of durable goods increase by about 14 and 17 percent, respectively, over baseline; U.S. exports of durables fall by 16 percent and exports from developing countries fall by 37 percent.[30] At the same time, capital flows cause Japanese and RO GNP to fall by less than GDP, since these countries' increased foreign investments offset some of the lost income from domestic production.

Overall, the effect of stabilization on countries with high abatement costs (Japan and RO) is to reduce GDP, cause an outflow of capital, depreciate the exchange rate and stimulate exports. The effect on low cost countries is the opposite: capital inflows tend to raise GDP, appreciate the exchange rate and diminish exports. Australia is somewhat of an exception: capital inflows benefit it slightly but the economy is substantially hurt by the impact of Japanese carbon controls on Australian coal exports.

The effect of the Protocol on developing countries is particularly interesting. In the case of the LDCs, the exchange rate appreciation has multiple costs and benefits. Exports (particularly of durables) become more expensive; however, not only do imports become cheaper, but the dollar value of LDC international debt falls dramatically, leading to a net *improvement* in the LDCs' net international investment position in spite of significant capital inflows. LDC gross domestic product rises by 1.6 percent in 2010, and gross national product rises by 2.6 percent. Clearly, the absence of commitments under the Kyoto Protocol confers significant benefits to LDCs through international policy transmission.

In addition, the decline in Annex I oil demand leads to a 10 percent decline in OPEC oil exports and a 16 percent decline in and world oil prices, resulting in a 24 percent decline in OPEC oil export revenues. The decline in oil prices also benefits the LDCs, whose increased oil consumption causes an increase in LDC carbon emissions equivalent to approximately 9 percent

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[30] 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.

of Annex I emission reductions. This 9 percent “leakage effect,” however, does not translate into increased LDC exports of carbon-intensive durable goods, which are significantly dampened by the impact of capital inflows on LDC exchange rates. Instead it is the regions most adversely affected by mitigation policy – Japan and RO – who experience an increase in exports. In effect, these countries pay for their emissions permits with exports, particularly of durables. This seeming paradox, upon reflection, is the inevitable result of the simple analytics of international macroeconomics: countries which experience capital outflows must experience trade surpluses, while countries which experience capital inflows must experience trade deficits.

3.3 Annex I International Permit Trading

The third scenario is identical to the second except that we allow international trading in emissions permits among Annex I countries. The effect of allowing trading is twofold. First, arbitrage will cause the price of a permit to be equal in all Annex I countries. This will ensure that marginal costs of carbon abatement will be equal across countries and that Annex I 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 undertake less domestic abatement.

In addition, trading permits a relaxation of the overall constraint because the emissions of one Annex I region, the former Soviet Bloc, are likely to be below the limit specified under the Protocol. The relaxation of the constraint means that actual emission reductions under the Protocol will be considerably lower – perhaps as much as 40% lower – with international permit trading than without it, at least during the first budget period. The particular circumstances of the former Soviet Bloc thus make it difficult to determine the pure gains from permit trading, independent of the relaxation of the constraint.[31]

Results for this scenario are shown in Table 7. In contrast to independent stabilization, international permit trading leads to a uniform permit price throughout the Annex I that rises from

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[31] Previous analysis using the G-Cubed model indicates that the pure gains from trade are on the order of 20 to 25

about $37 per ton in 2010 to $77 per ton in 2020. These prices, lower than any OECD region's marginal mitigation cost in the absence of international permit trading, lead to lower increases in fossil fuel prices and considerably lower domestic mitigation than in the previous case. Lower domestic mitigation is offset by purchases of allowances from the former Soviet Bloc. At the 2010 permit price of $37 per ton, the former Soviet Bloc sells not only allowances for 426 million metric tons of carbon equivalent (MMTCe) emissions but also reduces emissions to sell an additional 166 MMTCe of allowances. Thus the OECD countries purchase nearly 600 MMTC of emission allowances from the former Soviet Bloc rather than undertake domestic reductions, thereby dramatically reducing the cost of meeting their commitments. These purchases particularly benefit Japan and RO, which use internationally purchased allowances to meet 81 percent and 76 percent of their obligations, respectively; and thus achieve 85 percent and 78 percent respective reductions in their marginal abatement costs. The United States and Australia use internationally purchased allowances to meet 39 percent and 38 percent of their respective obligations, and benefit from 42 percent and 35 percent reductions in marginal abatement costs. International purchases of former Soviet Bloc allowance amount to nearly $22 billion ($95) in 2010 and rise to nearly $41 billion by 2020.

Interestingly, as the regional economies continue to grow after 2010, the demand for emission allowances increases while the former Soviet Bloc's willingness to supply them declines. As a consequence, international permit prices rise continuously after 2010, and by 2020, prices rise to $77 per ton. At this price, the United States becomes a net permit *seller*, supplying about 120 MMTC of allowances to Japan and RO at a total cost of nearly $10 billion, and taking an equivalent quantity of domestic emission reductions in excess of its international commitment.

The impacts of the Protocol on regions' economies are generally significantly reduced by both the equalization of marginal mitigation costs and permit prices under an international permit trading regime, as well as the reduction in overall mitigation due to the sale of former Soviet Bloc's excess allowances. Japanese GDP costs are cut from 0.8 percent to 0.2 percent, Australia's

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percent in the case OECD international permit trading. See McKibbin, Shackleton and Wilcoxen (1998b).

from 2.5 percent to 2.0 percent, and RO's from 1.4 percent to 0.5 percent. In contrast, surprisingly, American GDP costs *rise* under international permit trading: rather than experiencing a minor increase, U.S. GDP falls by 0.1 percent because the benefits of reduced mitigation costs are not great enough to offset the loss of a large part of the significant capital inflows that occur under the no-trading regime. Facing lower mitigation costs, Japan and RO do not experience as large a relative decline in returns to capital, and thus do not experience as large net capital outflows as in the no-trading case. With reduced net capital flows, exchange rate effects are moderated everywhere. The LDCs experience only about half the improvement in terms of trade that they do in the no-trading case. The dollar appreciates by only 25% relative to the European countries, and depreciates by only about 17% relative to the developing countries. The European currencies depreciate by 33% relative to the developing countries.

Despite the small adverse effect of international permit trading on U.S. GDP, the U.S. is in fact better off under trading: much of the GDP gain in the absence of international trading accrued to residents of Japan and RO who invested financial capital in the U.S. The country's GNP loss, a more appropriate measure of national income, is cut from 0.3 percent to 0.2 percent. Likewise, Japanese GNP costs are cut from 0.8 percent to 0.2 percent, Australia's from 2.5 percent to 2.0 percent, and RO's from 1.4 percent to 0.5 percent.

The benefits of international permit trading do not, however, accrue to the LDCs, precisely because the large capital outflows triggered in the no-trading case are significantly moderated. With a more moderate exchange rate effect, the benefits of improved terms of trade are also moderated. The improvement in LDCs' GDP is reduced from 1.6 percent to 0.9 percent, and the improvement in GNP is reduced from 2.6 percent from 1.4 percent. Similarly, international permit trading leads to less decline in Annex I oil demand and OPEC oil exports and prices, and thus leads to less benefit to the LDCs. With less oil redirected from Annex I economies to the LDCs, the overall carbon "leakage effect" is reduced from 9 percent to 7 percent.

International permit trading reduces the OECD's overall GNP costs of meeting their commitments under the Kyoto Protocol by about 64 percent in 2010, from $269 billion to $96 billion, or by $172 billion.[32] On the basis of previous analysis using G-Cubed of OECD permit trading without former Soviet Bloc participation, we estimate that roughly 60 percent of these benefits are due to relaxation of the constraint, while the other 40 percent constitute true gains from trade. If we also take into account the spillover effects on China and the LDCs, the world GNP costs of meeting Kyoto commitments is cut by 74 percent from $175 billion to $46 billion, or by $129 billion. These 2010 GNP gains are very unequally dispersed, however: the U.S.[33] gains only $12 billion and Australia only $3 billion, while Japan and RO gain $36 billion and $122 billion, respectively, and the LDCs lose $44 billion. Chinese GNP is almost completely unaffected.

3.3 The “Double Umbrella”

The fourth scenario, in which the RO countries engage in exclusive permit trading and the rest of the Annex I countries engage in permit trading independently of the RO countries are contained in Table 8. These results are in many ways intermediate between the no-trading and full-trading cases. However, the scenario highlights one crucial difference: because the RO region does not engage in international permit trading with any other region, it faces the same high marginal mitigation cost that it does in the no-trading scenario, while the other OECD regions now have access to all of the permits available from the former Soviet Bloc, and – because the RO countries don't buy the permits – at 50% cheaper permit prices to boot. Greater permit availability allows the other OECD regions to achieve 70 to 80 percent of their targets through international purchases of emission permits. The U.S. benefits in two ways: from lower permit prices and also from relatively large capital flows from RO to the U.S (because high energy prices reduce returns to capital in RO). Thus for countries that undertake commitments under the Protocol, refusal to participate in international permit trading not only imposes high costs on countries that do not participate, but actually confers additional benefits on the countries that do participate, and on countries that do not undertake commitments.

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[32] We do not provide estimates of GNP effects for the former Soviet Bloc because of the difficulties mentioned previously.

[33] The U.S. experiences a small GDP loss from trading in 2010 is due to business cycle effects stemming from our assumption that wages adjust slowly: the sharp increase in U.S. energy prices under the trading scenario temporarily reduces labor demand relative to the no-trading case.

3.4 Global Trading

In the final scenario, we assume that the non-Annex I developing countries agree to distribute annual quantities of domestic emission permits consistent with their baseline emissions, and to allow these permits to be traded on international markets.[34] These results are contained in Table 9. The consequence of bringing developing countries into the trading regime is that Annex I countries can purchase emission allowances from owners in developing countries. These owners, in turn, would be willing to sell allowances to Annex I buyers only if the allowance price exceeded the marginal cost to the owners of undertaking emission reductions within the developing countries. The market process would thus lead to least cost reductions on a global scale: emission reductions would be taken wherever, they are cheapest, but Annex I countries would pay for them.

Full global trading cuts the permit cost to $13/MTC in 2010 and $23/MTC in 2020 and has negligible impacts on the Annex I economies. In 2010, the OECD regions achieve 78 to 94 percent of their targets through international purchases of emission allowances. Moreover, since wider availability of emission allowances reduces permit prices, OECD regions are able to purchase international permits at a lower overall cost than in the preceding scenarios: in 2010, international permit sales total less than $12 billion in the global trading case, slightly more than half the $22 billion value of former Soviet Bloc international permit sales in the Annex I trading case. China provides about 280 MMTC of these allowances, and the other LDCs provide about 120 MMTC; the former Soviet Bloc provides another 490 MMTC. Nearly all of the reductions in China and the LDCs are achieved through reductions in coal use. Finally, global trading eliminates the possibility of carbon leakage.

The reduction in mitigation costs and the equalization of mitigation costs across regions greatly reduces the international macroeconomic effects of the Kyoto Protocol, compared with the previous scenarios. Except for Australia, OECD regions experience GDP and GNP impacts of

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[34] As with the Annex I regions, we assume that developing regions sell a fixed number of permits at auction on an

at most 0.2 percent[35]. Capital flows, exchange rate impacts and trade effects are all considerably muted. Relative to the no-trading case, aggregate OECD GNP costs in 2010 are cut by 90 percent from $269 billion to $26 billion; and relative to the Annex I trading case, costs are cut by over 70 percent. All OECD regions benefit, and in the case of the U.S. GNP costs are eliminated altogether.

Nevertheless, an interesting result emerges: relative to scenarios in which they do not participate in controlling emissions, the developing countries are significantly worse off because they no longer experience significant capital inflows, exchange rate appreciations, reductions in the value of their debt burdens, or lower oil prices. Moreover, the reduction in domestic energy use slightly lowers the return to labor in these regions. China loses about half a percent of GDP/GNP in 2010, even relative to its baseline (although its GNP rises above baseline in the longer run). The LDCs, in contrast, experience relatively minor GDP/GNP impacts relative to their baselines, but they lose the significant GDP/GNP gains that they experience in the scenarios in which Annex I regions act alone or in concert without non-Annex I participation. Rather than gaining 0.9 percent of GDP and 1.4 percent of GNP in 2010, the LDCs lose 0.1 percent of GDP and gain only 0.2 percent of GNP. In terms of GNP, participating in global trading costs the LDCs $86 billion relative to the Annex I no-trading case, and $43 billion relative to the Annex I trading case. These results suggest that that the Annex I countries may have to use part of their savings ($70 billion from moving from Annex I trading to global trading) simply to induce the developing countries to participate in helping them meet their commitments under the Protocol.

4. Alternative Revenue Recycling Mechanisms

The preceding results are all based on the assumption that countries that undertake commitments to auction emission permits and return the revenues to households in lump-sum payments. We have used the G-Cubed model to perform additional scenarios, using alternative

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annual basis, and return the revenues to households as a lump-sum payment.

[35] The results for Australia reflect relative importance of coal for energy generation through exports relative to other countries

assumptions about the distribution of permits and/or recycling of revenues[36]. While we do not present those results in detail here, we note that the results suggest that alternative revenue recycling mechanisms that serve to increase national savings and/or investment do not have any substantial impact on the marginal costs of meeting targets (under any given set of rules about international permit trading), but can have substantially different international macroeconomic effects. For example, when permit revenues are used to reduce fiscal deficits or increase fiscal surpluses, regions' national savings increase and the global cost of capital falls. Changes in the cost of capital leads to different net international capital flows, exchange rate impacts, and GDP/GNP effects. Extending this insight, we note that the distribution of costs and benefits may be substantially affected if regions pursue differing policies; for example if some regions pursue revenue recycling policies that encourage saving and investment and other regions pursue policies that encourage current consumption. We intend to explore these issues further in continued work with the model.

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 Annex I and globally, abatement costs are indeed quite heterogeneous. The marginal cost of meeting Kyoto targets in Japan is nearly four times as high – and in the "Rest of the OECD" region, nearly three times as high – as it is in the United States; and large quantities of relatively inexpensive emission reductions are available from the former Soviet Bloc and non-Annex I developing regions. Because of these differences, international trading offers large potential benefits to parties with relatively high mitigation costs.

Our results also highlight the potentially important role of international trade and capital flows in global responses to the Kyoto Protocol, a role not adequately captured in any other

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[36] See McKibbin and Wilcoxen (1995b) for results on recycling assumptions using an earlier version of the model.

modeling system of which we are aware. The results suggest that regions that do not participate in permit trading systems, or that can reduce carbon emissions at relatively low cost, will benefit from significant inflows of international financial capital under any Annex I policy, with or without trading. It appears that the United States and to a lesser extent Australia are likely to experience capital inflows, exchange rate appreciation, decreased exports, and some GDP gains. In contrast, Japan and the "Rest of the OECD", as high cost countries, will see capital outflows, exchange rate depreciation, increased exports of durables and greater GDP losses. Total flows of capital could accumulate to roughly a trillion dollars over the period between 2000 and 2020 in the absence of international permit trading, perhaps half to three-quarters of that with Annex I permit trading.[37] Global participation in a permit trading system would substantially offset these international impacts, but is likely to require additional payments to developing countries to induce them to forgo the benefits that accrue to them if they do not participate.

Because the model is calibrated to a year in which the former Soviet Bloc and China did not participate extensively in global trade, the model effectively assumes that these regions never experience extensive capital inflows or outflows. If these regions become fully participating members of the international trade and finance system by 2010, then the international trade and capital effects in our scenarios would have to be revised. In particular, the capital that flows to the U.S. and LDCs in these scenarios might be spread to the former Soviet Bloc and China too, with more modest exchange rate and trade balance effects in any given region.

The model's results are also sensitive to assumptions that determine the mitigation cost differences among regions. Different results would be obtained if U.S. domestic mitigation costs were significantly higher but the other regions' permit prices were on the same order of magnitude as in these scenarios (this is the case, for example, in the SGM model from which we derive mitigation cost curves for the former Soviet Bloc). With a smaller relative control cost differential between the U.S. and other countries in the OECD, the magnitude of capital flows to the U.S., and the costs and benefits of those flows, would all be smaller.

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[37] Compare these magnitudes to the more than trillion dollar decline just in the U.S. net international investment position

Finally, it must be remembered that there are inescapable uncertainties in the values of the model’s behavioral parameters and the future values of exogenous variables. As a consequence, our results should be interpreted as point estimates in a range of possible outcomes. It is clear, however, that in an increasingly interconnected world in which international financial flows play a crucial role, the impact of greenhouse abatement policy cannot be determined without paying attention to the impact of these policies on the return to capital in different economies. Focusing only on domestic effects would miss a crucial part of the economy’s response to climate change policy. To understand the full adjustment process to international greenhouse abatement policy it is essential to model international capital flows explicitly.

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in the past fifteen years. See the U.S. Government’s *Survey of Current Business* (July 1998).

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

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. Action

	2005	2010	2015	2020
Permit price ($95)	--	$56	$59	$64
Carbon emissions	0.1%	-28%	-33%	-38%
Coal consumption	0.0%	-45%	-51%	-57%
Oil consumption	0.0%	-9%	-12%	-14%
Gas consumption	0.0%	-3%	-3%	-4%
GDP	0.1%	-0.6%	-0.5%	-0.5%
Consumption	0.3%	-0.5%	-0.3%	0.1%
Investment	1.0%	-1.2%	-1.1%	-0.9%
Exchange rate	2.0%	1.8%	3.1%	4.0%
Exports	-2.2%	-1.8%	-3.1%	-4.0%
Imports	0.0%	1.0%	-1.1%	-1.1%
Net foreign assets (Bil. $95)	-$46	-$69	$2	$72
GNP	0.1%	-0.6%	-0.5%	-0.4%

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

	2005		2010		2020	
	Price	Qty	*Price*	Qty	*Price*	Qty
Energy Industries						
Electric utilities	*-0.0%*	0.2%	*4.5%*	-3.8%	*7.4%*	-5.5%
Gas utilities	*-0.0%*	0.3%	*4.7%*	-2.5%	*7.2%*	-3.9%
Petroleum refining	*-0.0%*	0.2%	*9.5%*	-9.4%	*13.8%*	-14.3%
Coal mining	*0.2%*	0.0%	*135.2%*	-44.7%	*179.0%*	-57.1%
Oil and gas extraction	*0.2%*	0.0%	*18.9%*	-15.7%	*27.1%*	-28.2%
Other Sectors						
Other mining	*-0.2%*	-0.1%	*0.6%*	-1.3%	*0.4%*	-1.8%
Agriculture	*-0.0%*	0.2%	*-0.1%*	-0.7%	*-0.5%*	-0.3%
Forestry and wood	*-0.2%*	0.1%	*-0.2%*	-0.5%	*-0.7%*	-0.4%
Durable goods	*-0.3%*	-0.2%	*-0.3%*	-0.8%	*-0.9%*	-0.9%
Nondurables	*-0.1%*	0.2%	*0.1%*	-1.0%	*-0.2%*	-0.5%
Transportation	*-0.1%*	0.2%	*-0.2%*	-0.8%	*-0.5%*	-0.5%
Services	*-0.0%*	0.3%	*-0.7%*	-0.1%	*-0.9%*	0.5%

Table 6: Annex I Commitments Without International Permit Trading

	United States	Japan	Australia	Other OECD	China	LDCs
2005						
Permit price ($95)	--	--	--	--	--	--
Carbon emissions	1.4%	-3.5%	1.3%	-2.3%	-0.8%	4.2%
Coal consumption	1.0%	-0.6%	0.7%	-0.8%	-0.8%	0.2%
Oil consumption	3.2%	-6.1%	2.9%	-4.1%	-1.3%	12.4%
Gas consumption	2.3%	-2.4%	0.9%	-2.1%	-2.0%	6.9%
GDP	0.6%	-0.4%	0.8%	-0.4%	-0.3%	1.1%
Investment	7.7%	-5.4%	4.4%	-6.0%	-0.2%	18.2%
Exports	-15.3%	15.6%	-9.2%	18.5%	3.4%	-38.2%
Exchange rate	14.4%	-24.2%	15.0%	-26.1%	-2.0%	53.2%
Net foreign assets (Bil. $95)	-$321	-$66	-$24	$267	$23	$146
GNP	0.4%	0.1%	-0.3%	-0.3%	-0.3%	1.9%
2010						
Permit price ($95)	$63	$252	$57	$167	--	--
Carbon emissions	-29%	-29%	-20%	-25%	0.1%	6.4%
Coal consumption	-49%	-24%	-30%	-46%	-0.4%	0.5%
Oil consumption	-6%	-20%	-2%	-14%	0.0%	14.9%
Gas consumption	0%	-7%	-1%	-6%	-1.3%	9.5%
GDP	0.1%	-1.6%	-0.1%	-1.5%	-0.1%	1.6%
Investment	5.4%	-6.9%	-0.5%	-8.1%	0.1%	14.8%
Exports	-15.8%	13.8%	-10.4%	16.7%	0.7%	-37.8%
Exchange rate	13.3%	-24.2%	16.8%	-25.8%	-1.3%	53.2%
Net foreign assets (Bil. $95)	-$668	$25	-$78	$584	$43	$162
GNP	-0.3%	-0.8%	-2.5%	-1.4%	0.0%	2.7%
2020						
Permit price ($95)	$71	$268	$96	$244	--	--
Carbon emissions	-39%	-35%	-39%	-40%	0.4%	5.6%
Coal consumption	-62%	-31%	-56%	-72%	-0.1%	0.5%
Oil consumption	-10%	-27%	-9%	-22%	0.1%	14.1%
Gas consumption	-1%	-10%	-6%	-9%	-1.4%	9.9%
GDP	0.2%	-1.5%	-1.2%	-1.7%	-0.1%	1.3%
Investment	5.4%	-6.4%	-1.4%	-8.7%	-0.2%	12.6%
Exports	-19.7%	13.2%	-6.8%	15.6%	0.2%	-27.8%
Exchange rate	15.1%	-24.0%	9.9%	-24.8%	-1.4%	49.2%
Net foreign assets (Bil. $95)	-$720	$26	-$191	$850	$70	$153
GNP	-0.2%	-0.3%	-4.6%	-1.8%	0.1%	2.5%

Table 7: Annex I Commitments With International Permit Trading

	United States	Japan	Australia	Other OECD	China	LDCs
2005						
Permit price ($95)	--	--	--	--	--	--
Annual permit sales (Bil. $95)	--	--	--	--	--	--
Carbon emissions	0.4%	-1.9%	1.1%	-1.4%	-0.4%	2.2%
Coal consumption	0.4%	-0.4%	0.7%	-0.4%	-0.3%	0.1%
Oil consumption	1.0%	-3.4%	2.5%	-2.7%	-0.6%	6.6%
Gas consumption	1.0%	-1.3%	0.9%	-1.3%	-1.0%	3.7%
GDP	0.2%	-0.2%	0.6%	-0.2%	-0.1%	0.6%
Investment	3.3%	-2.8%	3.6%	-3.8%	0.0%	9.8%
Exports	-6.6%	8.4%	-6.7%	11.9%	1.3%	-20.5%
Exchange rate	6.0%	-13.9%	11.9%	-16.3%	-0.3%	26.4%
Net foreign assets (Bil. $95)	-$113	-$16	-$26	$203	$13	$69
GNP	0.2%	0.0%	-0.3%	-0.1%	-0.1%	1.0%
2010						
Permit price ($95)	$37	$37	$37	$37	--	--
Annual permit sales (Bil. $95)	-$7.0	-$3.0	-$0.3	-$11.4	--	--
Carbon emissions	-17.6%	-5.2%	-13.1%	-6.3%	-0.1%	3.1%
Coal consumption	-28.9%	-4.7%	-19.6%	-10.5%	-0.3%	0.4%
Oil consumption	-4.4%	-5.5%	-0.6%	-4.7%	-0.1%	7.7%
Gas consumption	-0.4%	-2.3%	-1.2%	-2.2%	-0.4%	5.0%
GDP	-0.1%	-0.5%	0.1%	-0.5%	-0.1%	0.9%
Investment	2.0%	-2.8%	-0.1%	-3.9%	0.0%	7.9%
Exports	-6.4%	7.6%	-6.9%	10.8%	0.2%	-20.0%
Exchange rate	5.5%	-13.9%	13.0%	-15.8%	0.2%	26.5%
Net foreign assets (Bil. $95)	-$274	$58	-$71	$462	$25	$72
GNP	-0.2%	-0.2%	-2.0%	-0.5%	0.0%	1.4%
2020						
Permit price ($95)	$77	$77	$77	$77	--	--
Annual permit sales (Bil. $95)	$9.5	-$8.3	-$0.8	-$41.1	--	--
Carbon emissions	-44.2%	-10.6%	-30.8%	-13.0%	0.2%	3.3%
Coal consumption	-67.9%	-10.2%	-43.9%	-23.0%	-0.1%	0.4%
Oil consumption	-13.3%	-9.1%	-6.6%	-7.8%	0.2%	8.0%
Gas consumption	-3.0%	-3.5%	-4.2%	-3.5%	-0.4%	5.5%
GDP	-0.4%	-0.6%	-0.9%	-0.7%	0.0%	0.7%
Investment	0.9%	-3.0%	-1.6%	-4.4%	-0.1%	7.1%
Exports	-9.2%	7.0%	-4.1%	9.9%	-0.4%	-15.3%
Exchange rate	7.4%	-13.8%	9.1%	-15.6%	0.3%	24.7%
Net foreign assets (Bil. $95)	-$305	$109	-$169	$694	$44	$44
GNP	-0.7%	-0.1%	-4.1%	-0.9%	0.1%	1.3%

Table 8: Annex I Commitments With “Double Umbrella”

	United States	Japan	Australia	Other OECD	China	LDCs
2005						
Permit price ($95)	--	--	--	--	--	--
Annual permit sales (Bil. $95)	--	--	--	--	--	--
Carbon emissions	0.8%	-2.1%	0.5%	-1.7%	-0.4%	2.6%
Coal consumption	0.6%	-0.4%	0.4%	-0.5%	-0.3%	0.1%
Oil consumption	1.7%	-3.8%	0.9%	-3.1%	-0.7%	7.9%
Gas consumption	1.4%	-1.5%	0.0%	-1.5%	-1.0%	4.4%
GDP	0.3%	-0.2%	0.3%	-0.3%	-0.2%	0.7%
Investment	4.6%	-3.1%	1.9%	-4.6%	0.0%	11.7%
Exports	-9.1%	9.4%	-3.5%	13.8%	1.7%	-24.5%
Exchange rate	8.3%	-15.5%	6.5%	-19.1%	-0.5%	32.3%
Net foreign assets (Bil. $95)	-$176	-$36	-$5	$214	$14	$95
GNP	0.2%	0.0%	-0.3%	-0.2%	-0.1%	1.3%
2010						
Permit price ($95)	$18	$18	$18	$167	--	--
Annual permit sales (Bil. $95)	-$7.3	-$1.6	-$0.3	--	--	--
Carbon emissions	-7.0%	-3.5%	-6.2%	-24.9%	0.0%	3.7%
Coal consumption	-13.8%	-2.6%	-9.6%	-45.9%	-0.1%	0.4%
Oil consumption	-0.3%	-4.8%	-0.3%	-13.1%	-0.2%	9.2%
Gas consumption	1.1%	-2.1%	-0.8%	-5.2%	-0.9%	6.0%
GDP	0.3%	-0.5%	0.1%	-1.3%	-0.1%	1.0%
Investment	4.1%	-2.7%	-0.1%	-7.1%	0.1%	9.4%
Exports	-9.6%	8.5%	-4.1%	12.8%	0.4%	-24.0%
Exchange rate	7.6%	-15.6%	7.1%	-18.6%	0.1%	32.4%
Net foreign assets (Bil. $95)	-$395	$33	-$24	$490	$27	$117
GNP	0.1%	-0.1%	-1.3%	-1.2%	0.0%	1.8%
2020						
Permit price ($95)	$46	$46	$46	$244	--	--
Annual permit sales (Bil. $95)	-$14.2	-$5.5	-$1.5	--	--	--
Carbon emissions	-24.5%	-7.0%	-18.2%	-40.0%	0.3%	3.7%
Coal consumption	-39.9%	-6.4%	-26.2%	-71.9%	0.0%	0.3%
Oil consumption	-6.6%	-7.3%	-4.4%	-20.9%	0.0%	9.2%
Gas consumption	-0.6%	-3.0%	-2.6%	-8.3%	-0.4%	6.5%
GDP	0.0%	-0.6%	-0.6%	-1.6%	0.0%	0.8%
Investment	2.9%	-2.9%	-1.3%	-7.5%	0.0%	8.2%
Exports	-11.8%	7.6%	-2.6%	10.8%	-0.4%	-18.3%
Exchange rate	8.2%	-15.5%	4.4%	-17.3%	0.1%	29.8%
Net foreign assets (Bil. $95)	-$417	$112	-$72	$751	$46	$119
GNP	-0.1%	0.1%	-2.6%	-1.5%	0.1%	1.7%

Table 9: Annex I Commitments With Global Permit Trading

	United States	Japan	Australia	Other OECD	China	LDCs
2005						
Permit price ($95)	--	--	--	--	--	--
Annual permit sales (Bil. $95)	--	--	--	--	--	--
Carbon emissions	0.3%	-0.7%	0.3%	-0.5%	0.6%	0.6%
Coal consumption	0.2%	-0.1%	0.4%	-0.2%	0.5%	0.3%
Oil consumption	0.6%	-1.3%	0.5%	-1.0%	1.0%	1.6%
Gas consumption	0.5%	-0.5%	0.5%	-0.5%	1.5%	1.0%
GDP	0.1%	-0.1%	0.1%	-0.1%	0.3%	0.1%
Investment	1.4%	-1.2%	0.6%	-1.5%	2.1%	2.3%
Exports	-2.7%	3.5%	-1.1%	4.7%	-5.3%	-4.9%
Exchange rate	2.9%	-5.4%	2.6%	-6.1%	8.2%	6.4%
Net foreign assets (Bil. $95)	-$37	-$4	-$2	$92	-23	$40
GNP	0.1%	0.0%	-0.1%	-0.1%	0.1%	0.3%
2010						
Permit price ($95)	$13	$13	$13	$13	$13	$13
Annual permit sales (Bil. $95)	-$5.4	-$1.2	-$0.3	-$4.7	$3.8	$1.7
Carbon emissions	-5.6%	-1.7%	-4.6%	-2.1%	-25.9%	-8.3%
Coal consumption	-9.9%	-1.6%	-6.7%	-3.6%	-27.5%	-14.2%
Oil consumption	-1.1%	-2.0%	-0.6%	-1.6%	-3.1%	-0.5%
Gas consumption	0.1%	-0.8%	-0.8%	-0.8%	-8.3%	0.5%
GDP	0.0%	-0.2%	-0.1%	-0.2%	-0.6%	-0.1%
Investment	0.9%	-1.0%	-0.5%	-1.4%	2.7%	0.2%
Exports	-2.8%	3.0%	-1.8%	4.0%	-5.1%	-5.5%
Exchange rate	2.7%	-5.4%	3.1%	-5.9%	7.4%	6.8%
Net foreign assets (Bil. $95)	-$89	$28	-$10	$210	-47	$59
GNP	0.0%	0.0%	-0.7%	-0.2%	-0.5%	0.2%
2020						
Permit price ($95)	$23	$23	$23	$23	$23	$23
Annual permit sales (Bil. $95)	-$13.0	-$3.2	-$1.1	-$16.2	$16.6	$7.4
Carbon emissions	-12.7%	-3.0%	-9.3%	-3.8%	-52.8%	-16.6%
Coal consumption	-20.2%	-3.1%	-13.2%	-6.9%	-56.0%	-25.6%
Oil consumption	-3.6%	-3.1%	-2.2%	-2.4%	-6.5%	-3.6%
Gas consumption	-0.6%	-1.1%	-1.3%	-1.1%	-16.1%	-0.7%
GDP	-0.1%	-0.2%	-0.3%	-0.2%	-0.7%	-0.3%
Investment	0.5%	-1.1%	-0.8%	-1.6%	2.0%	-0.7%
Exports	-3.7%	2.9%	-1.0%	3.7%	-8.4%	-4.3%
Exchange rate	3.1%	-5.8%	1.7%	-5.9%	14.4%	6.0%
Net foreign assets (Bil. $95)	-$54	$43	-$31	$358	-$41	$46
GNP	0.0%	0.0%	-1.3%	-0.3%	0.3%	0.1%

Figure 1: 2010 Permit Prices

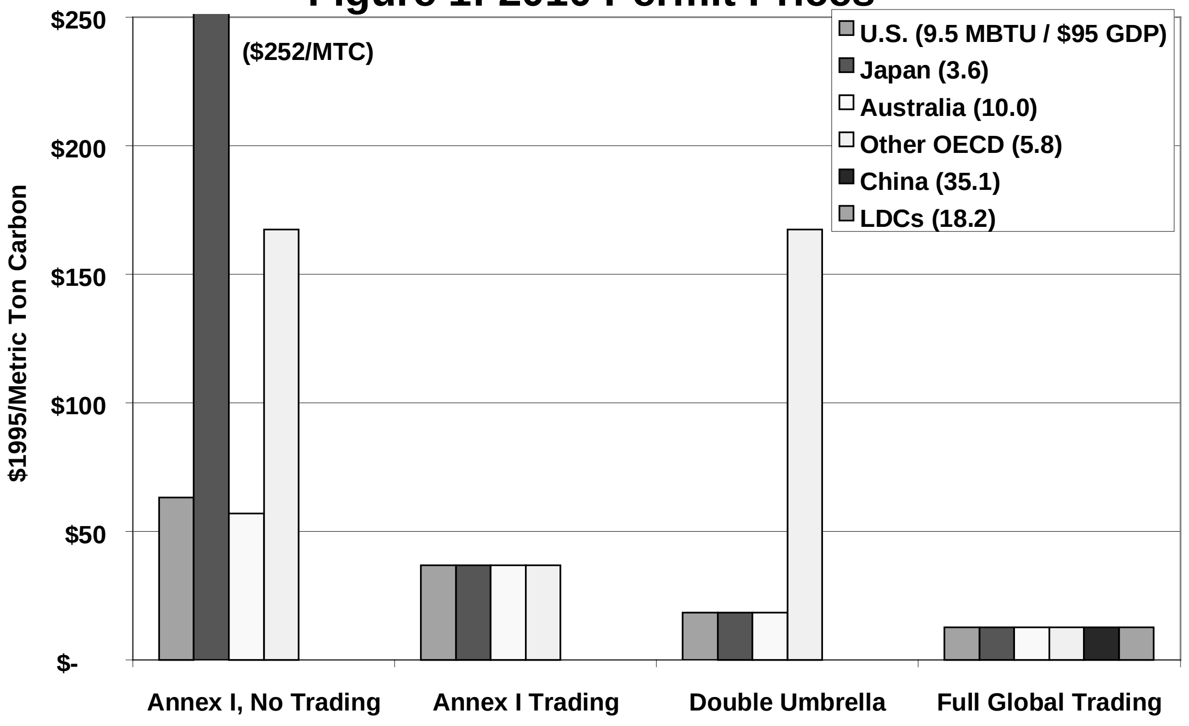


Figure 2: 2010 Emission Reductions (MMTC)

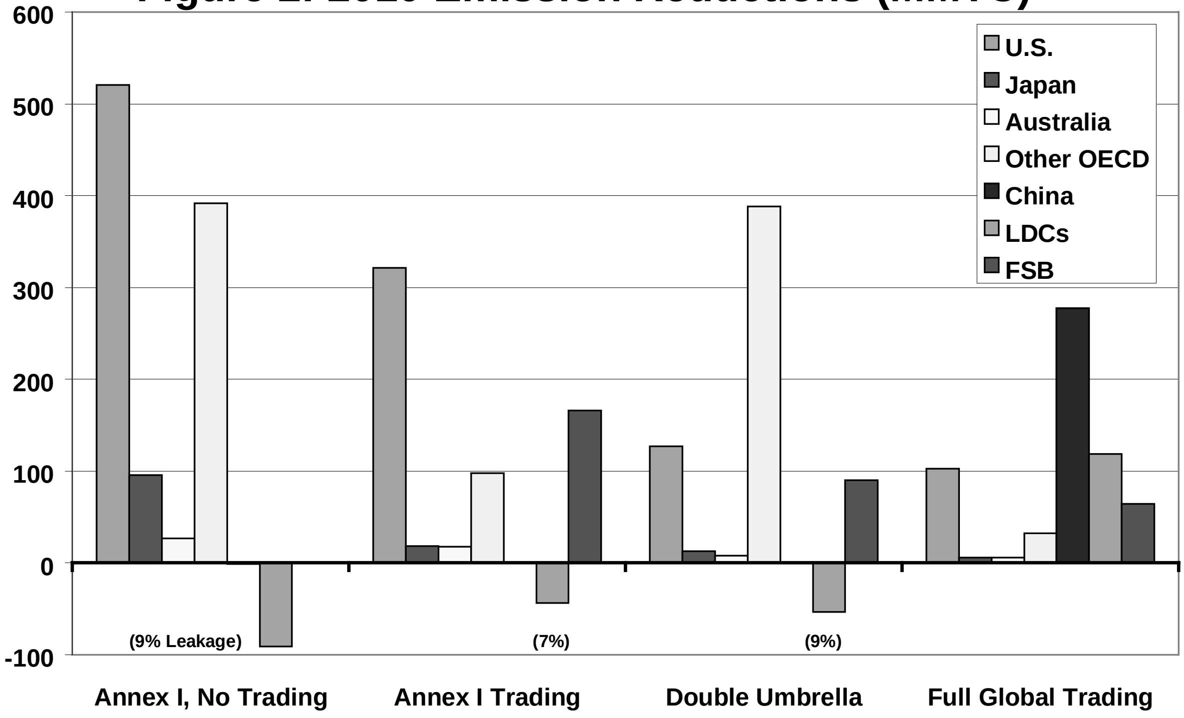


Figure 3: 2010 Emission Purchases ($95 Billion)

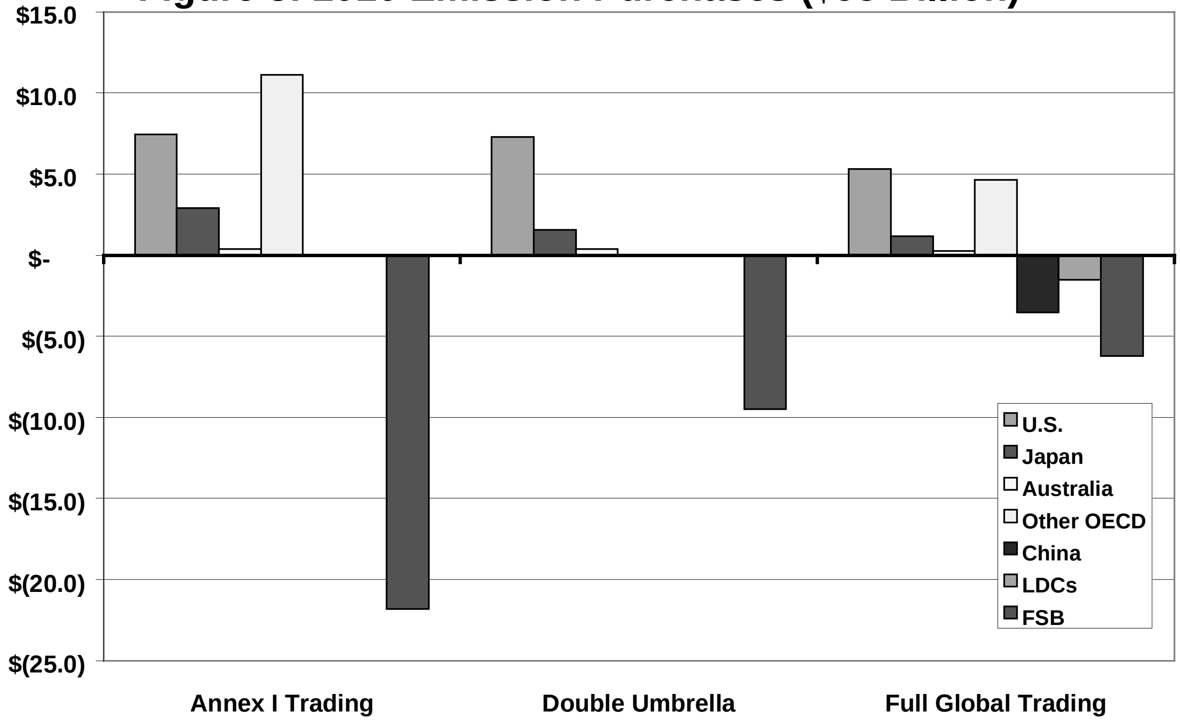
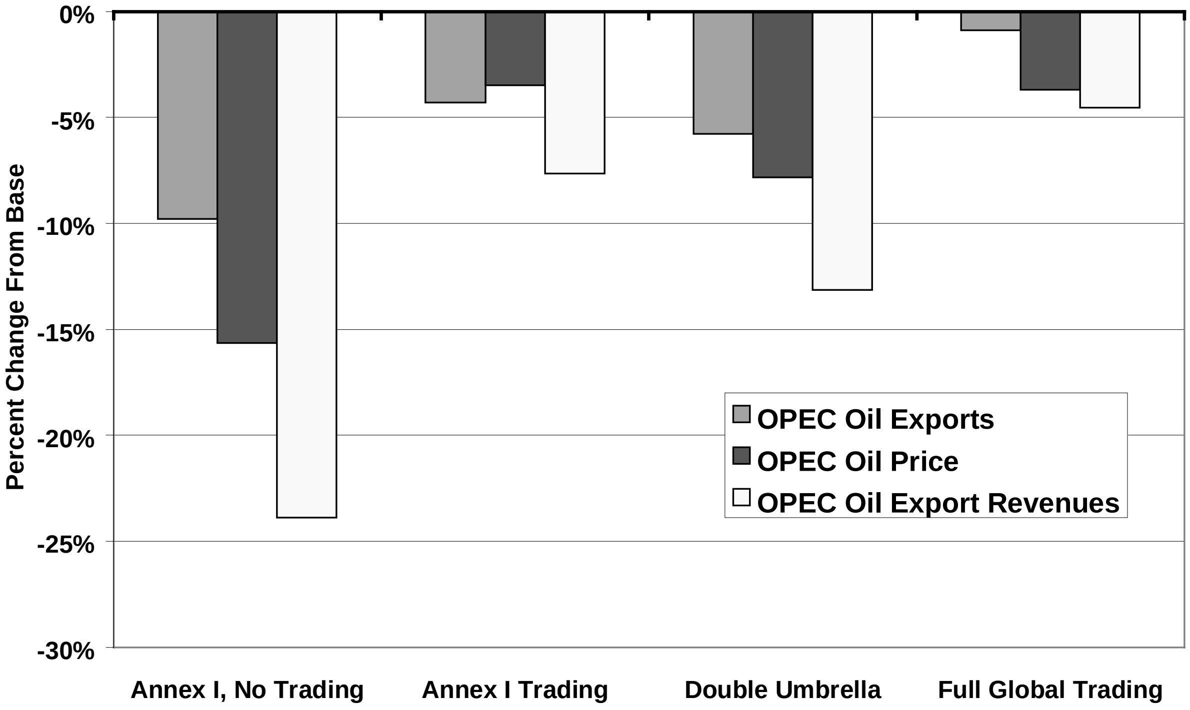


Figure 4: 2010 OPEC Oil



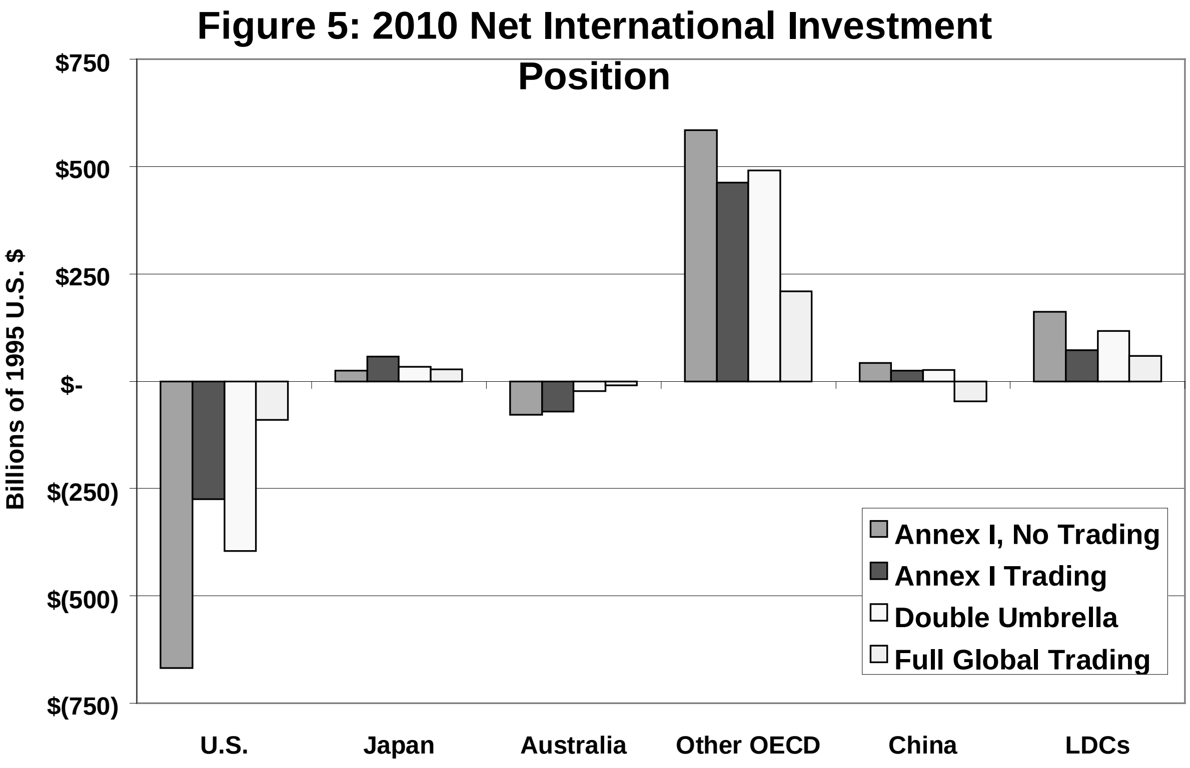


Figure 5: 2010 Net International Investment Position

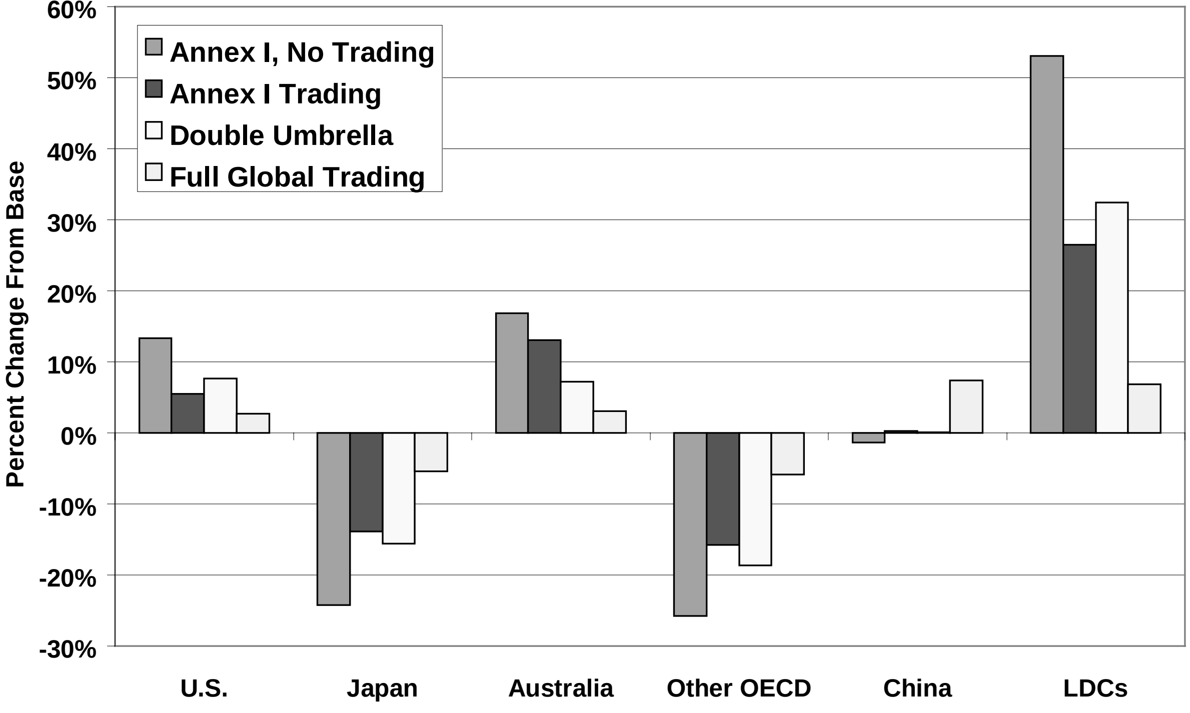


Figure 6: 2010 Real Exchange Rates

Figure 7: 2010 Gross Domestic Product

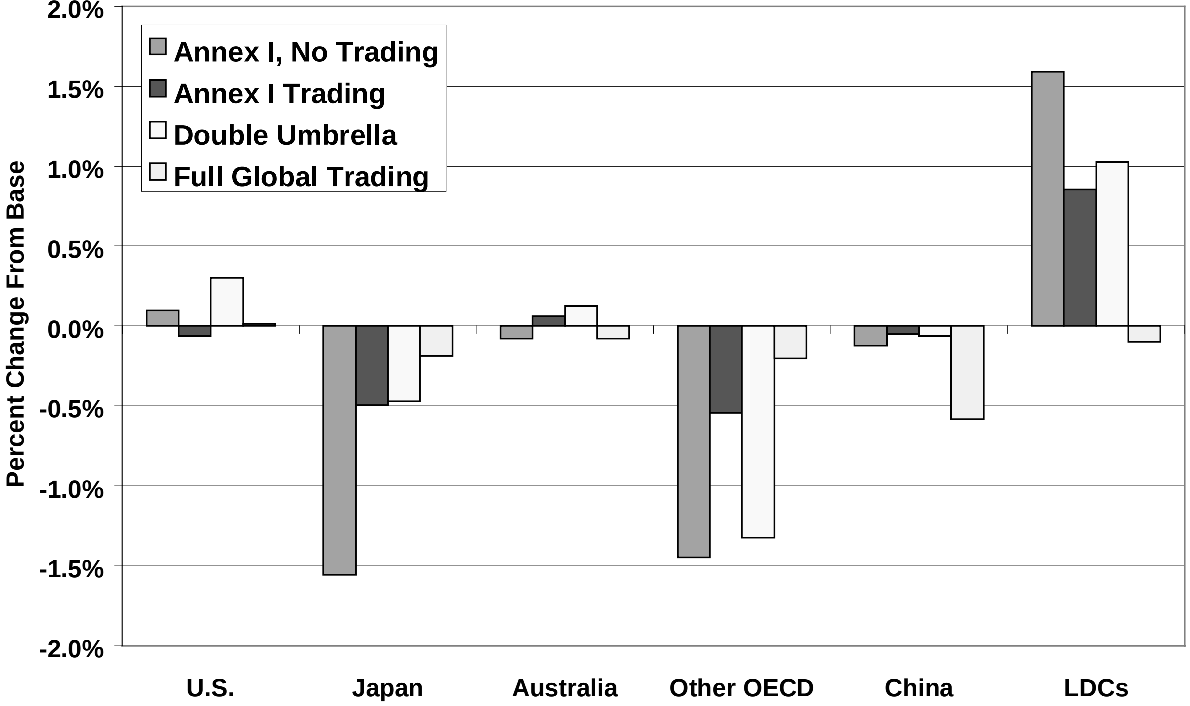
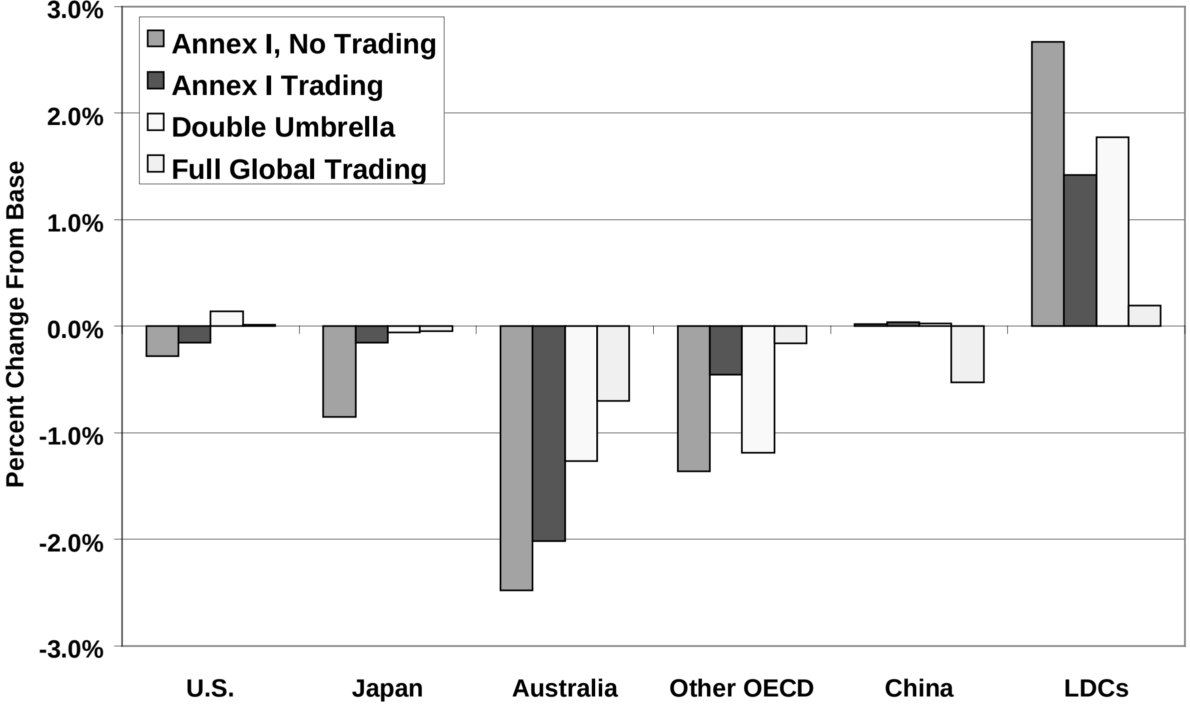


Figure 8: 2010 Gross National Product



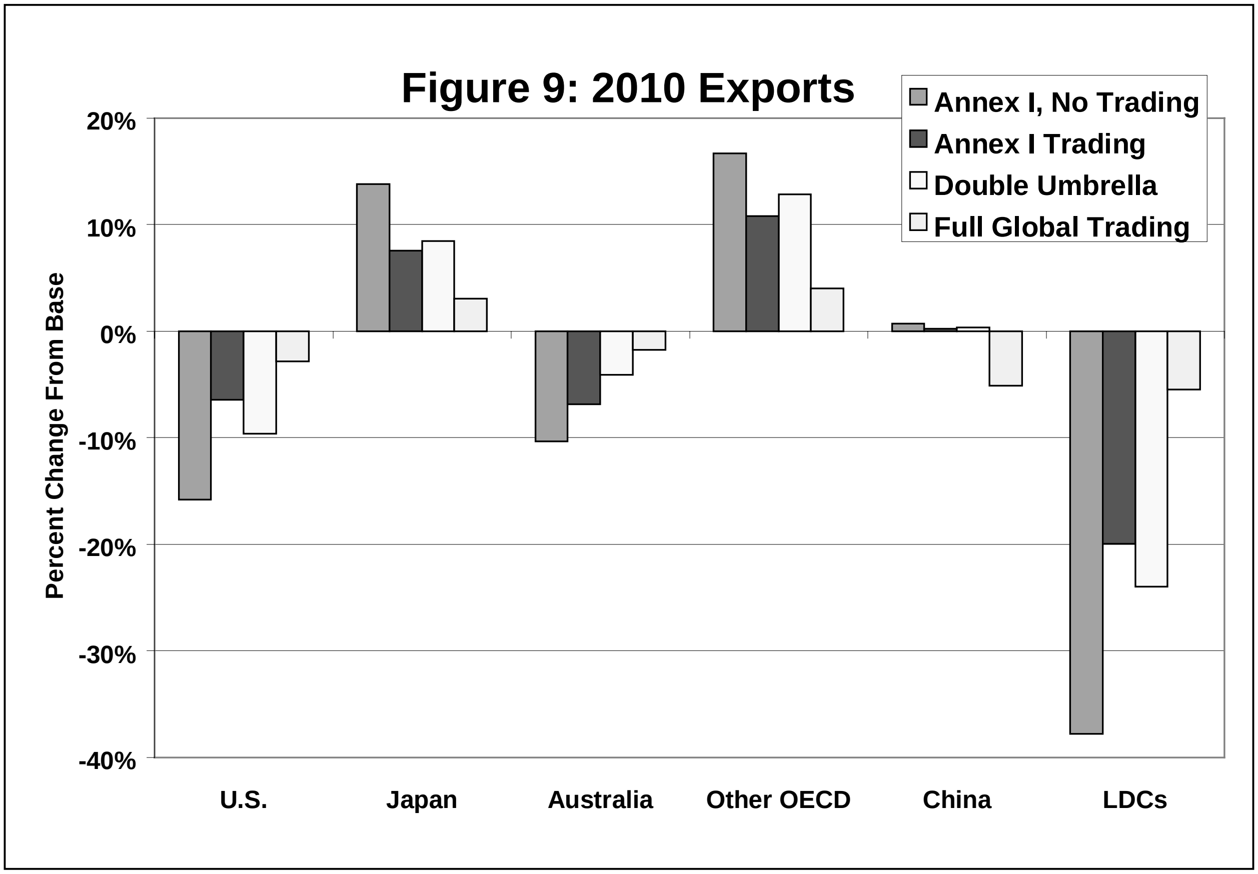


Figure 9: 2010 Exports
Annex I, No Trading
Annex I Trading
Double Umbrella
Full Global Trading
Percent Change From Base
20%
10%
0%
-10%
-20%
-30%
-40%
U.S.
Japan
Australia
Other OECD
China
LDCs