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Equity and the Kyoto Protocol: measuring the distributional effects of alternative emissions trading regimes

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Abstract

This paper offers a few preliminary steps in bringing the equity implications of building global emissions trading, Annex B trading only, and no trading to the fore as an issue to be considered in the negotiations of how to implement the Kyoto Protocol. All three policy regimes worked within the Charles Rivers State Impacts Assessment Model to make the distribution of per capita gross state product across the United States worse than it would be otherwise, but not significantly. In terms of the distribution of per capita consumption across the states, though, all three of the policy alternatives worked to improve equity (even more) modestly with the largest improvement associated with the "No Trade" option. The equity implications of alternative trading regimes were far more striking in the global context. Global trading did sustain the highest mean in per capita consumption, but the "No Trade" and "Annex B" trading alternatives reduced significantly the underlying inequity in the distribution of per capita. Weighted by a logarithmic utility function, the present value of the certainty equivalent level of mean per capita consumption would fall by more than five times the efficiency gain if global trading were allowed instead of limited Annex B trading. Moreover, this measure of willingness to pay to avoid inequity would be more than eight times larger than the efficiency gain if global trading were chosen over the "No Trade" alternative. The estimates reported here are, of course, highly speculative and extremely model-specific. Different models and, more importantly, different allocations of permits within the United States and/or across the globe would produce different results. The results do not mean that global trading in emissions permits should be shelved because the equity properties are so poor. Much like the other studies that have identified issues that need to be monitored carefully in the design of mechanisms with which the signators of Kyoto Protocol might meet their commitments, though, they do emphatically add equity to the list of fundamental concerns that must be considered.

Keywords: Kyoto Protocol; Equity; Permit trading

The Kyoto Protocol was drafted at the Third Conference of the Parties of the United Nations Convention on Climate Change (FCCC) in December of 1997. Strict adherence to the Protocol would limit greenhouse gas emissions from the United States to roughly 93% of 1990 levels by the year 2012. Strict adherence would also limit emissions from other industrial countries ("Annex B" countries) to varying degrees. Some Annex B countries would hold their emissions below targets that were more than 93% of their 1990 levels, but others would face even more restrictive constraints. The Protocol would, meanwhile, allow the so-called "non-Annex B" countries to continue to increase their emissions without restriction. The Protocol was, however, silent on the precise mechanism by which the aggregate limit on global emissions would be achieved. Would countries be required to meet their targets unilaterally, or would they be allowed to trade "emissions permits" among themselves? And if trade were allowed, would it be restricted to Annex B countries for whom targets were well defined, or would it somehow include non-Annex B countries?

The work described here looked at the distributional implications of three different variants that span these two questions. More specifically, three alternative policy designs were considered:

- "No Trade" in which each of the Annex B countries must meet its own Kyoto Protocol commitment.

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Domestically, though, the least-cost means of implementing internally tradable emissions permits was assumed.
- "Annex B" in which each of the Annex B countries would be allocated a number of permits equal to its Kyoto Protocol commitment and these were internationally tradable within Annex B. Again, the least-cost means of implementing internally tradable domestic emissions permits was assumed.
- "Global Trade" in which Annex B countries were allocated a number of permits equal to its Kyoto Protocol commitment and non-signatory or non-Annex B nations were allocated permits according to their baseline emissions projections. All permits were internationally tradable, and the least-cost means of implementing internally tradable domestic emissions permits was still presumed.

This list of alternatives certainly does not cover the full range of possibilities. It does, however, offer sufficient variance in design to investigate the hypothesis that policy design underlying compliance with the Kyoto Protocol has serious equity implications both domestically within the United States and internationally across the globe.

This paper begins with a brief description of the models employed to examine this hypothesis in Section 1. They are two in number, and they have been constructed by P. Bernstein, D. Montgomery, T. Rutherford and other colleagues at Charles Rivers Associates to be mutually and internally consistent representations of the global and United States economies. One therefore supports an examination of distributional effects globally while the other supports a comparable examination of the same effects domestically within the United States. Section 2 describes the measures of inequality and efficiency that were employed and reports results for the United States. Section 3 then reports the corresponding results for the global model before concluding remarks provide some context within which to judge the degree to which the hypothesis can be expected to hold: domestic distributional effects within the United States, driven mostly by trade effects of different global policies and dispersed across a well-developed market-based economy, could be modest; but differences in the international distributional effects of the same policy alternatives across the globe could be enormous.

1. The models and their structures[2]

The results reported here for the United States were drawn from the State Impact Assessment Model (SIAM) created by D. Montgomery, P. Bernstein and T. Rutherford. Its mechanics are described fully in CRA (1999). SIAM was designed explicitly to allow interactive analysis and discussion of alternative carbon abatement proposals and their effects on individual states. In particular, SIAM was designed to examine the ways in which different state-level economies could respond to changes in economic conditions that might result from current Kyoto-based negotiations. International economic models have, of course, been used to assess not only the cost of reaching alternative carbon abatement goals, but also the potential gains from implementing market-based policies to meet any given goal. The purpose of SIAM was to translate consistently those costs and gains to the state level.

Beyond the direct effects of limiting its own emissions of greenhouse gases, some of the effects on the United States of implementing the Kyoto Protocol would be transmitted through international trade markets. Developing countries would not have made any commitments to limit their emissions, and some developed countries would have to substantially lower emissions relative to their projected levels in the year 2010. As a result, the Protocol would create incentives for these countries to specialize in production that is relatively fossil-fuel intensive; this is the so-called "leakage" problem discussed in, e.g., Manne (1999). Energy-intensive industries in the United States would therefore face much stiffer competition from developing countries, and states in which these industries are concentrated could face significant economic hardship. Moreover, differences in energy intensity of production would effect competition between industries in different states for product share and, through general equilibrium effects, for labor, capital, and other non-energy materials. The SIAM was thus designed to overcome the challenge of creating a computationally tractable computable general equilibrium model that provided state-level detail while also incorporating major external market adjusts.

The SIAM relies on the hierarchical structure of companion models. A multi-region trade model of the world, MRT, establishes international trading patterns for the United States. A US multi-regional model is then used to establish interstate trading patterns. And finally, state-level models tie changes in global markets, impacts on trade within the United States, and emissions policies together to produce sets of consistent results for individual states.

The data required to characterize the interrelationships of commodities within the US economy were drawn from a Social Accounting Matrix (SAM) created by the Minnesota IMPLAN Group, Inc. to track the intensities of commodity use in each of the 50 states' production and consumption sectors. In addition, SAM completes the circular flow across the country by accounting for factor incomes, household savings

[2] The descriptions offered here draw heavily on the descriptions reported by Montgomery, Bernstein and Rutherford in their Manual for the State Impact Assessment Model (CRA, 1999).

behavior, trade, and institutional transfers. The SAM employed, in fact, provided a snapshop of states' economies in 1993 along consistent dynamic growth paths. Agents in the SIAM are assumed to be forward-looking so that they invest to support a growing stock of capital. Interest rates and growth rates are also assumed to determine balanced dynamic equilibria which would be consistent with the standard Ramsey growth model; Lau et al. (1997) provide an overview of the Ramsey model and its operation within a computable general equilibrium model.

Dynamic equilibria were calibrated by incorporating growth forecasts made by the Bureau of Economic Analysis and the Energy Information Administration. Unlike steady-state models of growth, the BEA projections are flexible and incorporate consensus shifts in the mix of industries within individual states and across states. The SIAM can therefore use sector-specific output projections to constrain the multi-sector Ramsey model so that shifts in factor productivity required to meet projected equilibria can be deduced. Baseline trajectories through the year 2030 for each state are the result of all of this calibration.

The IMPLAN data also included portraits of state-level trade. For each state, then, total exports and imports by commodity are divided between trade with other states and trade with foreign countries. This does not, however, provide the full bilateral trading matrix by commodity and state that is required to correctly specify inter-regional trade. A least-squares procedure applied the the 1993 Commodity Flow Survey (US Department of Commerce, 1996) was therefore employed to meet this need.

The SIAM thus recognizes that climate policy can have two effects on states' economies: a limit on carbon emissions and a change in the states' trade position vis-a-vis other effected economies (other states and other economies). The additional information required to quantify these effects fully was drawn from the MS-MRT model. The MS-MRT model incorporates eight regional trading blocks and nine economies, and it tracks fully the physical flows of energy and their embodied carbon; it is described in Bernstein et al. (1999a). Because the United States is one of the trading blocks embedded in the MS-MRT model, it predicts carbon permit prices and changes in the prices of US imports and exports as part of its computed general equilibria.

2. Comparative results for the United States

Comparisons of the distributional implications of the three policy alternatives were drawn from state-by-state SIAM calculations of the effects of each on gross state product and consumption. Both sets of estimates were converted into per capita terms using state population projections offered by the US Bureau of the Census. Standard aggregate measures of equity were applied to the results under the assumption that distributions *within* states were equal (or at least would not change from their present configuration over time). This is certainly a bad assumption, but it does allow a first cut at judging the interstate implications of alternative policy designs. All of the measures of inequality reported here surely underestimate actual inequality across the entire population; but models that could support the requisite calculations at that micro-scale simply do not exist. It was also assumed that emissions permits within the United States were allocated in accord with the initial pattern of state-by-state emissions. Other allocations are possible, to be sure, and each would produce different interstate transfers of resources and, as a consequence, different distributional implications.

Table 1 reports the results in terms of gross state product for the three policy alternatives described in the introduction under the assumption of low fuel switching

Table 1
Aggregate indicators: gross state product with low fuel substitution

Year	Baseline	Annex B	Global	No trade
A. Mean per capita gross state product (× 1000$)				
2000	27.74	27.74	27.74	27.74
2005	27.95	27.99	27.97	27.97
2010	29.11	28.92	29.03	28.60
2015	29.47	29.06	29.31	28.41
2020	31.85	31.29	31.65	30.66
2025	32.36	31.70	32.14	31.11
2030	34.97	34.17	34.73	33.51
B. Gini coefficient				
2000	0.166	0.166	0.166	0.166
2005	0.173	0.173	0.173	0.173
2010	0.169	0.172	0.171	0.175
2015	0.188	0.193	0.190	0.198
2020	0.186	0.191	0.188	0.194
2025	0.195	0.201	0.197	0.206
2030	0.193	0.199	0.195	0.204
C. T10/B20 ratio				
2000	5.39	5.39	5.39	5.39
2005	5.40	5.40	5.40	5.40
2010	5.35	5.37	5.36	5.38
2015	5.45	5.47	5.46	5.50
2020	5.44	5.47	5.45	5.47
2025	5.45	5.49	5.46	5.51
2030	5.49	5.64	5.53	5.66
D. Insurance premium (× 1000$)				
2000	0.36	0.36	0.36	0.36
2005	0.38	0.38	0.38	0.38
2010	0.40	0.40	0.40	0.41
2015	0.46	0.47	0.46	0.48
2020	0.48	0.50	0.49	0.50
2025	0.53	0.54	0.53	0.56
2030	0.56	0.58	0.57	0.59

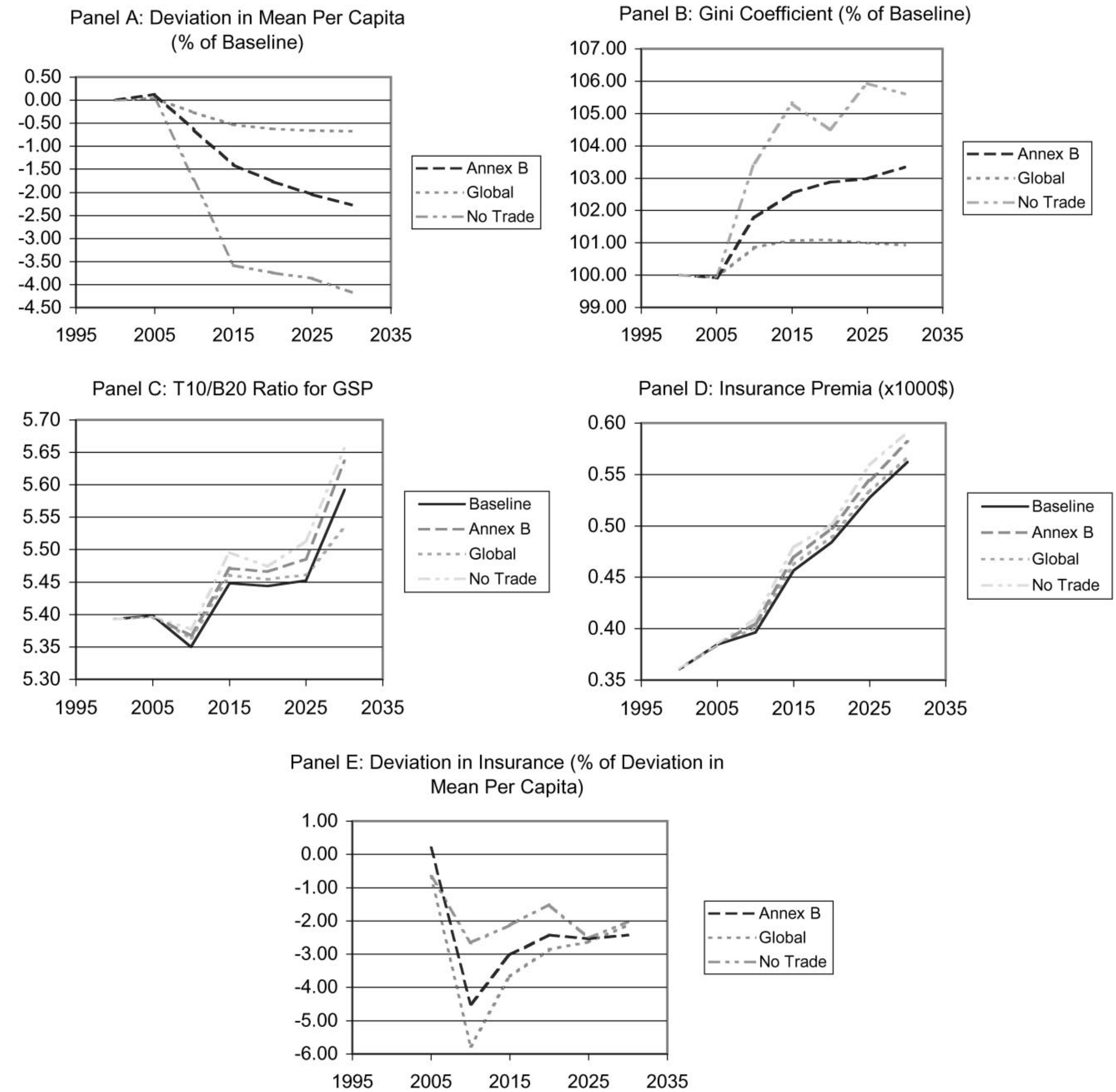

Fig. 1.

substitution in production.[3] Panel A shows that the economy can be expected to grow significantly through the year 2030 in any case, but imposing any of the three policy regimes would depress mean per capita state product relative to the baseline (no climate policy) case. Panel A of Fig. 1 displays the same results graphically. Note that the loss in mean per capita gross state product expands over time for every policy regime and that the "No Trade" case would generate a reduction of more than 3.5% by as early as 2015. Placing the United States into a regime of efficient global trading would, by way of contrast, create the smallest losses — internal and external efficiencies would work to hold reductions below 1% throughout the period.

Panel B of Table 1 begins the examination of the comparative distributional implications of the policy alternatives by reporting Gini coefficients computed on the basis of state-by-state computations of per capita

[3] More specifically, this case assumes that the elasticity of substitution between natural gas and coal equals 0.5 in nested production functions that embed different energy sources in a separate energy branch of aggregate factors of production.

gross state product. Gini coefficients are, of course, defined in terms of Lorenz curves — curves that plot the fraction of an economy's total income or consumption that is earned or enjoyed by the least affluent × (times 100) percent of the population as × climbs from zero to one. Gini coefficients are twice the area between any Lorenz curve and the "perfect equity" 45° line — a line that indicates that the least affluent × (times 100) percent of a population always receives enjoys × (times 100) percent of the income or consumption. Higher (lower) Gini coefficients therefore always signify a less (more) equal distributions.

Panel B shows, first of all, that the baseline-produced distributions that became less equal over time; indeed, the estimated Gini coefficients climbed by more than 16% from the year 2000 through the year 2030. Panel B of Fig. 1 shows that all three of the policy options would work to worsen this trend — increasing (after a small dip in 2005) the Gini computed for 2030 by 1% under the "Global Trade" regime and by more than 5% if no trading were allowed. All three climate policy regimes would, in other words, make the distribution of per capita gross state product even less equitable than would be expected along the baseline scenario.

Gini coefficients have been criticized because their use would detect no difference between transfers of income or consumption from one group of people to a poorer group people and equivalent transfers to *the poorest* group of people. The import of this concern is best conveyed by example. Consider, to that end, two distributions (call them "I" and "II") that would allocate 30% of total income to the poorest 50% of the population. Let this allocation be shared equally across the poorest 50% in distribution I, but assume that the poorest 25% in distribution II would share (equally) only 10% of total income while the next 25% of the population shared 20% (again equally). Assume, further, that the richest 25% of the population would share 55% of total income in distribution I while they would garner only 50% in distribution II. Some simple arithmetic shows that the Gini coefficients for both of these distributions would equal 0.3 even though it is clear that the poorest 25% of the population would be relatively worse-off in distribution II than in distribution I.

Top-to-bottom ratios can be used to respond to this concern. A Tα/Bβ ratio would, for example, compute the ratio of the proportion of income allocated to the top α percent of the population against the proportion allocated to the lowest β percent of the population. Panel C of Table 1 reports T10/B20 ratios through the year 2030 for the baseline and for each of the three policy alternatives. Panel C of Fig. 1 displays the same results graphically. As should be expected given the large increase in the Gini coefficients, all of the ratios climbed (at least after 2010). These trends therefore confirmed that climate policy would increase inequality in per capita gross state product over time, but they also suggest why. More inequality would be the result, at least in part, of an exaggeration in the disparity between the allocations of economic product to citizens of states inhabited by the richest 10% of the population and allocations to citizens of states inhabited by the poorest 20% of the population. The T10/B20 ratios were higher than the baseline throughout the time period for the "Annex B" and "No Trade" alternatives; but notice that the ratio for the "Global Trade" option actually fell below the baseline by the year 2030. Gini coefficients showed a less-equal distribution for the "Global Trade" option, but the T10/B20 ratios suggest that this must be the result of changes within the middle of the distribution that are sufficiently large to overcome a reduction in relative differences between the two extremes.

Top-to-bottom ratios also have their critics because they do not take comparisons of the extremes of a distribution far enough. Using them to reflect differences in the distribution of income assumes, at least implicitly, that the value of a marginal increment in income is the same at the top of the distribution as it is at the bottom. That is to say, top-to-bottom ratios ignore the possibility that the marginal utility of income declines as incomes rise. Atkinson (1970) among others took this criticism to heart. Armed with insights drawn from the literature on insurance, these researchers focused their attention, and ours, on the certainty equivalent income for any distribution. The idea is quite simple. Individuals, faced with uncertain incomes will try to buy insurance to protect themselves from risk. How much? No more, given actuarily fair insurance companies, than the difference between their anticipated mean income and a guaranteed income that would support the same level of expected utility. And no less, either, because the suppliers of insurance have to break even. This insurance purchase, therefore, represents a willingness to pay to avoid risk and uncertainty. It is a utility-based concept; and it should be no surprise that the willingness to pay depends upon the specification of the utility function — i.e., upon the degree of risk aversion displayed there.

Application of this idea to create a measure of inequity in the distribution of income (denoted y) is perhaps best described in the context of an arbitrary concave utility function in income denoted $U(y)$. Assume, for the sake of argument, that an individual is faced with a random draw from a set of possible incomes. Let the density function for this distribution be $f(y)$ so that

$$y_0 = \int y f(y)\,\mathrm{d}y$$

denotes the mean income across $f(y)$. Expected utility across this distribution is, of course,

$$EU = \int U(y) f(y)\,\mathrm{d}y,$$

and the corresponding certainty equivalent, to be denoted y_{ede}, solves

$$U(y_{ede}) = EU.$$

Put another way,

$$y_{ede} = U^{-1}(EU).$$

Diminishing marginal utility of income guarantees that $y_{ede} < y_0$, and the willingness to pay to avoid uncertainty income can be viewed as an insurance premium I defined by

$$I = y_0 - y_{ede}. \quad (1)$$

In the context of insurance, I represents the premium that an individual would pay to avoid risk and uncertainty in his or her income. In the context of the distribution of income, it represents the amount that society would be willing to pay to eliminate inequality — so it represents an aggregate, utility-based, willingness to pay measure of the cost of that inequality.

Panel D of Table 1 reports insurance premia defined by Eq.(1) for the baseline and the three policy regimes under the assumption that

$$U(y) = \ln y.$$

Panel D of Fig. 1 displays these premia graphically. Notice that they all rose over time — trends that again confirm less-equal distributions of income. Indeed, the trajectories showed increased estimates of the willingness to pay that were, in 2030, more than 50% larger than they were in 2000. They rose fastest along the "No Trade" alternative; but the "Global Trade" option trajectory matched the baseline fairly closely. Panel E draws the comparison with the baseline more starkly by plotting the deviation in the computed insurance policies for each policy relative to the baseline as a percentage of the deviations in mean per capita gross state product. Only the "Global Trade" option avoided a large dip around 2010 when the Kyoto restrictions would come on line; but the trends for all of the policies converged over time to something approximating 2%. It would appear, therefore, that the cost of increased inequality, weighted by a logarithmic utility function, would ultimately add 2% per year to the efficiency loss associated with any of the contemplated policy regimes. Put yet another way, these estimates suggest that adopting the "No Trade" option in lieu of global trading would reduce the present value of mean per capita state product by $7780 against a total of more than $475,000. Higher costs attributed to inequality across states assuming a logarithmic utility function would increase this cost by $144 per capita (by about 2%). Adopting the "Annex B" option in lieu of global trading would meanwhile reduce the present value of mean per capita state product by $2610 to which the higher cost of inequality across states would add $70 per capita (almost 3%).

Table 2
Aggregate indicators: gross state product with high fuel substitution

Year	Baseline	Annex B	Global	No trade
A. Mean per capita gross state product (× 1000$)				
2000	27.74	27.74	27.74	27.74
2005	27.95	27.99	27.97	27.97
2010	29.11	28.96	29.04	28.82
2015	29.47	20.12	29.33	28.81
2020	31.85	31.39	31.68	31.08
2025	32.36	31.83	32.17	31.56
2030	34.97	34.36	34.77	34.09
B. Gini coefficient				
2000	0.166	0.166	0.166	0.166
2005	0.173	0.172	0.173	0.173
2010	0.169	0.172	0.171	0.173
2015	0.188	0.192	0.190	0.195
2020	0.186	0.190	0.188	0.193
2025	0.195	0.200	0.197	0.202
2030	0.193	0.198	0.195	0.200
C. T10/B20 ratio				
2000	5.39	5.39	5.39	5.39
2005	5.40	5.40	5.40	5.40
2010	5.36	5.37	5.36	5.37
2015	5.45	5.47	5.46	5.48
2020	5.44	5.46	5.45	5.48
2025	5.45	5.48	5.46	5.49
2030	5.59	5.63	5.60	5.64
D. Insurace premium (× 1000$)				
2000	0.36	0.36	0.36	0.36
2005	0.38	0.38	0.38	0.38
2010	0.40	0.40	0.40	0.41
2015	0.46	0.47	0.46	0.47
2020	0.48	0.50	0.49	0.50
2025	0.53	0.54	0.53	0.55
2030	0.56	0.58	0.57	0.59

Table 2 and Fig. 2 report comparable results for gross state product under the assumption of high fuel switching potential in production.[4] Panel A again records mean per capital state product. The patterns for this high substitution case matched the results from the low substitution case, but a quick glace at the scale of the vertical axis reveals that the inefficiencies associated with "Annex B" and "No Trade" cases were diminished. The ability to substitute more easily from a high carbon fuel to a low carbon fuel clearly made it less costly to accommodate achieving the Kyoto targets under either policy regime. Panels B, C, and D in Fig. 2 meanwhile portray time trajectories for Gini coefficients, T10/B20 ratios and utility-base insurance premia. All three trajectories support drawing a similar conclusion on the equity side. Climate policy made the distribution of per capita gross state

[4] An elasticity of substitution between natural gas and coal equal, this time, to 2.0.

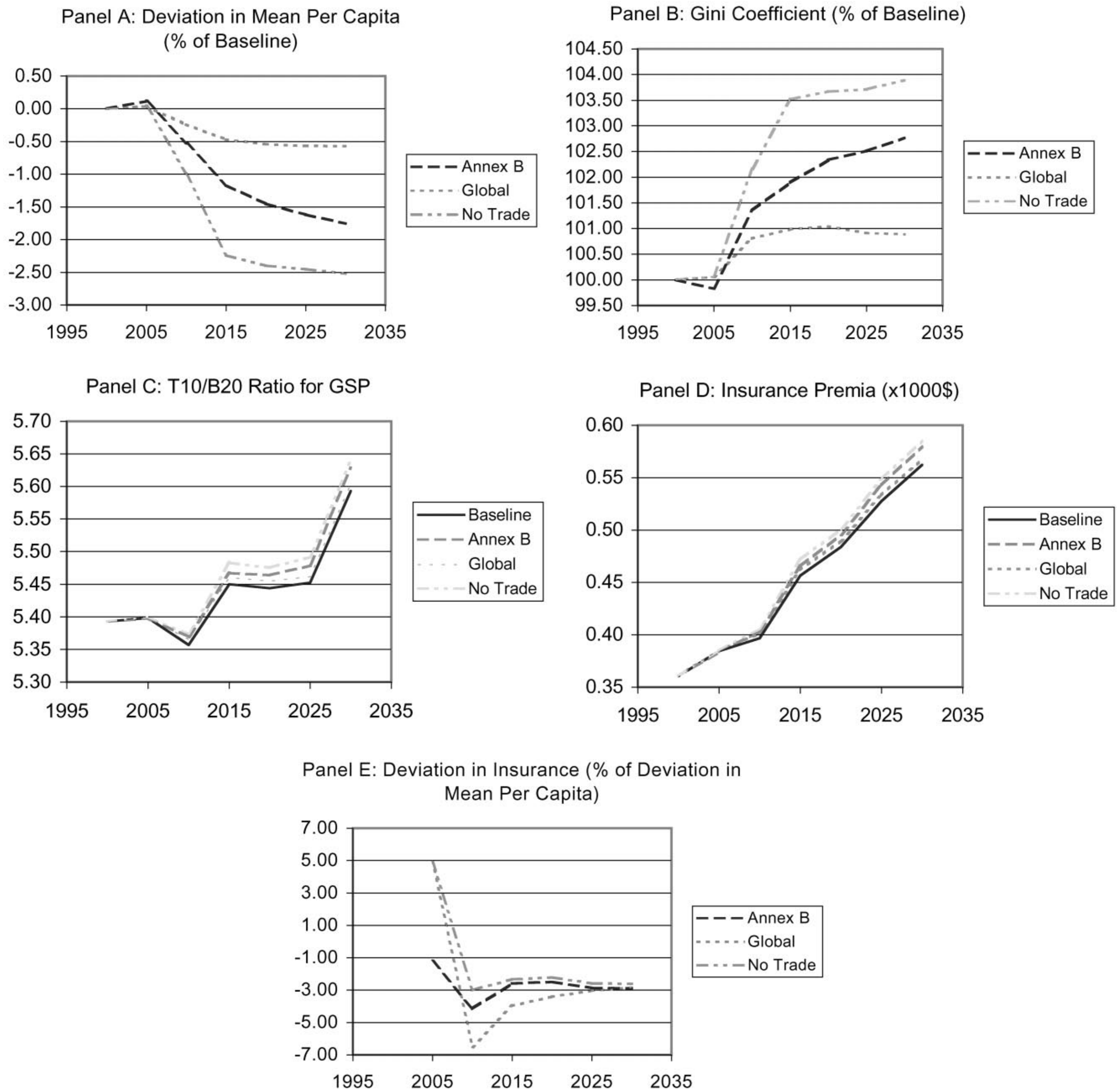

Fig. 2.

product less equitable, but with less force than before and especially for the "No Trade" case. Finally, Panel E of Fig. 2 shows that deviations in applicate insurance premia measures of the willingness to pay to avoid inequality converged to 3% of the deviation in mean per capital gross state product. This is a limit that represents a higher number than before that must be applied to smaller deviations in the means. These estimates assuming greater substitution suggest that adopting the "No Trade" option in lieu of global trading would now reduce the present value of mean per capita state product by \$3320, but that the higher cost of inequality across states assuming a logarithmic utility function would still add another 2%. And adopting the "Annex B" option in lieu of global trading would now reduce the present value of mean per capita state product by only \$2010 and add another 2% in higher inequity costs.

Table 3 and Fig. 3 finally report results in terms of per capita consumption across states for the original case built on the assumption of low fuel substitution. Notice in Panel A that each policy option imposed only a small efficiency loss relative to the baseline. Notice, too, that ordering the alternatives in terms of their inefficiency would find the "Global Trade" alternative to be least costly and the "No Trade" regime to be most costly. Both of these observations are, of course, consistent with the

Table 3
Aggregate indicators: consumption with low fuel subsitution

Year	Baseline	Annex B	Global	No trade
A. Mean per capita consumption (× 1000$)				
2000	17.77	17.77	17.77	17.77
2005	18.77	18.77	18.77	18.77
2010	20.48	20.41	20.46	20.21
2015	20.95	20.85	20.92	20.63
2020	22.89	22.72	22.84	22.42
2030	23.51	23.29	23.46	22.97
	25.70	25.40	25.64	25.08
B. Gini coefficient				
2000	0.104	0.104	0.104	0.104
2005	0.111	0.111	0.111	0.111
2010	0.108	0.108	0.108	0.108
2015	0.135	0.134	0.134	0.133
2020	0.134	0.133	0.134	0.133
2025	0.157	0.156	0.156	0.156
2030	0.156	0.155	0.155	0.154
C.T10/B20 ratio				
2000	4.93	4.93	4.93	4.93
2005	5.06	5.06	5.06	5.06
2010	5.06	5.06	5.06	5.06
2015	5.29	5.29	5.29	5.28
2020	5.31	5.31	5.31	5.31
2025	5.51	5.51	5.50	5.50
2030	5.53	5.53	5.53	5.53
D. Insurance premium (× 1000$)				
2000	0.13	0.13	0.13	0.13
2005	0.14	0.14	0.14	0.14
2010	0.15	0.15	0.15	0.15
2015	0.20	0.19	0.20	0.19
2020	0.22	0.21	0.21	0.21
2025	0.28	0.27	0.28	0.27
2030	0.31	0.31	0.31	0.30

results expressed in terms of gross state product. This consistency breaks down, however, when distributional implications are taken into account. Panel B shows that the Gini coefficients for consumption actually fell and that they fell the most for the "No Trade" alternative; i.e., climate policy actually worked to make the distribution of consumption more equal. Panels C and D meanwhile suggest that this "inverse" result was not the result of transfers from the largest consuming states to the smallest consuming states; the T10/B20 ratios for all policy alternatives were nearly identical through the year 2030. Note, though, that the baseline and the "Global Trade" option produced the highest utility-based willingness to pay estimates while the "No Trade" alternative generated the smallest. This suggests that the improvement in equity was the result of shrinking the dispersion in per capita consumption around somewhat smaller means. These estimates based on consumption suggest that adopting the "No Trade" option in lieu of global trading would reduce the present value of mean per capita consumption by $3320 but that *lower* costs attributed to inequity would *reduce* this loss by a little more than 1%. Finally, adopting the "Annex B" option in lieu of global trading would reduce the present value of mean per capita consumption by only $950 with lower costs of inequality across states again subtracting a little more than 1%.

3. Comparative results for international implications

The authors of the SIAM have also created the MS-MRT model with which they have examined the global implications of the same set of climate policies described above (see Bernstein et al., 1999a). As noted in Section 1, in fact, the MS-MRT model is employed by the SIAM to bring the terms of trade effects of alternative policy regimes across the globe to bear on the United States economy. Indeed, the MS-MRT model uses the same computable general equilibrium approach to track the effects of climate change and climate change policy across eight regions of the globe through the year 2030. It was, therefore, possible to use the MS-MRT model to explore comparable international equity implications of alternative policy designs in exactly the same way that the SIAM was employed to provide insight into domestic ramifications for the United States.[5]

Table 4 records time trajectories for mean per capita consumption, GINI coefficients, T10/B20 ration, and the logarithmic utility-based insurance measure of willingness to pay to avoid international inequity in per capita consumption. The estimates recorded there were derived from runs of the MS-MRT model that were calibrated to be consistent with the low fuel switching case for the United States. Permits were allocated to Annex B countries according to their Kyoto Protocol targets and, in the "Global Trade" case, according to an unregulated baseline for non-Annex B countries. The various panels of Fig. 4 depict graphically the results recorded in Table 4. Notice, in passing, that the Gini coefficients for the year 2000 are more than four times larger for the international model than were in Section 2 for the United States. Inequity in consumption is therefore far more widespread across the globe than it is within the United States. This is certainly not a surprise, but the dimension of the difference is perhaps startling. The T10/B20 ratios of the global comparison are twice as large in 2000 as they are in the domestic comparison. And the insurance premia computed for the globe was nearly one-third of

[5] The same assumption of equal distributions within regions was made; and is perhaps even more troubling. The eight regions are: the United States, the European Union, Canada, Japan, the formerly centrally planned economies of Eastern Europe, China, India, and the Middle East.

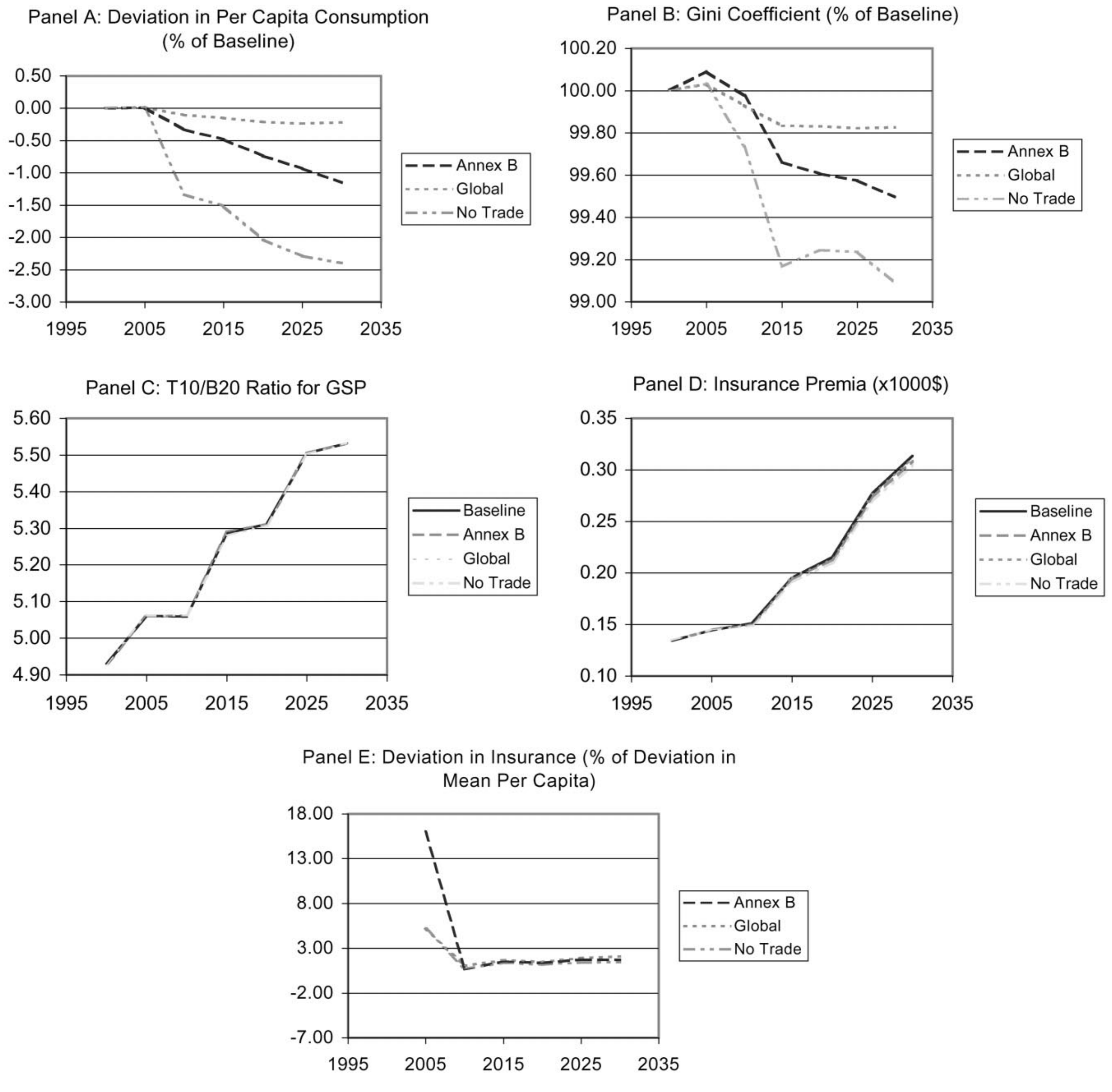

Fig. 3.

mean per capita consumption in 2000 while it they were less than 1% of mean percapita consumption in the United States.

Turning now to direct comparisons of policy design alternatives in the international context, notice that Figs. 3 and 4 display similar patterns. Note, in particular, that the "Global Trade" option did better with respect to efficiency and worse with respect to equity (as measured by GINI coefficients, the T10/B20 ratios, and the willingness to pay insurance premia) than either of the other two policy design options. Indeed, the "Global Trade" policy alternative came within $10 of the baseline in terms of mean per capita consumption in the year 2030. Note, though, that the "Global Trade" alternative held the Gini coefficients and the insurance premia relatively stable through the year 2030 and produced a 30% increase in the T10/B20 ratios from 2000 through 2030. All of these trends ran counter to the equity implications of the "Annex B" and "No Trade" alternatives, though, because all three of the inequity measures fell sharply and consistently for both through the year 2030.

The estimates recorded in Table 4 can be used to offer some insight into the relative magnitudes of these differences. The efficiency costs of choosing either the "Annex B" or "No Trade" design alternatives, measured as the discounted value of differences in mean per capita

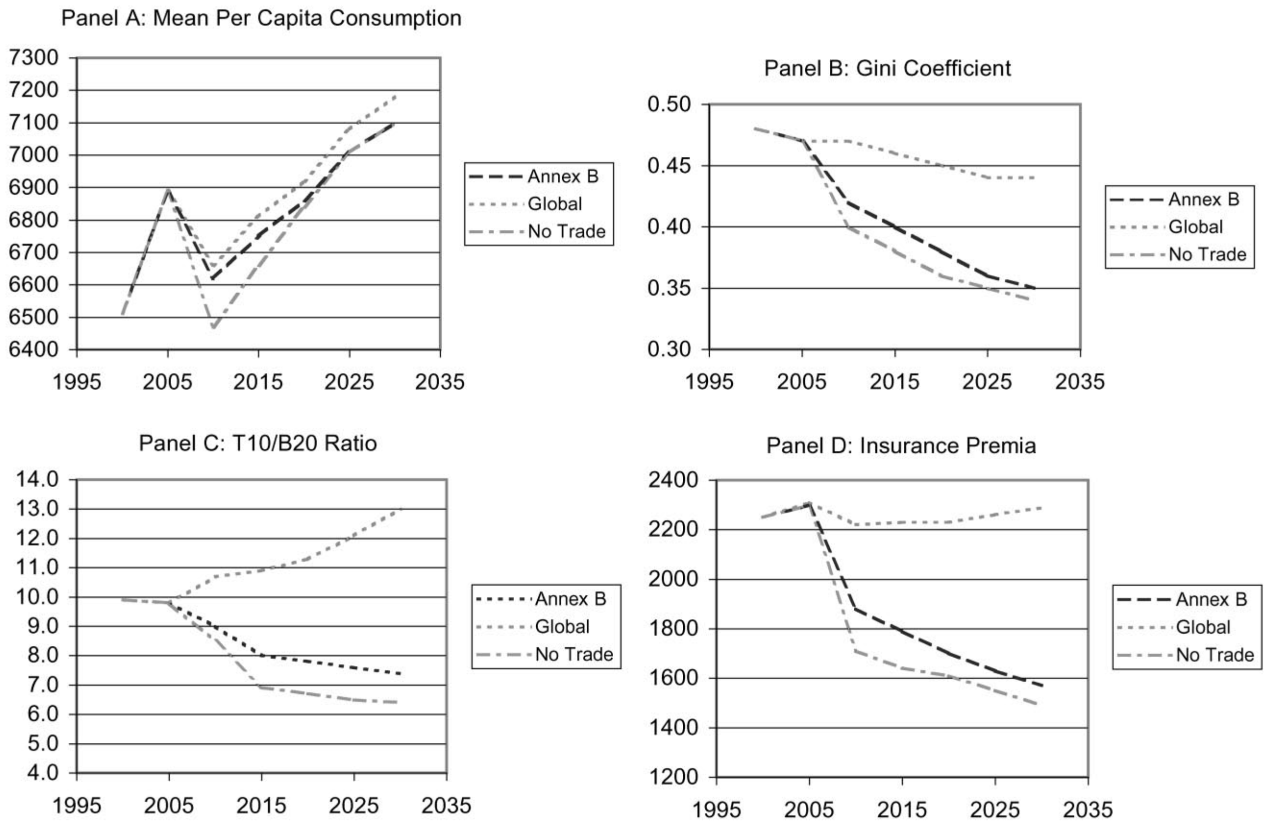

Fig. 4.

consumption (with a 5% discount rate) were $550 and $1290, respectively. But this inefficiency worked to make the distribution of consumption across the nine regions of the globe less inequitable. Indeed, choosing to implement the "Annex B" or "No Trade" alternatives in lieu of the most efficient "Global Trade" option would reduce the present value of the per capita insurance premia measures of the cost of inequality by $4720 and $6050, respectively.

Could it be that the efficiency of global trading could be so detrimental to the distribution of consumption that it should be avoided in favor of more restrictive and less-efficient policy regimes? The answer to this question clearly depends on your valuation metric. The "Global Trade" option did sustain the highest global mean in per capita consumption. When those extra dollars were weighted by a logarithmic utility function, though, the present value of the certainty equivalent level of per capita consumption fell considerably. By more than five times the efficiency gain relative to the "Annex B" option and by more than eight times the efficiency gain relative to the "No Trade" option. These estimates represent measures of economic cost denominated in terms of the willingness to pay to avoid global, to be sure; but they also identify economic surplus that could be redistributed in a "Global Trade" design that allocated emissions permits more equitably.

These results, based on an economic approach to the distribution of consumption, surely highlight the notion that policy design matters not only in terms of efficiency but also in terms of equity. They do not, of course, come close to handling the many social, political and cultural dimensions of equity and sustainability. Tol (1999) has, for example, begun to investigate the implications of policy in the context of diseases like malaria for which, it would appear, incidence falls dramatically when per capita incomes rise above $3000 per year. Utility-based measures can be suggestive of how the likelihood that such a threshold might be crossed across the globe as the future unfolds under alternative policy regimes; but they fall short of providing insight into the incidence of these crossings at the national and sub-national levels. Aggregate measures can, therefore, identify important questions that need to be explored, but they cannot be relied upon to support or to sustain the requisite explorations.

4. Concluding remarks

The negotiation of the Kyoto Protocol has spawned a growing literature that explores the ramifications of alternative means of designing and administrating policies that would achieve its global objectives. The Energy Modeling Forum, in fact, has served as a catalyst of sorts

Table 4
Aggregate indicators: global consumption

Year	Annex B	Global	No trade
A. Mean per capita consumption (1995$)			
2000	6510	6510	6510
2005	6890	6890	6890
2010	6620	6660	6470
2015	6750	6810	6660
2020	6860	6920	6840
2025	7010	7080	7010
2030	7100	7180	7100
B. Gini coefficient			
2000	0.48	0.48	0.48
2005	0.47	0.47	0.47
2010	0.42	0.47	0.40
2015	0.40	0.46	0.38
2020	0.38	0.45	0.36
2025	0.36	0.44	0.35
2030	0.35	0.44	0.34
C. T10/B20 ratio			
2000	9.9	9.9	9.9
2005	9.8	9.8	9.8
2010	9.0	10.7	8.5
2015	8.0	10.9	6.9
2020	7.8	11.3	6.7
2025	7.6	12.1	6.5
2030	7.4	13.0	6.4
D. Insurance premium (1995$)			
2000	2250	2250	2250
2005	2300	2310	2300
2010	1880	2220	1710
2015	1790	2230	1640
2020	1700	2230	1610
2025	1630	2260	1550
2030	1570	2290	1490

in this effort by undertaking a new exercise (EMF-16). Research teams who have decided to participate in EMF-16 have committed themselves to examining systematically the ramifications of meeting the Kyoto targets under a variety of assumptions about how the Protocol might be enacted. Differences in the ability of natural and artificial sinks to counterbalance carbon emissions and the means by which their cleansing effect might be applied in emissions accounting have been postulated. Different schemes for counting reductions in the emission of greenhouse gases other than carbon dioxide against carbon emissions targets have also been considered. So, too, have differences in post-2012 climate policy objectives. And, of course, different assumptions about how emissions permits might be traded either among Annex B countries or across the globe have been highlighted.

Results from the EMF-16 process have already identified some critical issues that must be considered as negotiations turn to policy design. Manne and Richels (1997) among others have noted, for example, that the burden of meeting Kyoto targets on the way to stabilizing atmospheric concentrations of greenhouse gases would be shared differently for different allocations of emissions rights and/or different permit trading schemes. McKibben and Wilcoxen (1999) have led a small group of research teams in noting that terms of trade effects could undermine seriously the welfare gains that might flow to non-Annex B countries under alternative emissions rights allocations. Manne (1999) has, meanwhile, joined Bernstein et al. (1999b) and others in observing that serious leakage in emissions might occur if non-Annex B countries do not sign onto the Protocol and are thereby free to expand without restraint their investment in fossil-fuel intensive industries. None of these studies have, however, employed standard measures of equity across distributions of income or consumption to explore the equity implications of alternative policy designs. And few studies have paid much attention to the domestic impacts of global climate policy within a large and open economy. This paper offers a few preliminary steps in both directions by exploiting the SIAM (CRA, 1999) and the MS-MRT model of Bernstein et al. (1999a) to explore the relative equity implicates of building global trade, Annex B trade only, and no trade provisions into the implementation of the Kyoto Protocol.

Results that summarize domestic results for the United States from the SIAM show that the trade effects of enforcing the Kyoto Protocol combine under alternative international trading assumptions with the associated required emissions reductions to produce modestly different distributional effects across the 50 states. Global trading of emissions permits consistent with the Kyoto targets, limited Annex B trading of emissions permits, and no trading all worked within the SIAM to make the distribution of per capita gross state product worse than it would be otherwise, but not significantly. Global trading did the most damage in terms of equity. Estimates of the willingness to pay to avoid inequality based on a logarithmic utility function suggested that the extra cost would reduce the present value of the associated efficiency gain of global trading relative to Annex B trading or no trading by only 2%. In terms of the distribution of per capita consumption across the states, though, all three of the policy alternatives worked within the model to improve equity (even more) modestly with the largest improvement associated with the "No Trade" option. Moving to either restrictive trading regime from global trading would, however, increase the willingness to pay measure of the cost of inequality by roughly 1% of the present value of the associated efficiency gain.

The equity implications of the global trading, Annex B trading, and no-trading alternatives were far more striking in the global context where the efficiencies of market-based adaptation to the policies could not be exploited as fully. Global trading did sustain the highest mean in per capita consumption, but the "No Trade" and "Annex B" trading alternatives reduced significantly the underlying inequity in the distribution of per capita consumption across the eight regions reflected in the MS-MRT model. Weighed again by a logarithmic utility function, the present value of the certainty equivalent level of mean per capita consumption would fall by more than five times the efficiency gain if global trading were allowed instead of limited Annex B trading. Moreover, this measure of willingness to pay to avoid inequity would be more than eight times larger than the efficiency gain if global trading were chosen over the "No Trade" alternative.

The estimates reported here are, of course, highly speculative and extremely model-specific. Different models and, more importantly, different allocations of permits within the United States and/or across the globe would produce different results. Therefore, these results do not mean that global trading in emissions permits should be shelved because the equity properties are so poor. Much like the other studies cited above that have identified issues that need to be monitored carefully in the design of mechanisms with which the signators of Kyoto Protocol might meet their commitments, though, these results do emphatically add equity to the list of fundamental concerns that must be considered. And they also suggest that standard aggregate economic tools can, even at this stage, be employed to track progress and/or regression against whatever criteria are set forth to reflect this addition.

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