

Estimates of the costs of Kyoto: Marrakesh versus the McKibbin–Wilcoxon blueprint

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Abstract

In this paper, we update our earlier estimates of the cost of the Kyoto Protocol using the G-Cubed model, taking into account the new sink allowances from recent negotiations as well as allowing for multiple gases and new land clearing estimates. We then compare the protocol to an alternative policy outlined in McKibbin et al. (Brookings Policy Brief, No. 17. June, The Brookings Institution, Washington, 1997; Climate Change Policy After Kyoto: A Blueprint for a Realistic Approach, The Brookings Institution, Washington, 2002a; J. Econom. Perspect. 16(2) (2002b) 107) that does not impose rigid emissions targets. We focus particular attention on the sensitivity of compliance costs under each policy to unexpected changes in future economic conditions. To illustrate the issue, we evaluate the policies under two plausible alternative assumptions about a single aspect of the future world economy: the rate of productivity growth in Russia. We find that moderate growth in Russia would raise the cost of the Kyoto Protocol by as much as 50 percent but would have little effect on the cost of the alternative policy. We conclude that the Kyoto Protocol is inherently unstable because unexpected future events could raise compliance costs substantially and place enormous pressure on governments to abrogate the agreement. The alternative policy would be far more stable because it does not subject future governments to adverse shocks in compliance costs.

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1. Introduction

The likelihood that the Kyoto Protocol will achieve significant real reductions in greenhouse gas emissions is very low. The United States withdrew from the protocol in March 2001, a move which was angrily denounced by surprised commentators in Europe and around the world. It was described as arrogant, isolationist, and a “betrayal [by the Bush Administration] of their responsibilities as global citizens”.¹ Yet the announcement was really nothing more than a blunt public acknowledgment of a fact that was well known within the policy community: the Kyoto Protocol was already dead in the United States. The US Senate, which must ratify all international treaties by a two-thirds majority, over-

whelmingly opposed the protocol and had voted 95-0 against US participation as early as July 1997, 5 months before the protocol was signed.² Opposition was so great that the Clinton Administration, which negotiated and signed the protocol, never bothered to submit it to the Senate for ratification. Even if the Bush Administration had enthusiastically supported the treaty—which it did not—there was little it could have done.

What doomed the protocol in the Senate is a critical flaw in its design: it requires each participating industrialized country to agree to achieve a specified emissions target regardless of the cost of doing so.³ The focus on rigid targets also makes the treaty impractical as a long-term climate policy for the rest of the world as well. Because the costs of reducing emissions are unknown and could be very large, countries with

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¹ “World Leaders Criticize Bush on Global Warming,” Associated Press, March 30, 2001.

² Senate Resolution 98 of the 105th Congress, generally known as the “Byrd-Hagel Resolution” after two of its authors.

³ This is known as the “targets and timetables” approach and it will be discussed in more detail below.

substantial emissions have insisted on increasingly lax targets as a condition for their continued participation. Japan, Canada and Russia, for example, were able to negotiate large increases in their “sink” allowances during the resumed sixth Conference of the Parties (COP) to the United Nations Framework Convention on Climate Change (UNFCCC), namely, COP6bis, held in Bonn, and the seventh COP (COP7), held in Marrakesh.⁴ Between the US withdrawal and the increase in sink allowances, the protocol has been relaxed substantially. The effect on estimated emissions permit prices in the 2008–2012 period is dramatic. Relative to the original Kyoto agreement, permit prices are likely to be reduced by 14 percent (Bohringer, 2001) to 85 percent (Kemfert, 2001).⁵

In this paper, we update our earlier estimates⁶ of the cost of the Kyoto Protocol using the G-Cubed model, taking into account the new sink allowances from recent negotiations as well as allowing for multiple gases and new land clearing estimates. We then move on to the paper’s main topic, which is an examination of the protocol’s core flaw—the sensitivity of compliance costs to unexpected changes in future economic conditions. To explore this point we consider two plausible alternative assumptions about a single aspect of the future world economy and evaluate the protocol under each assumption. The two cases we examine are: (1) moderate productivity growth in Russia sufficient to produce a 3.24 percent average rate of economic growth from 2000 to 2012; and (2) higher productivity growth leading to a 4.24 percent average rate of economic growth over 2000 to 2012.⁷ Comparing the two sets of results shows the sensitivity of greenhouse gas abatement costs to variables that are very difficult to predict. The cost of the protocol in foregone GNP, for example, varies by up to 50 percent. The comparison thus illustrates the risks created by the protocol’s focus on rigid emissions targets.

We also evaluate an alternative climate change policy described in McKibbin and Wilcoxon (1997, 2002a, b) under both Russian growth scenarios. The alternative policy, hereafter called the “Blueprint”, differs sharply from the protocol because it does not impose fixed emissions targets.⁸ Its design, which will be discussed in more detail below, takes explicit account of the vast

uncertainties surrounding climate change. As a result, the policy’s costs are predictable and are affected very little by the change in Russian economic growth.⁹ Predictability of costs is essential because a climate agreement will have to remain in force indefinitely: unexpected future increases in compliance costs would place enormous pressure on governments to abrogate the agreement. At the same time, the stability of costs does not necessarily compromise the policy’s effect on emissions: because costs are limited and predictable, participation in the policy would be likely to be broader than under the Kyoto Protocol, and reductions would be undertaken sooner. To illustrate this effect we compare cumulative emissions under both policies through the year 2015. Although the Blueprint is less stringent than the protocol, with wider participation (by the United States, in particular), it can actually have a substantially larger effect on emissions. Overall, the Blueprint is a promising alternative to the Kyoto Protocol.

The remainder of the paper is structured as follows. In Section 2, we give a brief overview of the Kyoto Protocol and highlight the quantitative changes that have occurred to the effective targets facing countries from COP3 to COP7.¹⁰ In Section 3, we present a brief critique of the protocol and describe the alternative Blueprint proposal. Section 4 gives an overview of G-Cubed, the multi-country, multi-sector general equilibrium model we use to evaluate each of the policies. Section 5 discusses the key elements of our baseline simulation and presents our results. The baseline is particularly important because the rate at which emissions grow in the absence of a climate change policy is a major determinant of the cost of the Kyoto Protocol: the more emissions rise in the baseline, the more they must be reduced to hit the protocol’s targets. Major world economic events that have occurred since our previous analysis of the Kyoto Protocol (McKibbin and Wilcoxon, 1999)—including the Asian financial crisis and the global recession of 2001–2002—are reflected in the baseline.¹¹ Following discussion of the baseline, the remainder of Section 5 evaluates and compares the Kyoto Protocol and the Blueprint. Our conclusions are presented in Section 6.

⁴Sink allowances enable countries to offset a portion of their carbon emissions by enhancing activities, such as forestry, that remove carbon dioxide from the atmosphere.

⁵See Buchner et al. (2001) for a survey of estimates.

⁶See McKibbin et al. (1999).

⁷Economic growth is endogenously determined based on sectoral productivity growth rates, population growth assumptions and capital accumulation. Productivity and population growth rates are both exogenous. The moderate growth scenario uses our baseline assumptions about Russian productivity.

⁸The name “blueprint” comes from the title of McKibbin and Wilcoxon (2002a).

⁹In this paper our focus is uncertainty in the costs of reducing emissions. Pizer (1997), Newell and Pizer (1999), and Hoel and Karp (2002) examine uncertainty in benefits as well as costs, although in a more abstract level.

¹⁰The original COP3 version of the protocol has been analyzed extensively; see Weyant (1999).

¹¹Because of the difference in baselines, the results in this paper are not directly comparable to our previous work. Direct comparisons of the COP3 and COP7 versions of the protocol, holding baseline assumptions constant, can be found in Bohringer (2001), Buchner et al. (2001), Kemfert (2001), and Löschel and Zhang (2002). The papers use different models but reach similar overall insights.

2. Climate negotiations and the Kyoto Protocol

International negotiations on climate change policy began in earnest in 1992 at the Rio Earth Summit organized by the United Nations. The result of the summit was the UNFCCC, a non-binding agreement aimed at reducing atmospheric concentrations of greenhouse gases so as to achieve the goal of “preventing dangerous anthropogenic interference with the Earth’s climate system.”¹² It was signed and ratified by most of the countries in the world, including the United States, and entered into force in 1994.

The Convention’s intent was to stabilize emissions of greenhouse gases at 1990 levels by the year 2000 through voluntary measures taken by individual countries. Most of the burden was to be assumed by 40 industrialized countries listed in Annex I to the Convention. In particular, Article 4, Paragraph 2(a) required each of these countries to “adopt national policies and take corresponding measures on the mitigation of climate change” in order to reduce its emissions. Annex I countries were also required to contribute to a financial fund (subsequently merged into the Global Environment Facility (GEF)) to be used to help pay for climate-friendly projects in developing countries.

In the subsequent decade, however, few substantive policies were implemented and global emissions of greenhouse gases rose considerably. From that perspective, the UNFCCC failed to achieve its goal. However, its real contribution was to set up a mechanism under which negotiations could continue as periodic COP meetings.

The first Conference of the Parties to the UNFCCC, COP 1, was held in Berlin in March and April of 1995. The second Conference, COP 2, was held in Geneva in July of 1996. The third Conference, COP 3, was held in Kyoto in December of 1997. The result of the meeting was document called the “Kyoto Protocol,” a treaty that formalized the “targets and timetables” approach that had been taking shape since COP 1. The Protocol set explicit emissions targets for 39 countries listed in its Annex B, which included essentially all industrialized countries who were signatories.¹³ Each of these countries was to reduce its greenhouse gas emissions so that its total emissions, when converted to a carbon-equivalent basis, did not exceed a specified percentage of its “base period” emissions. For most countries the base period was 1990 but countries having economies in transition were allowed to choose other base periods

during COP 2.¹⁴ Average emissions over the “budget period” 2008–2012 were to be at or below the target.¹⁵ The Annex B limits are shown in Table 1 in which countries designated as “economies in transition” are marked with an asterisk.

The commitments in Table 1 amount to about a 5 percent reduction below 1990 emissions for the Annex B countries as a group, or about 245 million metric tons of carbon.¹⁶ The Protocol was designed to allow Annex B countries flexibility in meeting their commitments. Some of the flexibility concerns the unilateral actions that countries can take to comply with the Protocol. First, the specific policies to be used to reduce emissions were left completely to the discretion of each country. Second, compliance could be achieved by any mix of carbon-equivalent reductions in four individual gases and two classes of halocarbon: carbon dioxide, methane, nitrous oxide, sulfur hexafluoride, hydrofluorocarbons (HFCs) and perfluorocarbons (PFCs). Third, countries could offset some of their emissions by enhancing “sinks” of carbon dioxide: forests or other mechanisms that remove carbon dioxide from the atmosphere. Fourth, reductions in excess of the Annex B commitments could be carried forward and used to count toward compliance in future periods.

The Protocol also provides three mechanisms that allow for flexibility on a multilateral basis. The most important is international emissions permit trading (IET), which is allowed among Annex B countries under the Protocol’s Article 17. In addition, Article 6 of the Protocol allows for “Joint Implementation” (JI), a project-based system under which one Annex B country can receive credit for emissions-reducing activities it finances in another Annex B country. The use of emissions trading and JI, however, must be “supplemental to domestic actions,” a vague phrase that left open the possibility that quantitative limits could be imposed on the amount of trading and JI.¹⁷

For the Protocol to come into force it must be ratified by 55 percent of its signatories, and they must jointly account for at least 55 percent of total carbon dioxide emissions in 1990 from Annex I countries. Most of the

¹⁴Decision 9 of COP 2 established the base periods for Annex I countries.

¹⁵Gases other than carbon dioxide are converted to a carbon-equivalent basis using “global warming potentials” established by the Intergovernmental Panel on Climate Change. A country’s carbon-equivalent emissions over the 5 year period 2008–2012 was required to be less than or equal to the specified fraction of base period emissions.

¹⁶The exact reduction depends on the treatment of land use changes, which had not been finalized by the end of COP6.

¹⁷The European Union, in particular, was in favor of limiting the degree to which compliance could be achieved by trading and JI. The United States was opposed to any restrictions. See Zhang (2000, 2001) for detailed discussion on the supplementarity provision and on the assessment of the European Union proposal for ceilings on the use of Kyoto flexibility mechanisms.

¹²For more information about the UNFCCC and the various COP meetings that followed it, see the UNFCCC web site: <http://www.unfccc.org/>.

¹³The Annex B list is a subset of the countries listed in Annex I of the UNFCCC. It excludes Belarus, which had not ratified the UNFCCC by the time COP 3 was held, and Turkey, which requested that it be removed from Annex I at COP 3.

Table 1
Kyoto protocol emissions limits or reduction commitments (Percent of 1990 or base period emissions)

Country	Target	Country	Target
Australia	108	Liechtenstein	92
Austria	92	Lithuania ^a	92
Belgium	92	Luxembourg	92
Bulgaria ^a	92	Monaco	92
Canada	94	Netherlands	92
Croatia ^a	95	New Zealand	100
Czech Republic ^a	92	Norway	101
Denmark	92	Poland ^a	94
Estonia ^a	92	Portugal	92
European Community	92	Romania ^a	92
Finland	92	Russian Federation ^a	100
France	92	Slovakia ^a	92
Germany	92	Slovenia ^a	92
Greece	92	Spain	92
Hungary ^a	94	Sweden	92
Iceland	110	Switzerland	92
Ireland	92	Ukraine ^a	100
Italy	92	United Kingdom	92
Japan	94	United States	93
Latvia ^a	92		

^aCountry designated as an “economy in transition.”

operational details of the Protocol’s international mechanisms—IET, JI and the CDM—were left for future COP meetings to resolve. There was no negotiation over issues of compliance, how institutional structures would work, or on how developing countries might be involved beyond the CDM. Meetings after COP 3 were devoted to working out the operational details of the Kyoto Protocol. Details can be found in McKibbin and Wilcoxon (2002a). For the purposes of this paper, the key issues are the relaxation of targets through changes in allowed sinks.

When the second part of COP6 was convened in Bonn in July of 2001, it was intended to resolve all remaining implementation details of the Kyoto Protocol. The outcome was a package of proposals known as the “Bonn Agreements” which included, among other things, an increase in the sink allowances for forestry and land-use changes that were granted to several countries.¹⁸ The total increase in sink allowances was large and reduced the overall stringency of the protocol by 54.5 million metric tons of carbon. Countries given sink allowances greater than one million metric tons of carbon-equivalent emissions are shown in Table 2. Although the Bonn Agreements were formulated during the second part of COP 6, they were not adopted as official decisions of the Conference. Instead, further discussion and formal adoption were deferred until COP7.

¹⁸Sink allowances enable countries to offset a portion of their carbon emissions by enhancing activities, such as forestry, that remove carbon dioxide from the atmosphere.

Table 2
Countries receiving sink allowances exceeding 1 MMT (Million metric tons of carbon)

Country	Allowance
Canada	12.00
Germany	1.24
Japan	13.00
Romania	1.10
Russia	17.63
Ukraine	1.11

COP 7 was held in Marrakesh in October and November 2001. It refined and extended the Bonn Agreements in three main areas: (1) defining the “principles, nature and scope” of the international flexibility mechanisms; (2) finalizing the accounting rules for sinks derived from land use changes and forestry; and (3) designing an enforcement mechanism to discourage noncompliance. The result was a document called the “Marrakesh Accords” that COP 7 participants hoped would remove all remaining obstacles to ratification of the Kyoto Protocol.

Finally, COP7 further relaxed the Kyoto emissions target by granting a Russian request that its sink allowance be increased from 17.63 to 33 MMT. Thus sinks have relaxed the Kyoto targets by roughly 70 MMT, which together with the withdrawal of the United States makes the Kyoto Protocol’s targets through 2012 very loose. Indeed, if world economic growth remains slow for a few years, the protocol’s emissions targets may not be binding.

3. An alternative to the Kyoto Protocol

At the heart of the climate change debate are two key facts. The first is the familiar and undisputed observation that human activity is rapidly increasing the concentration of greenhouse gases in the atmosphere. Each year, worldwide fossil fuel use adds about six billion metric tons of carbon to the atmosphere, and the concentration of carbon dioxide is now about 30 percent higher than it was at the dawn of the Industrial Revolution.

The second fact, however, is that no one fully understands how the climate will respond.¹⁹ The increase in greenhouse gases could lead to a sharp rise in global temperatures with severe consequences for ecosystems and human societies. On the other hand, it is possible that the temperature rise could be modest, easy to mitigate and far in the future. The most likely outcome is probably somewhere between the two but

¹⁹For an exhaustive survey of the scientific literature on climate change, see Intergovernmental Panel on Climate Change (2001).

the intrinsic complexity of the climate makes it impossible to know precisely what will happen with any degree of confidence. Determining the costs and benefits of policies that would limit greenhouse gas emissions is even more difficult. Costs, for example, depend heavily on how fast emissions would grow in the absence of a climate policy: the more quickly emissions rise, the more expensive it will be to reduce them to any given level. The rate of emissions growth, however, depends on factors that are impossible to predict accurately over long spans of time: population growth, educational attainment, productivity growth within different industries, convergence (or lack thereof) in incomes between developing and developed countries, fossil fuel prices, and many others. Plausible alternative assumptions about these factors can lead to vastly different estimates of future emissions.

3.1. *The Kyoto Protocol*

The most important problem with the Kyoto Protocol (outlined in the previous section) is that it fails to recognize and address this uncertainty. The heart of the Protocol is a set of “targets and timetables” requiring developed countries to reduce their greenhouse gas emissions. To ratify the protocol, each country must agree to reduce its emissions to a specified level—typically about 5 percent below in the country’s emissions in 1990—during the period from 2008 to 2012. By requiring participants to meet rigid emissions targets on a fixed timetable, however, the treaty implicitly adopted the position that the risks posed by climate change are so great that emissions must be reduced no matter what the cost. However, too little is known about the dangers posed by climate change, and about the costs of avoiding it, to draw that conclusion. Nor is there any evidence that the targets set by the protocol are the optimal levels of greenhouse gas emissions, either for an individual country or for the world as a whole. If anything, cost–benefit calculations based on studies to date tend to suggest that the costs exceed the benefits, at least in developed countries.²⁰

The Protocol’s lack of clear cost–benefit justification was not, however, the fatal flaw that led to such strong opposition in the US Senate. After all, governments often face uncertainty when evaluating potential policies. Because the damages caused by climate change could be very large, a prudent legislature might want to adopt a climate policy to hedge its bets as long as it could keep the policy’s costs within bounds. But Kyoto’s “targets and timetables” design makes that impossible. Governments that adopt the protocol risk taking on a disastrously expensive commitment. It was this aspect of

the Protocol that led to the nearly unanimous opposition it faced in the US Senate.

The Senate also objected to the absence of emissions limits for developing countries. Developing countries account for only a small portion of historical emissions and are especially reluctant to incur large costs in a climate change agreement. As a result, they were specifically exempted from emissions restrictions in the Kyoto Protocol. However, developing country emissions are growing far more rapidly than those of developed countries, and no climate agreement can succeed in the long run without developing country participation. As a result, the Senate insisted that the US refrain from participating in an agreement that did not include significant commitments by developing countries. Although it received considerable attention in the press, however, this consideration was subordinate to the Senate’s concern about the cost of the policy. Had the cost of the policy been known to be low, the Protocol’s asymmetrical treatment of developed and developing countries would have been a much less important issue. The Senate routinely approves other agreements having asymmetries between the US and other countries.

One additional problem with the Kyoto Protocol is that it lacks credible compliance measures and fails to give governments any incentive to police the agreement. Monitoring polluters is expensive, and punishing violators imposes costs on domestic residents in exchange for benefits that will go largely to foreigners. Governments would be strongly tempted to look the other way when firms exceed their emissions limits. Negotiators have tried to devise a strong international mechanism to monitor compliance and penalize violations, but so far have failed to produce a mechanism that is a credible deterrent for anything beyond very minor violations.²¹

3.2. *The Blueprint: a more realistic “hybrid” approach*

The uncertainties surrounding climate change have sharply polarized public debate. In essence, the division is over what it means to be prudent when faced with what could be a small chance of a very large loss. On one side are those who point to the possibly disastrous consequences of climate change and argue that emissions must be reduced sharply to lower the risk of a catastrophe. On the other side are those who point to the small probability of a disaster and argue that there are better uses of society’s resources than reducing an already small risk even further.

²¹ The main penalty that would be imposed on a country violating the protocol is a reduction in the amount of carbon dioxide it would be allowed to emit in the period following 2012. However, emissions limits beyond 2012 are not specified in the protocol and remain to be negotiated. A country violating the agreement could simply insist on a correspondingly higher post-2012 limit.

²⁰ See, for example, Nordhaus and Boyer (1999) or Tol (1999).

There are elements of truth in both positions but neither is an appropriate response to climate change. A balanced reading of the current scientific literature indicates that a moderate degree of effort should be made to slow the growth of greenhouse gas emissions. Taking some sort of action is clearly warranted: although climatologists disagree about how much warming will occur and when it will happen, no one seriously suggests that mankind can continue to add increasing amounts of carbon dioxide to the atmosphere every year without any adverse consequences. Moreover, climate change is essentially irreversible, so it makes sense to avoid causing more of it than necessary, at least until the potential risks are better understood. At the same time, current evidence does not justify a draconian cut in emissions: the cost would be enormous and the environmental benefits might be small. It is easily possible that the resources needed for a sharp reduction would be better spent on more immediate social problems. As a matter of common sense, therefore, the right approach must be a policy between the two extremes: it should provide incentives to reduce greenhouse gas emissions but avoid imposing unreasonably large costs.

In addition, a climate policy's political prospects will be substantially better if it does not require large transfers of wealth—either between countries or between households and firms within a country—or the surrender of a significant degree of national sovereignty. Finally, the system will need to remain in effect for many years so it must be designed to allow new countries to enter with minimum disruption and to survive the exit of some of its participants.

Neither of the standard market-based economic policy instruments satisfies all of these criteria. An ordinary tradable permit system would require participants to achieve a rigid emissions target regardless of cost. An emissions tax, on the other hand, would involve huge transfers of wealth and would be politically unrealistic. However, a hybrid policy, combining the best features of the two, would be an efficient and practical approach.²²

The particular hybrid policy we propose (hereafter referred to as the Blueprint) would allow each participating country to issue two kinds of emissions permits: perpetual permits that entitle the owner of the permit to emit 1 metric ton of carbon every year forever, and annual permits that allow 1 ton of carbon to be emitted in a single, specified year. Both types of permit would be

valid only within the country of issue—unlike the Kyoto Protocol, there would be no international permit trading. Each year, firms within a country would be required to have a total number of emissions permits, in any mixture of perpetual and annual permits, equal to the amount of emissions they produced that year.

The number of perpetual permits each country could issue would be decided by international agreement and could be based on the limits in the Kyoto Protocol—about 95 percent of most countries' 1990 emissions.²³ It would be up to each government to decide how to allocate its perpetual permits: some countries might want to give them to existing fuel users as a form of grandfathering, while others might prefer to sell or auction the permits to raise revenue. Once distributed, the perpetual permits could be traded among firms, or bought and retired by environmental groups.²⁴ In addition, the government itself could buy back permits in future years if new evidence on climate change indicates that emissions should be cut more sharply.

Annual permits would be sold at a stipulated price determined by international negotiations, such as US\$ 10 per ton. To put the fee in perspective, in the United States, US\$ 10 dollars per ton of carbon is equivalent to a tax of US\$ 1.40 per barrel of crude oil, raising the price of a US\$ 20 barrel of oil by about 7 percent. There would be no limit on the number of annual permits that could be sold in a given year.

Because it has two kinds of permits, the Blueprint is a bit more complicated than a simple permit system. However, it has all of the strengths of a traditional permit system and has additional advantages as well. It performs especially well in comparison to the Kyoto Protocol.

Like the Kyoto Protocol, the Blueprint encourages energy producers to keep emissions steady or, even better, to cut them. Firms that can cut emissions cheaply will do so and then sell unneeded perpetual permits to those whose emissions are increasing. As a result, emissions in each country will be reduced, and in a cost-effective manner.

²³The Kyoto reduction to 95 percent of 1990 emissions would slow climate change but not eliminate it entirely. Atmospheric concentrations of carbon dioxide, and hence global temperatures, would continue to rise. Stabilizing the temperature would require stabilizing the concentration of carbon dioxide, which would require net anthropogenic carbon dioxide emissions to be reduced to nearly zero. See McKibbin and Wilcoxon (2002a, b) for a discussion of how the Blueprint could be used to reduce emissions below the Kyoto target over the long run.

²⁴Countries could participate in the Blueprint even if they lacked appropriate markets where permits could be traded. In that case, a firm's allocation of perpetual permits would essentially be an emissions quota. Without tradability, the country would no longer be guaranteed of reducing its emissions at minimum cost. However, the existence of annual permits would reduce the excess cost caused by an inefficient allocation permits.

²²The economic theory behind regulation under uncertainty is due to Weitzman (1974), and the theory underlying hybrid regulatory policies is due to Roberts and Spence (1976). A hybrid approach to climate change was first proposed by McKibbin and Wilcoxon (1997) and has subsequently been endorsed or promoted by a range of authors and institutions. For further details, see McKibbin and Wilcoxon (2002a, b).

Unlike the Protocol, however, the Blueprint provides an upper limit on the cost of compliance. No firm would have to pay more than US\$ 10 per ton to reduce its emissions because it could always buy an annual emissions permit instead. Adopting the hybrid, in other words, does *not* require a country to make an open-ended commitment to reduce its emissions regardless of cost. As a result, it has a far better chance of ratification in the US or other countries having large carbon emissions. Moreover, that absence of a rigid upper limit on carbon emissions would also increase the possibility of significant participation by developing countries. The hybrid policy would have many other desirable attributes as well. These are summarized briefly below and discussed in more detail in [McKibbin and Wilcoxon \(2002a, b\)](#).

A key strength of the Blueprint is that it would be very stable with respect to changes in the mix of participating countries. Because permit markets are separate between countries—linked only by the common price of an annual emissions permit—the entry or exit of one country from the system would have no effect on the price of permits circulating in other countries. In contrast, a change in list of countries participating in the Kyoto Protocol would cause windfall gains or losses to ripple through permit markets around the world.

Another advantage is that countries would manage their own domestic permit trading system independently, using their own legal systems and financial institutions. International cooperation, although helpful, would not be essential beyond the initial design of the system. Monitoring firms to make sure they comply with the policy would be an internal matter for each country. Unlike the Kyoto Protocol, the Blueprint provides incentives for governments to monitor and enforce the agreement within their borders. One incentive is the revenue that could be raised from the sale of annual permits: low compliance would cause a government to sell fewer annual permits that it could have, lowering permit revenue. In addition, and perhaps more importantly, holders of perpetual permits will pressure their governments to be vigilant in order to maintain the market value of long term permits: low compliance would reduce prices in the permit market. The Kyoto Protocol, in contrast, requires international monitoring and a new international institution to ensure compliance. Moreover, poor monitoring and compliance in one country could debase the entire global permit trading system because it would affect emissions permit prices throughout the developed world.

Overall, the Blueprint is a practical and politically realistic approach to reducing greenhouse gas emissions. The main criticism leveled against it is that it does not guarantee precisely how much abatement will take place each year. If firms discover that it is very expensive to keep their emissions below their holdings of perpetual

permits, the option to buy annual permits allows them to emit more, although at a cost of US\$ 10 per ton. As a practical matter, however, the Blueprint would do far more to reduce emissions than a stronger treaty that could never be ratified or enforced.

In the following sections we illustrate the strengths of the Blueprint relative to the Kyoto Protocol especially when taking the considerable uncertainty about the future into account. But first we summarize the economic simulation framework being used.

4. An overview of the G-cubed multi-country model

The G-Cubed multi-country model was developed by [McKibbin and Wilcoxon \(1997\)](#) and has been updated in [McKibbin and Wilcoxon \(1998\)](#). It is an intertemporal general equilibrium model. It combines the approach taken in the earlier research of [McKibbin and Sachs \(1991\)](#) in the McKibbin Sachs Global model (MSG model) with the disaggregated, econometrically estimated, intertemporal general equilibrium model of the US economy by [Jorgenson and Wilcoxon \(1990\)](#).

G-Cubed has been constructed to contribute to the current policy debate on environmental policy and international trade with a focus on global warming policies, but it has many features that will make it useful for answering a range of issues in environmental regulation, microeconomic and macroeconomic policy questions. It is a world model with substantial regional disaggregation and sectoral detail. In addition, countries and regions are linked through trade and financial markets. G-Cubed contains a strong foundation for analysis of both short run macroeconomic policy analysis as well as long run growth consideration of alternative macroeconomic policies. Budget constraints are imposed on households, governments and nations (the latter through accumulations of foreign debt). To accommodate these constraints households and firms are assumed to use the model to generate forecasts of future economic performance and use these projections in their planning of consumption and investment decisions. The response of monetary and fiscal authorities in different countries can have important effects in the short to medium run which, given the long lags in physical capital and other asset accumulation, can be a substantial period of time. Overall, the model is designed to provide a bridge between computable general equilibrium (CGE) models that traditionally ignore the adjustment path between equilibria and macroeconomic models that ignore individual behavior and the sectoral composition of economies.

G-Cubed contains over 6000 equations and 110 intertemporal costate variables. A full theoretical description of the model is contained in [McKibbin and Wilcoxon \(1998\)](#); here we will summarize the model's

Table 3
Summary of main features of G-cubed

Specification of the demand and supply sides of economies;
 Integration of real and financial markets of these economies;
 Intertemporal accounting of stocks and flows of real resources and financial assets;
 Extensive econometric estimation of key elasticities of substitution from disaggregated data at the sectoral level;
 Imposition of intertemporal budget constraints so that agents and countries cannot forever borrow or lend without undertaking the required resource transfers necessary to service outstanding liabilities;
 Short run behavior is a weighted average of neoclassical optimizing behavior and ad-hoc “liquidity constrained” behavior;
 Disaggregated to allow for production and trade of multiple goods and services within and across economies;
 Full short run and long run macroeconomic closure with macro dynamics at an annual frequency around a long run Solow/Swan/Cass neoclassical growth model;
 Solved for a full rational expectations equilibrium at an annual frequency with an horizon of more than a century.

main features. Table 3 presents an overview of the model; its country and sectoral breakdowns are listed in Table 4. The range of countries modeled to date include the United States, Japan, Australia, Europe, the rest of the OECD, China, Oil Exporting developing countries (OPEC), Eastern Europe and states of the former Soviet Union (EFSU), and all other developing countries (LDCs). Production in each region is divided into twelve sectors. There are five energy sectors (electric utilities, natural gas utilities, petroleum processing, coal extraction, and crude oil and gas extraction) and seven non-energy sectors (mining, agriculture, forestry and wood products, durable manufacturing, non-durable manufacturing, transportation and services). This disaggregation enables us to capture the sectoral differences in the impact of alternative environmental policies.

Each economy or region in the model consists of several economic agents: households, the government, the financial sector and firms in the 12 production sectors listed above. The behavior of each type of agent is modeled. Each of the 12 sectors in each country in the model is represented by a single firm in each sector which chooses its inputs and its level of investment in order to maximize its stock market value subject to a multiple-input production function (defining technological feasibility) and a vector of prices it takes to be exogenous. For each sector, output is produced with inputs of capital, labor, energy, materials and a sector-specific resource. The nature of the sector specific resource varies across sectors. For example in the coal industry it is reserves of coal, in agriculture and forestry/wood products it is land which is substitutable between these two sectors.

Energy and materials are aggregates of inputs of intermediate goods. These intermediate goods are, in turn, aggregates of imported and domestic commodities which are taken to be imperfect substitutes.

The capital stock in each sector changes according to the rate of fixed capital formation and the rate of geometric depreciation. It is assumed that the investment process is subject to rising marginal costs of

Table 4
Overview of the G-cubed model

Regions

- United States
- Japan
- Australia
- Europe
- Rest of the OECD
- China
- Oil Exporting Developing Countries
- Eastern Europe and the former Soviet Union
- Other Developing Countries

Sectors

Energy

- Electric Utilities
- Gas Utilities
- Petroleum Refining
- Coal Mining
- Crude Oil and Gas Extraction

Non-energy

- Mining
- Agriculture, Fishing and Hunting
- Forestry/ Wood Products
- Durable Manufacturing
- Non-Durable Manufacturing
- Transportation
- Services

installation, with total real investment expenditures in each sector equal to the value of direct purchases of investment plus the per unit costs of installation. These per unit costs, in turn, are assumed to be a linear function of the rate of investment. One advantage of using an adjustment cost approach is that the adjustment cost parameter can be varied for different sectors to capture the degree to which capital is sector specific.

Households consume a basket of composite goods and services in every period and also demand labor and capital services. Household capital services consist of the service flows of consumer durables plus residential housing. Households receive income by providing labor

services to firms and the government, and from holding financial assets. In addition, they also receive transfers from the government. The household decision involves predicting expected future income from all sources (i.e. wealth) as well as current income. This information together with the relative prices of different goods and services then determine the pattern of consumption spending over time and the pattern of spending across the available goods.

It is assumed that the government in each country divides spending among final goods, services and labor according to the proportions in the base year input–output table for each country. This spending is financed by levying taxes on households and firms and on imports.

Households, firms and governments are assumed to interact with each other in markets for final goods and services; financial; and factor markets both foreign and domestic. The result of this interaction, given the desires of each economic entity, determine a set of relative prices that feed back into decision making by the different economic agents.

In summary, the G-Cubed model embodies a wide range of assumptions about individual behavior and empirical regularities in a general equilibrium framework. The complex interdependencies are then solved out using a computer. It is important to stress that the term “general equilibrium” is used here to signify that as many interactions are possible are captured, not that the economy is in a full market clearing equilibrium at each point in time. Although it is assumed that market forces eventually drive the world economy to a long run steady state equilibrium, unemployment does emerge for long periods due to different labor market institutions in different economies.

5. Some estimates of costs of Kyoto versus the Blueprint

In this section, we used the G-Cubed model to estimate the emissions reductions and changes in key economic variables that would arise under both the Marrakesh version of the Kyoto Protocol and the Blueprint.

5.1. Baseline business-as-usual projections

To solve the model, we first normalize all quantity variables by each 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

Table 5
Assumptions about population growth by country, 2000–2030

Region	2000–2010 (%)	2010–2020 (%)	2020–2030 (%)
USA	0.74	0.58	0.46
Japan	−0.09	−0.22	−0.28
Australia	0.84	0.55	0.37
Europe	0.05	−0.06	−0.11
Other OECD	0.63	0.35	0.20
China	0.89	0.67	0.50
Non-oil LDC’s	1.53	1.25	1.04
EEFSU	−0.16	−0.10	0.03
OPEC	1.59	1.29	1.13

percent, tax rates are held at their 1999 levels and that fiscal spending is allocated according to 1999 shares. Population growth rates vary across regions as per the 2000 World Bank population projections. Assumptions are contained in Table 5.

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).²⁵ 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 average rate of aggregate productivity growth over the past two decades. This approach attempts to capture the fact that the rate of technical change varies considerably across industries while reconciling it with regional differences in overall growth. This is clearly a rough approximation; if appropriate data were available it would be better to estimate productivity growth for each sector in each region.

Given these assumptions, we solve for the model’s perfect-foresight equilibrium growth path over the period 1999–2080. This a formidable task: the endogenous variables in *each* of the 82 periods number over 7000 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

²⁵ Estimated rates of US productivity growth, including total factor productivity growth and biases toward or away from specific factors, were obtained from Jorgenson et al. (1987). The values were then converted to equivalent increases in labor-augmenting productivity as described in Bagnoli et al. (1999). For a more detailed discussion of the importance of accounting for heterogeneity in sector-level productivity growth rates see Bagnoli et al. (1999).

all regions, and government deficits.²⁶ At the solution, the budget constraints for all agents are satisfied, including both intra-temporal and inter-temporal constraints.

5.2. Simulating the Kyoto Protocol and the Blueprint

Given the baseline scenario, we then impose the applicable post-COP7 Kyoto targets on each country or region.²⁷ In terms of the model's aggregation, we assume that Japan, Europe, Australia and the Rest of the OECD are part of the Kyoto permit trading system and have Kyoto targets. The United States and the remaining countries in the model have no targets. The targets are assumed to be binding from 2008 to 2012 and then continue after 2012 as the same target for emissions for the indefinite future. The permit price for each year is endogenous and is the value that clears the international market in emission permits. There is no banking or borrowing between years.

Fig. 1 contains the results for cumulative emissions from 1999 to 2015. Cumulative rather than annual emissions are compared because it is the cumulative emissions that matter for the climate. The first point to note is that relative to the unconstrained case, both the Kyoto and Blueprint alternatives have a relatively small impact on cumulative emissions. The Kyoto agreement, for example, reduces cumulative emissions over the period by less than 2 percent. This point can be made even more stark if we compare the impacts of both regimes on cumulative emissions since the industrial revolution.

The second point to note from Fig. 1 is that the nominal stringency of a climate policy is a poor indication of its effectiveness. A moderate policy, such as the Blueprint, can have a substantially larger effect on cumulative emissions than the Kyoto Protocol if it is enacted sooner and has broader participation. In other words, a modest policy that takes effect in the next few years and has relatively broad participation will do more to reduce climate change than the Kyoto Protocol, which constrains only a few countries and imposes its constraints a decade in the future.

Cumulative emissions under the Blueprint are lower than under the Kyoto Protocol because the Blueprint begins reducing emissions immediately, whereas the Kyoto Protocol does not restrain emissions until late in the 2008–2012 budget period (given the loosened targets

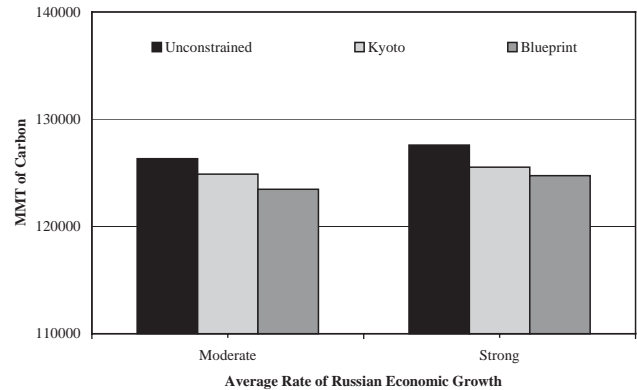


Fig. 1. Cumulative world carbon emissions, 1999–2015 by policy and rate of Russian economic growth.

and withdrawal of the United States). Moreover, the Blueprint simulation includes participation by the United States because the policy was designed to meet the key US objection to Kyoto. Expanding participation further—to developing countries, for example—would result in even larger gains relative to Kyoto.

The other major result from these simulations is the effect of each policy on each region's Gross National Product (GNP). Changes in GNP are a proxy for the welfare costs (reductions in GNP) or benefits (increase in GNP) generated by a policy. Fig. 2 contains results for each region expressed as the percent deviation of GNP under Kyoto or the Blueprint relative to the business as usual path. There are four lines in each chart representing the moderate and high Russian economic growth assumptions for the two policy regimes. For example, in the top right hand corner we show results for Japan. By 2010 GNP is close to 0.8 percent lower than baseline in the case of high Russian economic growth under Kyoto. This compares to a reduction of approximately 0.4 percent when Russian growth is moderate. Thus, a 1 percent increase in annual Russian economic growth for a decade would increase the cost of the Kyoto Protocol to Japan by 0.4 percent of baseline Japanese GNP. In contrast, Russian growth has so little effect on the costs imposed by the Blueprint that the scenarios are very difficult to distinguish on the graph. In either case, the change in Japanese GNP is less than 0.2 percent by 2010.

Fig. 2 shows several other important results as well. First, Japan is not unique: in other countries faster Russian growth also raises the GNP cost from Kyoto considerably with little effect on the cost of the Blueprint. Europe is an example: by 2015, the GNP loss from Kyoto would be as low as 0.8 percent or as high as 1.1 percent; the change in Russian growth, in other words, would raise the GNP cost of Kyoto by 38 percent. Compare this to the results for the Blueprint from which it is clear that: (1) the variation in the GNP effect is much smaller under the Blueprint than under

²⁶Since the model is solved for a perfect-foresight equilibrium over an 82 year period, the numerical complexity of the problem is on the order of 82 times what the single-period set of variables would suggest. We use software developed by McKibbin and Sachs (1991) for solving large models with rational expectations on a personal computer.

²⁷The targets are the COP3 values adjusted by sink allowances established during the Bonn and Marrakesh COP meetings. Non-Annex B countries have no targets.

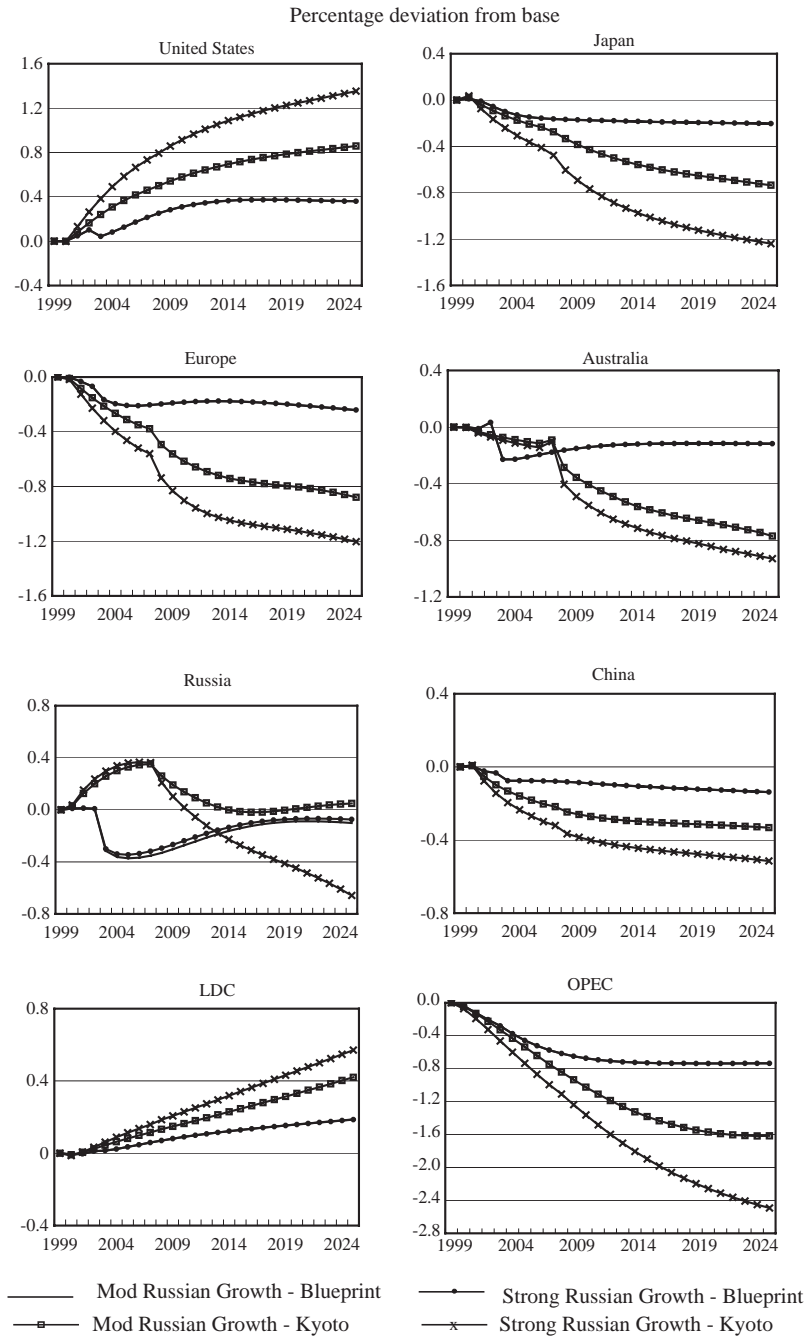


Fig. 2. Change in GNP under Kyoto and Blueprint. Percentage deviation from base.

Kyoto for all countries; and (2) the GNP loss is much lower for most countries than under Kyoto.

The first point is critical to understanding the opposition faced by the Kyoto Protocol in the US Senate and elsewhere: compliance costs are highly uncertain. Under the alternative Russian growth scenarios, the Kyoto permit price varies considerably. With high Russian economic growth, Russia will sell relatively few permits on the world market. As a result, all countries involved in permit trading will face a higher permit prices and will have higher compliance costs as a

result. Fig. 3 shows permit prices under the two assumptions. The relatively small increase in Russian economic growth is sufficient to raise the 2012 Kyoto permit price by about 50 percent: from \$US 19 to \$US 27. Under the Blueprint, in contrast, the costs are more certain because the policy includes a fixed upper bound on the annual price of an emissions permit.

In order to quantify the effect of uncertainty about Russian growth on the costs of the two policies, we compute the difference in the GNP effect between the two scenarios. The results are shown in Fig. 4 for Kyoto

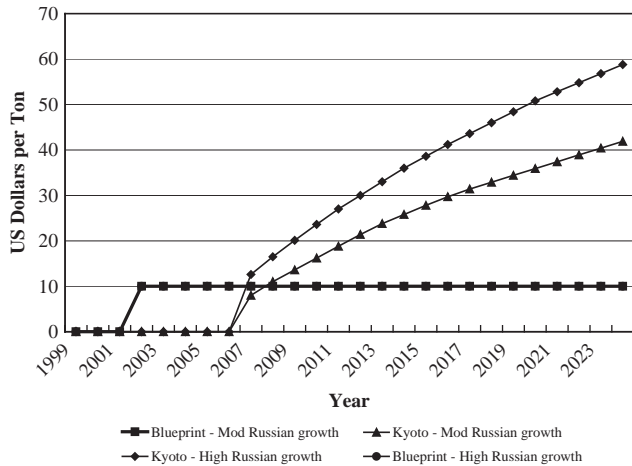


Fig. 3. Permit price.

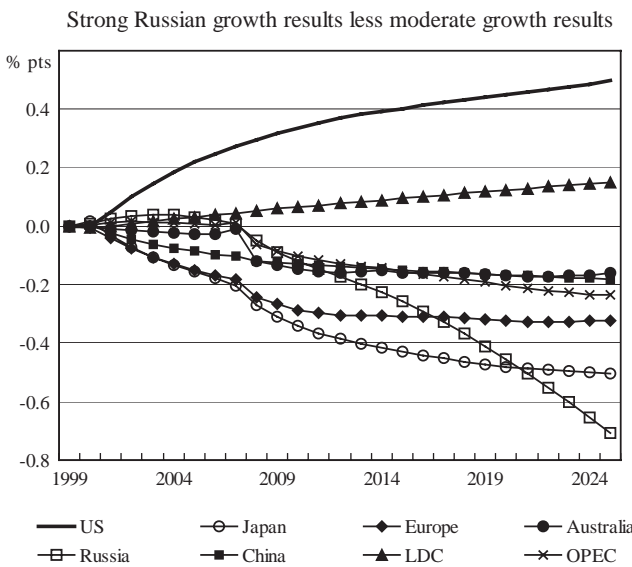


Fig. 4. Difference in GNP Effect of Kyoto. Strong Russian growth results less moderate growth results.

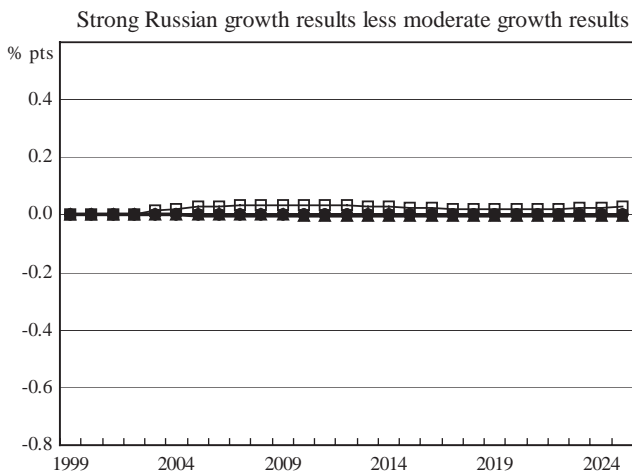


Fig. 5. Difference in GNP effect of the Blueprint. Strong Russian growth results less moderate growth results.

and Fig. 5 for the Blueprint. It is clear from these figures that a small change in a single assumption about Russian growth over a decade has a very large impact on the estimated costs of Kyoto. For example, in Europe the additional Russian growth raises the cost of Kyoto by 0.3 percent of GNP forever by 2010. In contrast, under the Blueprint the cost of the policy is almost invariant with respect to Russian economic growth. This illustrates the fundamental strength of the Blueprint and weakness of the Kyoto Protocol.

6. Conclusion

The Kyoto Protocol never had much chance of reducing greenhouse gas emissions significantly because its design was deeply flawed. Following the withdrawal of the United States and the weakening of the protocol’s targets at COP6bis and COP7, it is likely to do nothing to reduce global emissions through the end of the 2008–2012 commitment period. The protocol’s core flaw is its focus on “targets and timetables” that, in effect, require participants to agree to reduce greenhouse gas emissions to specified levels regardless of the cost. Our results confirm that the costs of the protocol are very sensitive to key economic variables that cannot be predicted with any precision. A single, modest change in projected productivity growth in Russia changes the costs of the protocol substantially. Many other variables would have similarly large effects. In order to ratify the protocol, therefore, a country must be willing to undertake an uncertain and possibly very expensive commitment. Moreover, unexpected future changes in economic conditions could raise the cost of the protocol sharply, which would create strong pressures for participating countries to withdraw at that point. In short, the protocol’s emphasis on emissions targets undermines participation for two reasons: (1) it discourages countries from ratifying the agreement; and (2) it causes the protocol to be particularly vulnerable to future events.

The Blueprint policy, in contrast, is more attractive to initial participants because it does not require an open-ended commitment, and it is more sustainable over long periods because future events have little effect on compliance costs. The Blueprint, in other words, is transparent: the upper bound on annual permit prices allows a potential participant to determine its maximum compliance costs in any future period without having to know in advance how the myriad uncertainties surrounding climate change will be resolved. A country considering participation in the agreement will know exactly what to expect and will have little reason to abandoning the policy later. Moreover, the Blueprint has the potential to achieve greater cumulative emissions reductions than the Kyoto Protocol, and to achieve them at lower cost, because it would encourage wider

participation and earlier reductions. Overall, it is a viable and promising alternative to the Kyoto Protocol.

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References

- Bagnoli, P., McKibbin, W.J., Wilcoxon, P.J., 1999. Global economic prospects: medium term projections and structural change. In: Lo, F.C., Morita, T., Shishido, S. (Eds.), *The Sustainable Future of the Global System*. The United National University, Tokyo.
- Bohringer, C., 2001. Climate policies from Kyoto to Bonn: from little to nothing? *ZEW Discussion Paper No. 01-49*, Mannheim.
- Buchner B., Carraro, C., Cersosimo, I., 2001. On the Consequences of the US Withdrawal from the Kyoto/Bonn Protocol. Paper Presented at the 17th Annual Congress of the European Economic Association, Venice, August 2002.
- Hoel, M., Karp, L., 2002. Taxes vs. quotas for a stock pollutant. *Resource and Energy Economics* 24, 367–384.
- Intergovernmental Panel on Climate Change, 2001. *Climate Change 2001*, 3 volumes. Cambridge University Press, Cambridge
- Jorgenson, D.W., Wilcoxon, P.J., 1990. Environmental regulation and US economic growth. *The Rand Journal* 21 (2), 314–340.
- Jorgenson, D.W., Gollop, F.M., Fraumeni, B.M., 1987. *Productivity and US Economic Growth*. Harvard University Press, Cambridge.
- Kemfert, C., 2001. Economic effects of alternative climate policy strategies. FEEM Working paper 85.01, Milan.
- Löschel, A., Zhang, Z.X., 2002. The economic and environmental implications of the US repudiation of the Kyoto Protocol and the subsequent deals in Bonn and Marrakech. *Weltwirtschaftliches Archiv—Review of World Economics* 138 (4), 711–746.
- McKibbin, W.J., Sachs, J., 1991. *Global Linkages: Macroeconomic Interdependence and Cooperation in the World Economy*. The Brookings Institution, Washington.
- McKibbin, W.J., Wilcoxon, P.J., 1997. A better way to slow global climate change. *Brookings Policy Brief no. 17*, June. The Brookings Institution, Washington.
- McKibbin, W.J., Wilcoxon, P.J., 1998. The theoretical and empirical structure of the G-cubed model. *Economic Modelling* 16 (1), 123–148.
- McKibbin, W.J., Wilcoxon, P.J., 2002a. *Climate Change Policy After Kyoto: A Blueprint for a Realistic Approach*. The Brookings Institution, Washington.
- McKibbin, W.J., Wilcoxon, P.J., 2002b. The role of economics in climate change policy. *Journal of Economic Perspectives* 16 (2), 107–130.
- McKibbin, W.J., Ross, M., Shackleton, R., Wilcoxon, P.J., 1999. Emissions Trading, Capital Flows and the Kyoto Protocol. *The Energy Journal (Special Issue on “The Costs of the Kyoto Protocol: A Multi-model Evaluation”)*, 287–334.
- Newell, R.G., Pizer, W.A., 1999. *Regulating stock externalities under uncertainty*. Resources for the Future Discussion Paper 99-10, Resources for the Future, Washington.
- Nordhaus, W.D., Boyer, J.G., 1999. Requiem for Kyoto. *Energy Journal (Special Issue on “The Costs of the Kyoto Protocol: A Multi-model Evaluation”)*, 93–130.
- Pizer, W.A., 1997. Prices vs. quantities revisited: the case of climate change. Resources for the Future Discussion Paper 98-02, Resources for the Future, Washington.
- Roberts, M.J., Spence, A.M., 1976. Effluent charges and licenses under uncertainty. *Journal of Public Economics* 5, 193–208.
- Tol, R.S.J., 1999. Kyoto, efficiency, and cost-effectiveness: applications of FUND. *Energy Journal (Special Issue on “The Costs of the Kyoto Protocol: A Multi-model Evaluation”)*, 131–156.
- Weitzman, M.L., 1974. Prices vs. quantities. *Review of Economic Studies* 41, 477–491.
- Weyant, J. (Ed.), 1999. *The costs of the Kyoto Protocol: a multi-model evaluation*. The Energy Journal, Special Issue.
- Zhang, Z.X., 2000. Estimating the size of the potential market for the Kyoto flexibility mechanisms. *Weltwirtschaftliches Archiv—Review of World Economics* 136 (3), 491–521.
- Zhang, Z.X., 2001. An assessment of the EU proposal for ceilings on the use of Kyoto flexibility mechanisms. *Ecological Economics* 37 (1), 53–69.