Building on Kyoto: Towards A Realistic Global Climate Agreement[*]

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1 Introduction

As a mechanism for controlling climate change, the Kyoto Protocol has not been a success. Over the decade from its signing in 1997 to the beginning of its first commitment period in 2008, greenhouse gas emissions in the industrial countries subject to targets under the protocol did not fall as the protocol intended. Instead, emissions in many countries rose rapidly. It is now abundantly clear that as a group, the countries bound by the protocol have little chance of achieving their Kyoto targets by the end of the first commitment period in 2012. Moreover, emissions have increased substantially as well in countries such as China, which were not bound by the protocol but which will eventually have to be part of any serious climate change regime.

Although the protocol has not been effective at reducing emissions, it has been very effective at demonstrating a few important lessons about the form future international climate agreements should take. As negotiations begin in earnest on a successor agreement to take effect in 2012, it is important to learn from experience with the Kyoto Protocol in order to avoid making the same mistakes over again and to design a more durable post-2012 international agreement.

The first lesson is that a rigid system of targets and timetables for emissions reductions is difficult to negotiate because it pushes participants into a zero sum game. To reach a given target for global greenhouse gas concentrations, for example, countries must negotiate over shares of a fixed budget of future global emissions. A looser target for one country would have to be matched by a tighter target for another. It is clear that this has been an important obstacle for much of the history of negotiations conducted under the auspices of the United National Framework Convention on Climate Change, not just the Kyoto Protocol. From the beginning, developing countries have refused to participate in dividing up a fixed emissions budget. Not only that, but many observers have argued that if such a budget were ever to be divided, it should be done on the basis of population rather than the historical emissions which were the basis of the Kyoto Protocol.

A second lesson is that it is difficult for countries to commit themselves to achieving specified emissions targets when the costs of doing so are large and uncertain. At its core, the targets and timetables approach requires each participant to achieve its national emissions target regardless of the cost of doing so. Countries facing potentially high costs either refused to ratify the protocol, such as the United States, or simply failed to achieve their targets. Countries on track to meet their obligations were able to do so because of historical events largely unrelated to climate policy, such as German reunification, the Thatcher government's reform of coal mining in Britain, or the collapse of the Russian economy in the early 1990's.

The third lesson is perhaps the most important of all: even countries earnestly engaged in a targets and timetables process may be unable to meet their targets due to unforeseen events. Two excellent examples are New Zealand and Canada. No one anticipated during the 1997 negotiations that a decade later New Zealand would be facing a dramatic rise in Asian demand for beef and diary products. The impact on increasing methane emissions in New Zealand has been so large that it has completely offset the reductions New Zealand was able to achieve in the earlier 1990's via reduced methane from declining numbers of sheep and improved sinks of carbon due to growth in forestry. Similarly, no one expected that Canada would find its tar sand deposits so valuable that extraction would be viable at oil prices reached two years ago let alone at current world oil prices.

One reason there has been so much interest in a targets and timetables strategy has been a widespread misunderstanding about the precision of scientific knowledge regarding the climate. It is widely agreed among atmospheric scientists that atmospheric concentrations of greenhouse gases are rising rapidly, and that emission should be reduced.[1] However, there is little agreement about how much emissions should be cut in any given year, and there is no guarantee that stabilizing at any particular concentration will eliminate the risk of dangerous climate change. Yet it is often implied that climate science translates directly into a specific emissions target and a fixed emissions budget.[2] On the contrary, however, the uncertainties still remaining in the science are important and should be a core consideration in the design of climate policy.

All of the lessons above illustrate problems inherent in the targets and timetables approach. First, it forces countries into confrontations during negotiations over shares of a fixed global emissions budget. Second, committing to achieve a rigid emissions target is difficult for countries facing uncertain and potentially very high costs. Third, unexpected events can force even well-intentioned participants into non-compliance. In the face of these problems, some observers have argued that the solution is more of the same: a broader protocol with tighter targets and deeper cuts. However, there is little reason to expect the outcome to be any different, and in the mean time emissions will continue to rise. A better approach would be to recognize that focusing on targets and timetables has undermined the ultimate goal of actual emissions reductions, and that it is critical to move negotiations in a new direction. The Hokkaido Summit to be held in Japan this year is an important opportunity to make that shift, and to move the focus of climate change negotiations in a more realistic direction.

In this paper, we discuss an alternative framework for international climate policy, the McKibbin-Wilcoxen Hybrid[3] - an approach that focuses on coordinated actions rather than

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1 See the IPCC (2007).

2 For example, the UK Stern Review (2007) and the Australian Garnaut Review (2008) acknowledge the uncertainties but then somehow move from uncertain science to certainty in the emissions target or budget required over time.

3 Also known as the McKibbin-Wilcoxen Blueprint.

mandated, inflexible outcomes. Rather than committing to achieve specified emissions targets, participating countries would agree to adopt coordinated actions that are clear, measurable and enforceable within national borders. Because it does not start from a fixed emissions target (although an emissions budget does guide the design of the actions we propose), the Hybrid avoids all three of the problems discussed above. Shifting to an approach based on agreed actions, rather than specific emissions outcomes, will be a critical step in the evolution of climate negotiations. It will also make national policy actions more feasible than fixed target, since a target would be little more than a hopeful pledge given how little is known for certain about the costs of reducing emissions.

Moreover, a framework based on common actions rather than common targets is particularly useful for accommodating the needs of developing countries. Developing countries face even greater uncertainty about their future economic growth prospects and future emissions paths than developed countries, and certainly do not want to undermine their development prospects by committing to an excessively stringent emissions target.

To illustrate the differences between the targets and timetables approach and one based on the Hybrid, we present a number of numerical simulations of the world economy using the G-Cubed global economic model. We focus particular attention on two of the problems with targets and timetables: the high stakes involved in negotiating over emissions budgets, and the risks stemming from uncertainty about costs. We first show that the outcome of a Kyoto-style targets and timetables policy with global emissions trading depends significantly on the allocation scheme for the emissions targets. We present one set of results using an allocation based on historical emissions and another set of results based on an equal per capita allocation. The results show how different the national costs of the policy will be depending on how emissions rights are allocated. We then examine the performance of the Kyoto-style allocation under one source of uncertainty: the rate of growth in developing countries, particularly China and India.

2 The Impact of Uncertainty in a Targets-and-Timetables System

In this section we use a global economic model called G-Cubed to explore the uncertainty in costs for different countries. The G-Cubed model is summarized in Table 1, with greater detail provided in the Appendix. It is a widely-used dynamic intertemporal general equilibrium model of the world economy with 10 regions and 12 sectors of production in each region. It produces annual results for trajectories running decades into the future. In this paper, we present a new version of G-Cubed (80J) that has been extended to India as a separate region.

We explore a number of issues in this section. First we assemble a set of business-as-usual (BAU) projections about population growth, productivity growth by sector, energy efficiency improvements by sector and by country, monetary policy and fiscal policy settings, and so on. Given these assumptions, we then solve the model for a trajectory running from 2002 out 150 years into the future. The outcomes for emissions in this baseline from 2008 to 2050 are shown for each region in the model in Figure 1 (the diamond line marked BAU). We then make assumptions about the emissions targets that will be achieved by each country under a scenario described in more detail below, and add up those emissions to determine a corresponding global target. This target is similar to the target used in the April 2008 IMF World Economic Outlook, in which emissions from fossil fuel combustion rise for several decades, peak around 2028, and then fall to 60% below 2002 emission by 2100. The profile is such that by 2050 most countries have returned to just below their 2008 emissions. After that, emissions fall sharply.

Table 1: Overview of the G-Cubed Model (Version 80J)

Regions	
1	United States
2	Japan
3	Australia
4	Europe
5	Rest of the OECD
6	China
7	India
8	Oil Exporting Developing Countries
9	Eastern Europe and the former Soviet Union
10	Other Developing Countries
Sectors	
Energy:	
1	Electric Utilities
2	Gas Utilities
3	Petroleum Refining
4	Coal Mining
5	Crude Oil and Gas Extraction
Non-Energy:	
6	Mining
7	Agriculture, Fishing and Hunting
8	Forestry/ Wood Products
9	Durable Manufacturing
10	Non-Durable Manufacturing
11	Transportation
12	Services
Other:	
13	Capital Producing Sector

The first simulation to be evaluated is the case where each country sets a price domestically to exactly reach the target path shown in Figure 1. This can be done either with a domestic tax, a domestic cap and trade policy, or a mix of the two policies such as the McKibbin-Wilcoxen Hybrid. The prices which emerge from these national actions are shown in Figure 2. The prices start low and rise over time, reflecting the nature of the targets that were specified. The targets are close to BAU emissions initially but then force emissions below BAU, as shown in Figure 1. Prices in Figure 2 reflect both the marginal abatement costs in each country (the cost of removing a unit of carbon from the economy) and the extent of BAU emissions growth. For example, the highest cost of carbon occurs in OPEC economies where there both a high cost of removing carbon from the economy and relatively high economic growth. Next highest is the LDC block, where there is strong economic growth along the baseline. The lowest carbon prices are found in the USA.

These results show what would happen if an international permit-trading regime were to be imposed. If the initial permit allocation were along the predetermined target paths (similar to the Kyoto-style approach where recent history drives the allocation), then countries with high costs will tend to buy permits. Countries with low costs will tend to abate and sell permits to high-cost economies. (A vastly different initial allocation of permits will change the direction of flow of permits, as will be discussed below.) The third line (triangles) in Figure 1 shows emissions within each economy once trading across borders is allowed. In this case the United States does more abatement than it would under the target policy and Japan does less. Japan, which has high abatement costs, is able to buy emissions permits from the US, which can abate at lower cost. A similar pattern emerges globally. Surprisingly, funds tend to flow from high abatement cost regions such as Europe, Japan and Australia to low abatement cost regions such as the United States and former Soviet Union within the Annex 1 countries. Perhaps even more surprising are the purchases by the LDC region (which includes Korea, Taiwan and a variety of developing countries). These purchases mostly reflect the high growth profile we assumed in the BAU and is very sensitive to the underlying baseline assumptions. It is important to stress that the outcome of the global system is very sensitive to a range of assumptions in the model, which itself illustrates just how uncertain the costs of achieving a particular target path for emissions will actually be.

The change in gross domestic product (GDP) as a result of the implementation of the carbon abatement policy is shown next in Figure 3. This shows results for two cases: when each country follows its own specific target (labeled “Target” and shown with square symbols), and when the countries can trade emissions permits in a global system (labeled "Trading" and shown with triangle symbols). It is clear that allowing trade reduces the GDP loss for high-cost economies and increases the GDP loss for low-cost economies. Note that the losses for Australia are significantly larger than for other economies. This is due to the impact of carbon pricing in other countries on Australian exports to these countries, particularly of coal and other fossil fuel intensive industries. These losses reflect the actions taken in other economies that reduce the demand for these exports from Australia. In fact most of the loss in GDP for Australia is due to the actions taken by other countries rather than the pricing of carbon within the Australian economy.

GDP is not a measure of well-being, however, because GDP reflects production rather than income (and is a poor measure of economic welfare for other reasons as well). Figure 4 shows the outcome for gross national product (GNP) which includes payments for permits by foreigners. Three sets of results are shown: those for country-specific targets; for trading; and for a third regime, to be discussed below, that is based on per-capita emissions allocations. Some results stand out. When Japan is allowed to buy permits, its GDP loss is reduced because reductions that would have been very expensive in Japan are replaced by cheaper reductions made in other countries. However, once income transfers are taken into account – as captured in the GNP results – the gains from trading are much less. Note that the same global environmental outcome occurs under each scenario, so the changes in GNP provide an appropriate relative measure of well-being.

These results show the usual insight that emissions trading helps to minimize the cost of achieving a fixed emissions target, even when allowances are not initially distributed in a pattern that would result in efficient abatement. Thus, economists have often advocated a global permit trading system as a way to reach a given reduction target at lowest global economic cost. The problem, however, is that under uncertainty countries do not know the magnitude of the costs with any precision, and are therefore reluctant to take to first step in reducing emissions.

This uncertainty is everywhere in the global economy, but now we focus on two issues that are relevant for the actual negotiations. First is the question of the initial allocation of permits. In the benchmark trading regime we used stylized allocations that are roughly consistent with historical emissions adjusted over time along the target path of reductions. We also considered a different allocation – distributing permits on a per-capita basis – which is often discussed in the literature. In that case, we took the global target path for emissions and allocated permits to countries at each point in time in proportion to their populations. The global target is the same as in the previous case, but the allocations of permits differs substantially.

Table 2: Allocations of Emissions Permits, in Millions of Metric Tons of Carbon Dioxide

Region	BAU 2013	Per Capita 2013		BAU 2040	Per Capita 2040
USA	6695	1502		6169	1484
Japan	1398	588		1286	414
Australia	415	103		385	104
Europe	4150	1713		3816	1429
Other OECD	666	296		618	278
China	8375	6321		9099	5197
India	1733	5852		1945	6045
Non-Oil LDCs	5139	12875		5930	14792
EEFSU	2860	1075		2726	758
OPEC	1690	2797		1587	3061
Total	33121	33121		33562	33562

Source: Model Simulations and UN Population Medium Term Projections, 2005

Table 2 shows the allocations for each region in 2013, when the system takes effect, and then again in 2040. The allocations under the BAU column show the total allocation to each country based on the target path specified for the country. The values under "per capita" show the total allocation for each country if per capita rights (adjusted along the target path) are used. Both columns have the same total but the distribution across countries differs. In the BAU case, emissions are divided based on the share of emissions in world emissions at each point in time. For the per capita case, world emissions are divided up based on the share of world population of each region. Under the per-capita scheme, the target emissions, the allocation to advanced economies falls significantly, whereas for most developing economies the allocation rises significantly. Interestingly, for China the initial allocation falls slightly because China is already receiving a large allocation by 2013 under the BAU approach. The model predicts an enormous growth in emissions from China from 2002 to 2012. The changing population composition over time also has an impact on the scale of allocation in per capita terms. For India the changing per capita allocation leads to a rising total emission allocation over time because of rising population whereas for China the allocation by 2040 is lower than in 2013 because of a declining population in the UN population data for China. According to this data the population of India overtakes the population of China by 2022.

Results for the differences between economic outcomes for the two permit allocation assumptions are contained in Figure 4. This shows GNP changes under the country specific target (“Target” - squares) versus the case when the allocation is BAU (“Trading” - triangles) and an alternative where the allocation is on a changing per capita basis (“Trading per capita” – diamond). The basic economics for reductions across countries is not changed much by the allocation mechanism since carbon prices at the global level have a similar impact. What changes are the transfers of wealth across borders. Countries that need to buy permits (generally the advanced economies) now need to spend more because their initial allocation is smaller than in the BAU case. This transfer of resources across borders does change the price of abatement as well as the GDP loss within each country due to the different spending patterns of countries globally. However this effect is small relative to the consequences of the income changes across borders. Note that by 2050 for the Unites States the different allocation mechanism has changed the GNP loss by 25% from -1.5% to -2% of GDP per year. For developing economies (except China) there are significantly lower GNP losses under a per capita allocation. For India there is a GNP gain because the transfers of income from other countries buying permits from India offset the domestic economic losses. Interestingly, China is worse off under the per-capita allocation because it receives a lower permit allocation than it would under the BAU scenario. This result for China is the opposite to that found in the IMF World Economic Outlook using the same economic model. The reason is that different assumptions about growth in China were used in the IMF study. The model's results are highly sensitive to assumptions made about overall growth and the sources of growth in each economy.

This section has illustrated the uncertainties inherent in projecting the future of the world economy, and in assessing the costs of climate policies based on targets and timetables. It is not surprising that negotiations over the targets and the allocation of emission rights have led to a stalemate in actual reductions for so many years. It is also not surprising that the domestic policy debates in many countries regarding climate policy have been so divisive since they have been couched in terms of target and timetables or "cap and trade" permit systems: no one knows what these policies will cost with any certainty. In the next section we present a route out of this quandary: a different strategy for climate policy at the global and national level.

3 An Alternative Approach: Coordinating Prices via a Hybrid Policy

As noted in the introduction, many of the problems posed by a rigid system of targets and timetables could be avoided by moving to a system of coordinated actions. One example of such a policy would be an internationally-coordinated system of national carbon taxes. However, carbon taxes potentially involve large transfers of wealth within countries, often making them difficult to establish. Moreover, even when a tax could be put in place, the transfers it would induce would create strong political pressure for it to be relaxed or repealed. Some countries have ruled out a tax approach, which makes negotiating a global tax strategy unrealistic. A hybrid policy, however, could combine the best features of taxes and tradable permits. It would address many of the problems that industry dislikes about carbon taxes and many of the problems of uncertain costs and price volatility that arise under a cap and trade permit system.

A hybrid policy for climate change was first proposed by McKibbin and Wilcoxen (1997) and is discussed in detail in McKibbin and Wilcoxen (2002a, 2002b). This policy combines a limited supply of long-term permits good for multiple years with a much more flexible supply of annual permits. Both types of permit are only valid in the country of issue: there is no trade across borders. Every year, firms would be required to hold a portfolio of permits equal to the amount of carbon they emit.[4] The portfolio could include any mix of long-term and annual permits. The long-term permits could be owned outright by the firm, or they could be leased from other permit owners. In the sections below we discuss each type of permit in more detail.

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4 This approach is known as a downstream policy because it applies to fuel users. It would also be possible to apply the policy upstream by imposing limits on the carbon embodied in fuels when they are produced (e.g., at the mine mouth or wellhead).

3.1 Long Term Permits

A country adopting the hybrid policy would create and distribute a set of long-term permits, each entitling the owner to emit a specified amount of carbon every year for the life of the permit. The simplest long-term permit would have no expiration date and would allow one ton of emissions every year forever. A more sophisticated alternative would be to issue long-term permits with a variety of expiration dates, much the way governments now issues bonds. For example, a country wishing to distribute 100 long-term permits might chose to issue 20 of them as perpetual permits, 40 as permits expiring in 50 years, and the remaining 40 as permits expiring in 20 years. In essence, this approach would create a family of assets with a term structure of expiration dates.[5] The supply of long-term permits would reflect the country's announced target path for emissions reductions.

Just as the expiration date of the permits can be varied, so could be the amount of emissions each permit allows at each point in time.[6] For reasons we will return to later in the paper, governments might find it useful to have the amount of emissions allowed by a long-term permit decline over the permit's life. For example, a permit might allow 1 ton of emissions per year for the first 20 years after it is issued, 75% of a ton during years 21-40, 50% of a ton in years 41-60, 25% of a ton after that. It would be analogous to distributing bundles of permits with varying expiration dates: an equivalent bundle would consist of four 0.25 ton permits: one valid for 20 years, one for 40 years, one for 60 years, and one valid in perpetuity. Computing the market value of such permits would be more complex than valuing permits allowing one ton per year. However, the added complications would be minimal as long as all long-term permits had the same issue and expiration dates, and hence

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5 Nicholas Gruen and Geoff Francis have made similar suggestions to us along these lines.

6 We are indebted to Rob Stavins for pointing out that long term permits need not allow constant emissions over their lifetimes. As we will discuss later in the paper, this feature would play a crucial role in the evolution of a hybrid system over time.

allowed identical paths of future emissions.[7] Moreover, this approach has a very significant advantage relative to a system of one-ton permits with varying expiration dates: all long-term permits would be identical, and would hence trade in a single market at a single price.

When initially distributed, the long-term permits could be given away, auctioned, or distributed in any other way the government of the country saw fit. One option would be to distribute them for free to industry in proportion to their historical fuel use. For example, a firm might receive permits equal to 90% of its 1990 carbon emissions. Such an approach would be relatively transparent and would limit the incentives for lobbying by firms. It is important to note that although the allocation would be based on historical emissions, the policy would not have the disadvantages of a traditional grandfathering scheme. Because the permits are completely tradable and are not tied in any way to the original recipient or any particular plant, they do not create differences in marginal costs across firms or plants. Moreover, the existence of annual permits limits the ability of incumbent firms to create entry barriers by keeping their long-term permits off the market: entrants could simply buy annual permits. Incumbent firms would benefit financially from the initial distribution of permits, but unless they were previously liquidity-constrained, they would not be able to use their gains to reduce competition.[8] Permits could also be allocated to individuals as compensation for the higher energy costs they would face in future years. This form of compensation would be transparent and politically attractive in many countries.

Another alternative would be to auction the permits. However, from the point of view of the energy industry, auctioned permits would be exactly like a carbon tax except with an added disadvantage: the industry would have to pay the entire present value of all future

7 Varying *both* attributes of long term permits (the expiration date and the time path of allowed emissions) would be a mistake. It would create unnecessary transactions costs by fracturing the long term permit market into many submarkets.

8 In passing, it's worth noting that anti-competitive behavior by the incumbents, while unlikely, would have an environmental benefit: it would reduce overall carbon emissions.

carbon taxes up front. To see why, suppose the number of long-term permits to be issued is small enough that at least a few annual permits would be sold in every year. The price of a permit during the auction would be bid up to the present value of a sequence of annual permit purchases. As far as the industry is concerned the policy would be equivalent to a carbon tax set at the annual permit price, except that it would have to pay the entire present value of all future tax payments on the emissions allowed by the permit at the time of the auction.

Once distributed, the long-term permits could be traded among firms, or bought and retired by environmental groups. The permits would be very valuable because: (1) there would be fewer available than needed for current emissions, and (2) each permit allows annual emissions over a long period of time. As a consequence, the owners of long-term permits would form the private-sector interest group needed for long-term credibility of the policy: they would have a clear financial interest in keeping the policy in place.

3.2 Annual Permits

The other component of the policy, annual emissions permits, would be straightforward: the government would agree to sell annual permits for a specified fee, say for $20 per ton of carbon. There would be no restriction on the number of annual permits sold, but each permit would be good only in the year it is issued. To put the fee in perspective, $20 dollars per ton of carbon is equivalent to a tax of about $12 per ton of coal and $3 per barrel of crude oil; other things equal, the price of a $44 ton of coal would rise by about 25% and the price of a $100 barrel of oil would rise by about 2%. The annual permits give the policy the advantages of an emissions tax: they provide clear financial incentives for emissions reductions but do not require governments to agree to achieve any particular emissions target regardless of cost.

3.3 International Cooperation and Harmonization

A key feature of the hybrid policy we propose is that emissions permits would be valid only in the country of issue. They would not be tradable internationally—permits issued in one country could not be used to cover emissions in another country.[9] Each country would manage its own domestic hybrid policy using its own existing legal system and financial and regulatory institutions. There would be no need for complex international trading rules, or for the creation of a powerful new international institution, or for participating governments to cede a significant degree of sovereignty to an outside authority. As a result, a treaty built around the hybrid policy would be very simple and would focus primarily on harmonizing the price of annual permits across participating countries.[10] To join the agreement, a country would establish a hybrid permit system and agree to charge the price for annual permits that would be specified in the treaty. Unlike an agreement focused on achieving a national emissions target, governments would be making commitments that are within their direct control.

Easy accession is very important. To be effective in the long run, the agreement will eventually need to include all countries with significant greenhouse gas emissions. However, it is unlikely that all countries will choose to participate at the beginning. Developing countries, for example, have repeatedly pointed out that current greenhouse gas emissions are overwhelmingly caused by industrialized countries, and that those countries, therefore,

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9 Strictly speaking, the term "country" is too narrow. The permits would be valid only within the political jurisdiction of issue. If the relevant jurisdiction is multinational—the EU, for example—permits could be traded between countries within the broader jurisdiction.

10 Because the core of the treaty would be the price of annual permits, it would be relatively straightforward to negotiate: only one key number is really involved. That is not to say, however, that negotiations would be trivial: getting agreement on the annual price would require considerable diplomacy. It is interesting to note that a treaty of this form has a strong built-in incentive for countries to participate in the initial negotiations. Countries that participate will have a role in setting the annual price while those who remain on the sidelines will not. We are indebted to Jonathan Pershing for pointing this out.

should take the lead in reducing emissions. As a result, an international climate policy will need to cope with gradual accessions taking place over many years. Its design, in other words, must be suitable for use by a small group of initial participants, a large group of participants many years in the future, and all levels in between. Because it is fundamentally a harmonized system of domestic policies, rather than a monolithic international policy, our hybrid proposal has exactly the flexibility needed. A country can participate by simply adopting the hybrid domestically, without any need for international negotiations.

Beyond specifying the price of annual permits, the treaty could provide a guideline for governments to use in determining the number of long-term permits to issue. It could, for example, suggest that signatories distribute no more long-term permits than their allotments under the Kyoto Protocol. However, governments wishing to tackle climate change more aggressively could choose to distribute fewer long-term permits.[11] Moreover, governments that for one reason or another would prefer a carbon tax could distribute no long-term permits at all.[12] The treaty does not need to specify rigid allocations of long-term permits because emissions will generally be controlled at the margin by the price of annual permits. As long as each country distributes few enough long-term permits that at least one annual permit is sold, the number of long-term permits only affects the distribution of permit revenue between the private sector and the government; it does not affect the country's total emissions. Distributing a small number of long-term permits means the government will earn a lot of revenue from annual permit sales, but it also means that the lobby group supporting the policy will be weak. Distributing a larger number means less government revenue and a

11 Countries have different degrees of concern about climate change and different abilities to implement climate policies. A coordinated system of hybrid policies provides participants with the ability to tailor the policy to their own circumstances.

12 A government might prefer a carbon tax if it lacks the institutional and administrative mechanisms needed to operate a permit market.

stronger supporting lobby. In either case, one country's decision has little effect on other signatories.

One important role for the treaty's long-term permit guidelines would be to distinguish between developed and developing countries. Developing countries could be allowed to distribute more long-term permits than needed for their current carbon emissions. In that case, a country adopting the treaty would be committing itself to slowing carbon emissions in the future, but would not need to reduce its emissions right away. As the country grows, its emissions will approach the number of long-term permits. The market price of long-term permits would gradually rise, and fuel users would face increasing incentives to reduce the growth of emissions[13].

A generous allotment of long-term permits would reduce the disincentives faced by developing countries, but that alone might not be enough to induce widespread participation. If stronger incentives are needed, it would be possible to augment the treaty with a system of foreign aid payments or with programs for technology transfer to participating developing countries. In any case, the result would be more transparent and more attractive to developing countries than the Kyoto Protocol, which essentially requires that compensation payments from developed to developing countries be in-kind, in the form of improved energy technology.

3.4 Advantages of Separate Markets

Because the permit markets under this policy are separate between countries, shocks to one permit market do not propagate to others. For example, accession by a new participant has no effect on the permit markets operating in other countries. Similarly, if a participating country withdraws from the agreement or fails to enforce its hybrid policy, permit markets in

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13 An illustration of how this would work in China is given in McKibbin, Wilcoxen and Woo (2008).

other countries are also unaffected.[14] Collapse of one or more national permit systems would be unfortunate in terms of emissions control, but it would not cause permit markets in other countries collapse as well. Separate permit markets are, in essence, a form of compartmentalization that lends stability to the international agreement. In contrast, under an international trading agreement, such as the Kyoto Protocol, shocks in one country—ineffective enforcement, or withdrawal from the agreement, for example—would cause changes in permit prices around the world. Permit owners would receive windfall gains or losses and permit users would be faced with volatile and unpredictable permit prices. From the perspective of both permit owners and permit users, investments in emissions reductions would be more risky.

Compartmentalization is especially important for a climate change agreement, which must endure for many, many years. Not only must it be able to survive noncompliance by some of its members, it must be able to able to survive through economic booms and busts; through wars and pandemics; and through times of low concern about the environment as well as in times of high concern. Moreover, because of the uncertainties surrounding climate change, it must also survive through intervals where warming seems to be proceeding more slowly than expected and there could be political pressure to abandon the agreement on the grounds that it isn't necessary. Such intervals could arise because of random fluctuations in global temperatures from year to year, or because the policy is actually succeeding in reducing the problem. The latter point is worth emphasizing: if a climate regime is successful at reducing warming and preventing significant damages, it will be easy for complacency to arise: many people may interpret the absence of disasters to mean that the risks of climate

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14 In contrast, a conventional international permit system could be particularly difficult to enforce because of the links it creates between countries. Restricting sales of permits by non-complying countries, as would be required under the Kyoto Protocol, would harm the interests of compliant countries by raising permit prices. The international links between permit markets thus provide a strong incentive against enforcement of the agreement.

change were overstated.

Another advantage of multiple national permit markets, rather than a single international one, is that individual governments would have little incentive to monitor and enforce an international market within their borders. It is easy to see why: monitoring polluters is expensive, and punishing violators would impose costs on domestic residents in exchange for benefits that will accrue largely to foreigners. There would be a strong temptation for governments to look the other way when firms exceed their emissions permits. For a treaty based on a single international market to be effective, therefore, it will need to include a strong international mechanism for monitoring compliance and penalizing violations. National permit markets reduce the problem substantially because monitoring and enforcement becomes a matter of enforcing the property rights of a group of domestic residents—the owners of long-term permits—in domestic markets.

One possible disadvantage of separate permit markets is that the prices of long-term permits might differ between countries. If so, the overall policy would not be minimizing the cost of abatement: it would be possible to lower overall abatement costs by doing more abatement in countries where permit prices are low and doing less abatement in countries where prices are high. However, it is unlikely that permit prices would differ significantly in practice. As long as each country's stock of long-term permits is small enough that at least one annual permit is sold, long-term permit prices in all participating countries will be equal to the present value of buying a stream of annual permits. With annual permit prices harmonized across countries, permit prices will therefore be equal.

Overall, the advantages of an internationally-coordinated system of national hybrid policies outweigh the potential disadvantages of separate permit markets. The policy would be implemented almost entirely via national governments and other existing institutions without the need for a powerful new international agency. It would require little sacrifice of sovereignty by participants. Accession would be straightforward and would not disturb existing permit markets. It would be robust, because adverse shocks in one permit market would not propagate to others. Finally, it would eliminate the disincentives national governments would face in monitoring and enforcing an international trading regime. It might not minimize costs completely, but that outcome only occurs in situations that are unlikely to arise in practice. Moreover, the potential loss of efficiency is likely to be insignificant when compared to the administrative gains achieved by using existing institutions.

3.5 Incentives for Investment

Although the policy is more complex than an emissions tax or conventional "cap and trade" permit system, it would provide an excellent foundation for the large private sector investments in capital and research that will be needed to address climate change. To see why, consider the incentives faced by a firm after the policy has been established. Suppose it has the opportunity to invest in a new production process that would reduce its carbon emissions by one ton every year. If the firm is currently covering that ton by buying annual permits, the new process would save it $20 per year every year. If the firm can borrow at a 5% real rate of interest, it would be profitable to adopt the process if the cost of the innovation were $400 or lower. For example, if the cost of adoption were $300, the firm would be able to avoid buying a $20 annual permit every year for an interest cost of only $15; adopting the process, in other words, would eliminate a ton of emissions and raise profits by $5 per year.

Firms owning long-term permits would face similar incentives to reduce emissions because doing so would allow them to sell their permits. Suppose a firm having exactly the number of long-term permits needed to cover its emissions faced the investment decision in the example above. Although the firm does not need to buy annual permits, the fact that it could sell or lease unneeded long-term permits provides it with a strong incentive to adopt the new process. To keep the calculation simple, suppose that the permits are perpetual and allow one ton of emissions per year. At a cost of adoption of $300, the firm could earn an extra $5 per year by borrowing money to adopt the process, paying an interest cost of $15 per year, and leasing the permit it would no longer need for $20 per year.

The investment incentive created by a hybrid policy rises in proportion to the annual permit fee as long as the fee is low enough to be binding – that is, low enough that at least a few annual permits are sold. For example, raising the fee from $20 to $30 raises the investment incentive from $400 to $600.

The upper limit on incentives created by the annual fee is the market-clearing rental price of a long-term permit in a pure tradable permit system. Above that price, there would be enough long-term permits in circulation to satisfy demand and no annual permits would be sold. For example, if long-term permits would rent for $90 a year under a pure permit system, the maximum price of an annual permit under the hybrid will be $90.

The critical importance of credibility becomes apparent when considering what would happen to these incentives if firms are not sure the policy will remain in force. If the policy were to lapse at some point in the future, emissions permits would no longer be needed. At that point, any investments made by a firm to reduce its emissions would no longer earn a return. The effect of uncertainty about the policy's prospects is thus to make the investments it seeks to encourage substantially more risky.

Since the incentives created by the policy increase with the price of an annual permit, a government might try to compensate for low credibility by imposing higher annual fees. For example, suppose a government would like a climate policy to generate a $400 incentive for investment but firms believe that there is a 10% chance the policy will be abandoned each year. For the policy to generate the desired incentive, the annual permit price would have to be $60 rather than $20. That is, the stringency of the policy (as measured by the annual permit fee) must *triple* in order to offset the two-thirds decline the incentives arising from the policy's lack of credibility. In practice, the situation is probably even worse. Increasing the policy's stringency is likely to reduce its credibility further, requiring even larger increases in the annual fee. For example, suppose that investors believe that the probability the government will abandon the policy rises by 1% for each $20 increase in the annual fee. In that case, maintaining a $400 investment incentive would require an annual fee of $70 rather than $60, which would be accompanied by an increase in the perceived likelihood of the policy being abandoned from 10% to 12.5%. The general lesson is clear and vitally important to the development of an effective climate policy: a modest but highly certain policy generates the same incentives for action as a policy that is much more stringent, but also less certain. A hybrid policy with a modest annual permit price would generate larger investment incentives than a more draconian, but less credible, emissions target imposed by a system of targets and timetables.

3.6 Summary

A hybrid policy combining a fixed supply of tradable long-term emissions permits with an elastic supply of annual permits would be a viable and efficient long-term climate policy at the national level. It would be more credible than many alternatives, especially a carbon tax, because it builds a political constituency with a large financial stake in preventing backsliding by future governments. It would also eliminate the short-term carbon price volatility inherent in a traditional "cap and trade" system, and it would provide a clear view of the maximum costs of the policy over time. It thus addresses the inherent difficulty that a democratic government faces in binding future governments to continue carrying out the policy. At the same time, the provision for annual permits allows the hybrid to avoid the inefficiencies and political hurdles that would arise with a conventional system of permits, which would impose a rigid cap on emissions. Thus, it would provide a strong foundation for investment decisions by the private sector because it creates credible, long-term returns for reducing greenhouse gas emissions. It combines the best features of a permit system and an emissions tax.

Over time, more information will become available about climate change, its effects, and about the costs of reducing emissions. Revising the agreement in light of new information is straightforward: if it becomes clear that emissions should be reduced more aggressively, the price of annual permits can be raised. The political prospects for an increase would be helped by the fact that raising the price of annual permits would produce a windfall gain for owners of long-term permits, since the market value of long-term permit prices would rise as well.[15]

If new information indicates that emissions should drop below the number allowed by long-term permits, raising the price of annual permits would need to be augmented by a reduction in the stock of long-term permits. One option would be for each government to buy and retire some of the long-term permits it issued. However, the costs involved could make that approach infeasible. A better option would be to design the original permits to expire gradually. Of the options discussed earlier in the paper, we favor an approach with perpetual permits whose allowed emissions gradually diminish over time. Such a system would establish long term property rights and strong, credible incentives but would still allow future governments room to maneuver. In addition, the gradual reduction in emissions entitlements will make the policy more attractive to environmental groups.

3.7 Building on the Foundation

The agreement outlined above—an internationally-coordinated system of national hybrid policies for controlling carbon emissions—provides a solid foundation for private-

15 Although long term permit owners would welcome an increase in the annual price, there is little risk that they would be able to drive prices up on their own. Given that other energy users provide countervailing pressure to keep energy prices low, it is hard to imagine that permit owners would be able to push a government into adopting an inefficiently high price and excessively stringent emissions policy.

sector investments to reduce emissions of carbon dioxide. It provides clear and credible financial incentives for developing and deploying new innovations that reduce fossil fuel use or capture and sequester carbon emissions. However, it need not be the only policy adopted and could easily be integrated with other actions taken at the national level.

For example, the hybrid policy could also be combined with a wide range of measures focused on energy technology, including product standards, informational campaigns, demand-side management, subsidies for investment in non-fossil energy sources, or research and development subsidies. Although each of these could be combined with the hybrid, none of them could replace it. Without the clear, credible incentives for investment provided by the hybrid, individuals and firms will be slow to adopt new technologies to reduce emissions. In fact, without a price-based instrument like the hybrid, many of these policies would be counter-productive. Subsidized research and development, in particular, would have the effect of *reducing* energy prices, thus tending to increase energy consumption and greenhouse gas emissions. Using the hybrid policy in combination with a research subsidy would offset this effect.

4 The Impact of Uncertainty in a Price-Based Policy Framework

As well as uncertainty about the economic structure of the world and the uncertainty about the allocation mechanism for permits which drives a key part of the cost uncertainty , the nature of the shocks that will buffer the world are also uncertain. In this section we use the model to explore the impact on the costs of taking climate action under a price based regime (as summarized in section 3) and a targets and timetables or “cap and trade” regime. The event we consider is a rise in productivity growth in developing countries (China, India, and LDCs in the model) of 3% per year over 2003 to 2020, after which growth returns to BAU rates. We assume a world in which the targets and timetables policy is in place from 2013 with the historical allocation of permits along the target path expected before the growth shock. We then introduce the shock to developing countries without changing the allocation of permits nor the global cap. In comparison we use the price based system of either a global carbon tax with countries keeping the revenue they raise or a McKibbin-Wilcoxen Hybrid with all long term permits allocated along the target path on a country by country basis with a safety valve price set to be the carbon price solved out in the permit price simulation. In other words we are to compare the two alternative regimes when there is a significant shock to world growth. The main difference is that under a cap and trade system there is not flexibility to respond and the outcome for the carbon price and GDP is driven by the shock plus the carbon constraint. In the price based systems, the carbon tax is kept along the pre announced path, or in the Hybrid, annual permits are auctioned to keep the carbon price at the pre announced path.

Results are shown in Figure 5 for the change in GDP when a global permit trading system is in place ("Permit System" – squares) versus the outcome when a price system is in place ("Price" – triangles). When developing countries experience strong growth, this is transmitted positively to other countries directly via trade flows with developing countries and indirectly through high global wealth and trade flows more generally. It is also transmitted through international capital flows which achieve a higher rate of return in rapidly growing economies and therefore raise incomes globally. In the countries where growth is occurring (China, India and LDCs) there is higher growth under a price-based system because there is no response of permit prices which act to slow activity. The difference the emission cap makes can be seen more clearly in the countries where the growth effects spillover. Here it is clear that the differences are large. For example in the United States, by 2020 GDP is approximately 0.2% higher in a permit world compared to 0.6% higher in a carbon price world. For some countries (Australia, ROECD, Former Soviet Union and OPEC) the negative global carbon price effects of growth in developing countries outweigh the positive growth effects through trade and financial spillovers and GDP is found to be lower than otherwise under a cap and trade world yet it is higher than otherwise under a price based system.

These results clearly demonstrate that the uncertainty of the future can be compounded under a targets and timetable world even when permit trading is allowed across countries. This is a significant barrier to countries taking the first step to implement effective climate policy, and the barrier is higher than it would be under a price based system.

5 Accelerated Deployment of Advanced Technology

The business-as-usual results so far have been based on the assumption that energy technologies in each economy gradually improve at rates similar to those seen in recent historical data. However, many policies now under discussion are explicitly intended to accelerate the development and deployment of advanced technologies that would reduce greenhouse gas emissions. Some of these technologies, such as the integrated gasification combined cycle (IGCC) process to generate electricity from coal, reduce carbon dioxide emissions by substantially improving the efficiency of fossil fuel combustion. Other technologies, such as carbon capture and sequestration (CCS), would reduce emissions by removing carbon dioxide from the exhaust stream after combustion. Yet other technologies, such as hybrid engines or carbon fiber components for automobiles would reduce emissions by lowering the fuel required per unit of service demanded (vehicle miles traveled, for example). Finally, advanced technology for non-fossil sources of electricity, including nuclear power and renewables, would reduce carbon dioxide emissions by shifting the overall fuel mix. In this section, we examine the potential for accelerated deployment of advanced technology to reduce carbon dioxide emissions associated with electric power generation.

Since improved technology would allow more electricity to be produced from any given input of fossil fuel, we represent advanced technologies in the model via fuel-augmenting technical change. In essence, this approach captures the fact that new technology allows the same outcomes (output produced, distance traveled, etc.) to be produced with less physical energy. Factor-augmenting technical change introduces a distinction between physical inputs of energy (kWh, for example) and the effective value of those inputs to energy users. For example, increasing the efficiency of a coal-fired power plant from 41% to 49% using ultra-supercritical boiler technology would allow 19.5% more electricity to be produced from a given amount of coal (an 8% gain on a base of 41%). In effect, the technology allows a new plant using one ton of coal to produce the same amount of electricity that would have required 1.195 tons of coal in an older plant. The technology, in effect, serves to augment the physical fuel used.

Because G-Cubed aggregates all electric power technologies into a single electric sector in each country, shifts of the fuel mix away from fossil fuels toward nuclear and renewables can also be modeled as fossil-fuel augmenting technical change. For example, a country increasing the share of non-fossil generation in its fuel mix from 40% to 55%, and hence reducing its fossil share from 60% to 45%, is effectively generating 33% more electricity for any given input of fossil fuel.

Using industry projections of the rate of diffusion of a range of innovations in electricity generation between 2008 and 2030, we produced the augmentation factors shown in Table 3. The values shown include both effects mentioned above: improvements in the efficiency of fossil fuel combustion, and shifts in the fuel mix away from fossil fuels. By 2030, for example, the 1.66 shown for Japan indicates that advanced technology and fuel-switching will mean that the ratio of total electricity produced to fossil fuel input will be 1.66 times that ratio today. We assume that technology and fuel switching continue beyond 2030, although at a diminishing rate. By 2045, for example, the augmentation factor for Japan increases to 2.09. The augmentation factors vary considerably by country. Improvements are very limited in LDCs other than China and India: the 2030 augmentation factor is only 1.13. India's augmentation factors are quite high, reflecting the fact that India currently relies heavily on coal burned in boilers with very low efficiency. Better technology thus improves India's performance considerably. In contrast, Europe's augmentation factors are relatively low: it currently relies least on fossil fuels of all of the regions, and its current technology is relatively efficient. It thus has less room for improvement.

Table 3: Fossil Fuel Augmentation Factors

Region	2030	2045
United States	1.67	2.10
Japan	1.66	2.09
Australia	1.73	2.19
Europe	1.49	1.80
ROECD	1.67	2.09
China	1.67	2.10
India	1.80	2.31
Other LDC	1.13	1.22
Former Soviet Union	1.71	2.16
OPEC	1.22	1.35

Figure 6 shows the effect the advanced technology scenario on carbon emissions by region. For comparison, the business-as-usual results are shown as well. The BAU trajectories are indicated with diamonds and the advanced technology trajectories are indicated with triangles and labeled "high innovation". By 2050, emissions are considerably lower in several countries. In the United States, for example, carbon dioxide emissions in 2050 would be reduced by about 1000 million metric tons, a reduction of about 10 percent. Australia's emissions would be lower by about 8 percent, and there would be smaller decreases in Japan, Europe and the ROECD regions as well.

Future research will explore the interaction of alternative technology policies with the cost of carbon abatement under the Hybrid Policy. Combining these approaches offers a way forward that would provide a strong foundation for a global agreement based on economic incentives and technological innovation.

6 Summary and Conclusions for Policy

The targets and timetables approach underlying the Kyoto Protocol has been a major impediment to progress in addressing climate change. It forces countries into confrontations during negotiations over shares of a fixed global emissions budget; committing to achieve a rigid emissions target is difficult for countries facing uncertain and potentially very high costs; and unexpected events can force even well-intentioned participants into non-compliance. Further, India and China's rapid economic growth makes it clear that any serious international climate regime must be explicitly designed for eventual accession by developing countries. After a decade of negotiations that have failed to slow emissions growth significantly, the Kyoto Framework must now evolve towards a more effective approach.

One alternative framework is the McKibbin-Wilcoxen Hybrid, which focuses on actions rather than outcomes. Shifting to an approach based on agreed actions, rather than specific emissions outcomes, will be a critical step in the evolution of climate negotiations and will be particularly useful for accommodating the needs of developing countries. Under this approach, each participating country would agree to attempt to achieve a target path of emissions reductions, but with an explicit international agreement on the maximum carbon price it would be expected to incur at each point in time. The two-pronged approach – a target path plus a cap on compliance costs –has a better chance of being implemented by more countries than any other policy.

Our numerical simulations illustrate two of the problems with targets and timetables: the high stakes involved in negotiating over emissions budgets, and the risks stemming from uncertainty about costs. The results show how different the costs of the policy will be depending on how emissions rights are allocated, and how the performance of the scheme varies as a function of one source of uncertainty: the rate of growth in major developing countries.

Combining the Hybrid approach with maximum effort to deploy advanced technologies in energy generation and end uses has the potential to produce effective global action against climate change. The Hybrid policy will act as a powerful incentive to develop and deploy technological innovation which reinforces the contribution of technology to reducing emissions. Combined with a ramping up in research and development expenditure, the costs of emission reduction can be substantially reduced and the uncertainty over actions can be minimized. Reaching an effective international agreement on the basis of agreed actions supplemented with technological innovation will be much easier to negotiate than a set of rigid targets and timetables. Moreover, a successfully-negotiated international agreement will immediately begin to drive technological innovation, which in turn will reinforce the policy.

Moving away from a focus on targets and timetables as a basis for negotiation will be an essential step in building a comprehensive global approach to climate change.

Appendix A: The G-Cubed Model

The G-Cubed model is an intertemporal general equilibrium model of the world economy. The theoretical structure is outlined in McKibbin and Wilcoxen (1998)[16]. A number of studies—summarized in McKibbin and Vines (2000)—show that the G-cubed modeling approach has been useful in assessing a range of issues across a number of countries since the mid-1980s.[17] Some of the principal features of the model are as follows:

- The model is based on explicit intertemporal optimization by the agents (consumers and firms) in each economy[18]. In contrast to static CGE models, time and dynamics are of fundamental importance in the G-Cubed model. The MSG-Cubed model is known as a DSGE (Dynamic Stochastic General Equilibrium) model in the macroeconomics literature and a Dynamic Intertemporal General Equilibrium (DIGE) model in the computable general equilibrium literature.

- In order to track the macro time series, the behavior of agents is modified to allow for short run deviations from optimal behavior either due to myopia or to restrictions on the ability of households and firms to borrow at the risk free bond rate on government debt. For both households and firms, deviations from intertemporal optimizing behavior take the form of rules of thumb, which are consistent with an optimizing agent that does not update predictions based on new information about future events. These rules of thumb are chosen to generate the same steady state behavior as optimizing agents so that in the long run there is only a single intertemporal optimizing equilibrium of the model. In the short run, actual behavior is assumed to be a weighted average of the optimizing and the rule of thumb assumptions. Thus aggregate consumption is a weighted average of consumption based on wealth (current asset valuation and expected future after tax labor income) and consumption based on current disposable income. Similarly, aggregate investment is a weighted average of investment based on Tobin's q (a market valuation of the expected future change in the marginal product of capital relative to the cost) and investment based on a backward looking version of Q.

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16 Full details of the model including a list of equations and parameters can be found online at: www.gcubed.com

17 These issues include: Reaganomics in the 1980s; German Unification in the early 1990s; fiscal consolidation in Europe in the mid-1990s; the formation of NAFTA; the Asian crisis; and the productivity boom in the US.

18 See Blanchard and Fischer (1989) and Obstfeld and Rogoff (1996).

- There is an explicit treatment of the holding of financial assets, including money. Money is introduced into the model through a restriction that households require money to purchase goods.

- The model also allows for short run nominal wage rigidity (by different degrees in different countries) and therefore allows for significant periods of unemployment depending on the labor market institutions in each country. This assumption, when taken together with the explicit role for money, is what gives the model its “macroeconomic” characteristics. (Here again the model's assumptions differ from the standard market clearing assumption in most CGE models.)

- The model distinguishes between the stickiness of physical capital within sectors and within countries and the flexibility of financial capital, which immediately flows to where expected returns are highest. This important distinction leads to a critical difference between the quantity of physical capital that is available at any time to produce goods and services, and the valuation of that capital as a result of decisions about the allocation of financial capital.

As a result of this structure, the G-Cubed model contains rich dynamic behavior, driven on the one hand by asset accumulation and, on the other by wage adjustment to a neoclassical steady state. It embodies a wide range of assumptions about individual behavior and empirical regularities in a general equilibrium framework. The interdependencies are solved out using a computer algorithm that solves for the rational expectations equilibrium of the global economy. It is important to stress that the term ‘general equilibrium’ is used to signify that as many interactions as possible are captured, not that all economies are 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 neoclassical steady state growth equilibrium, unemployment does emerge for long periods due to wage stickiness, to an extent that differs between countries due to differences in labor market institutions.

Table A-1: Overview of the G-Cubed Model (version 80J)

Regions
United States Japan Australia Europe Rest of the OECD China India 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 Capital Producing Sector

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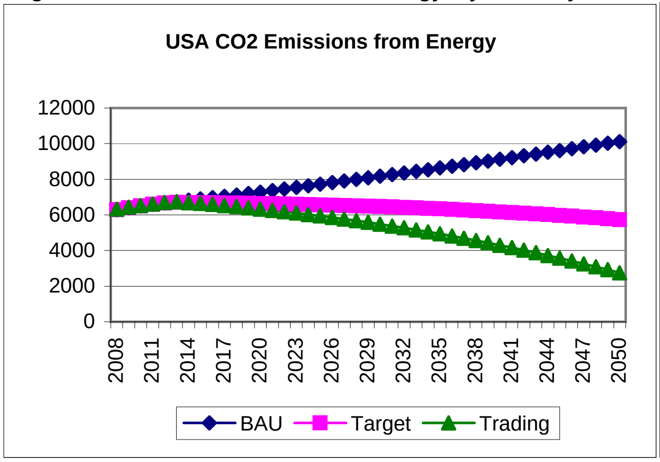
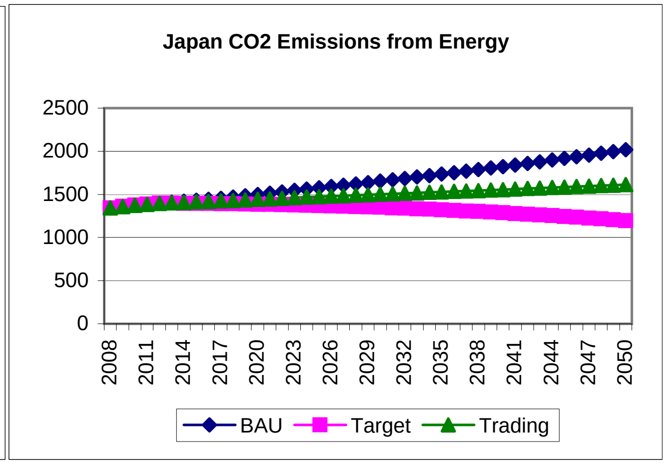
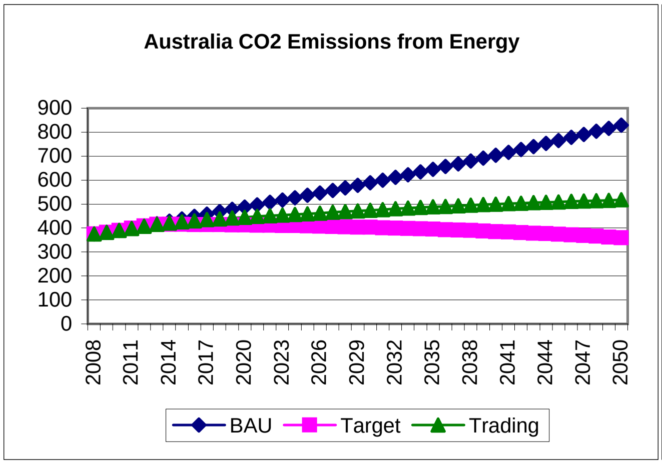
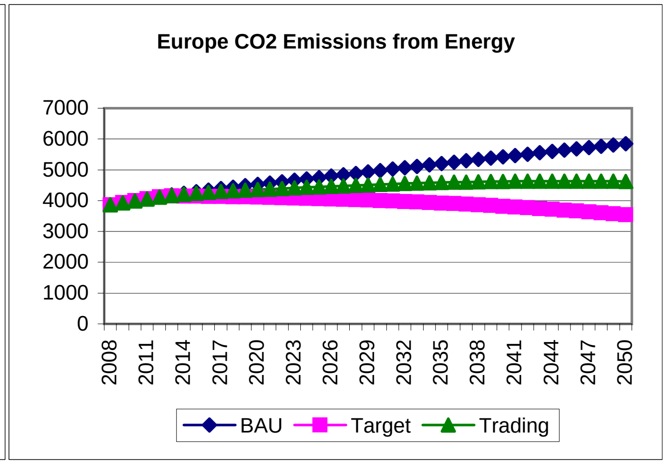
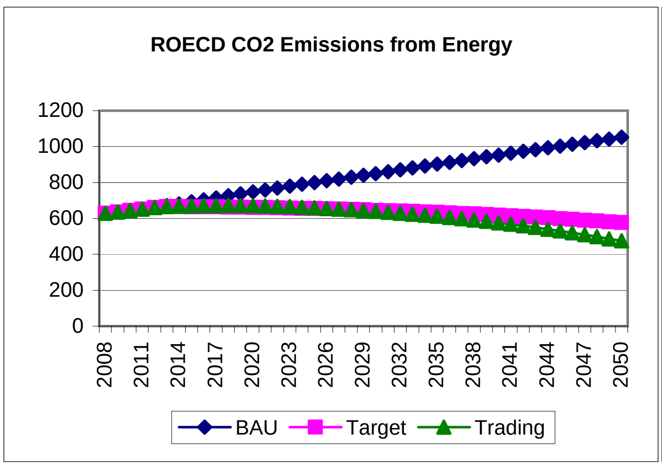
Figure 1: CO2 Emissions from Energy By Country











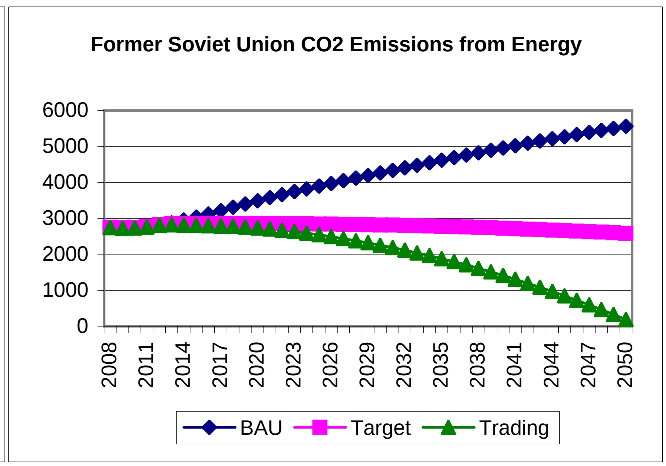


Figure 1 (continued): CO2 Emissions from Energy By Country

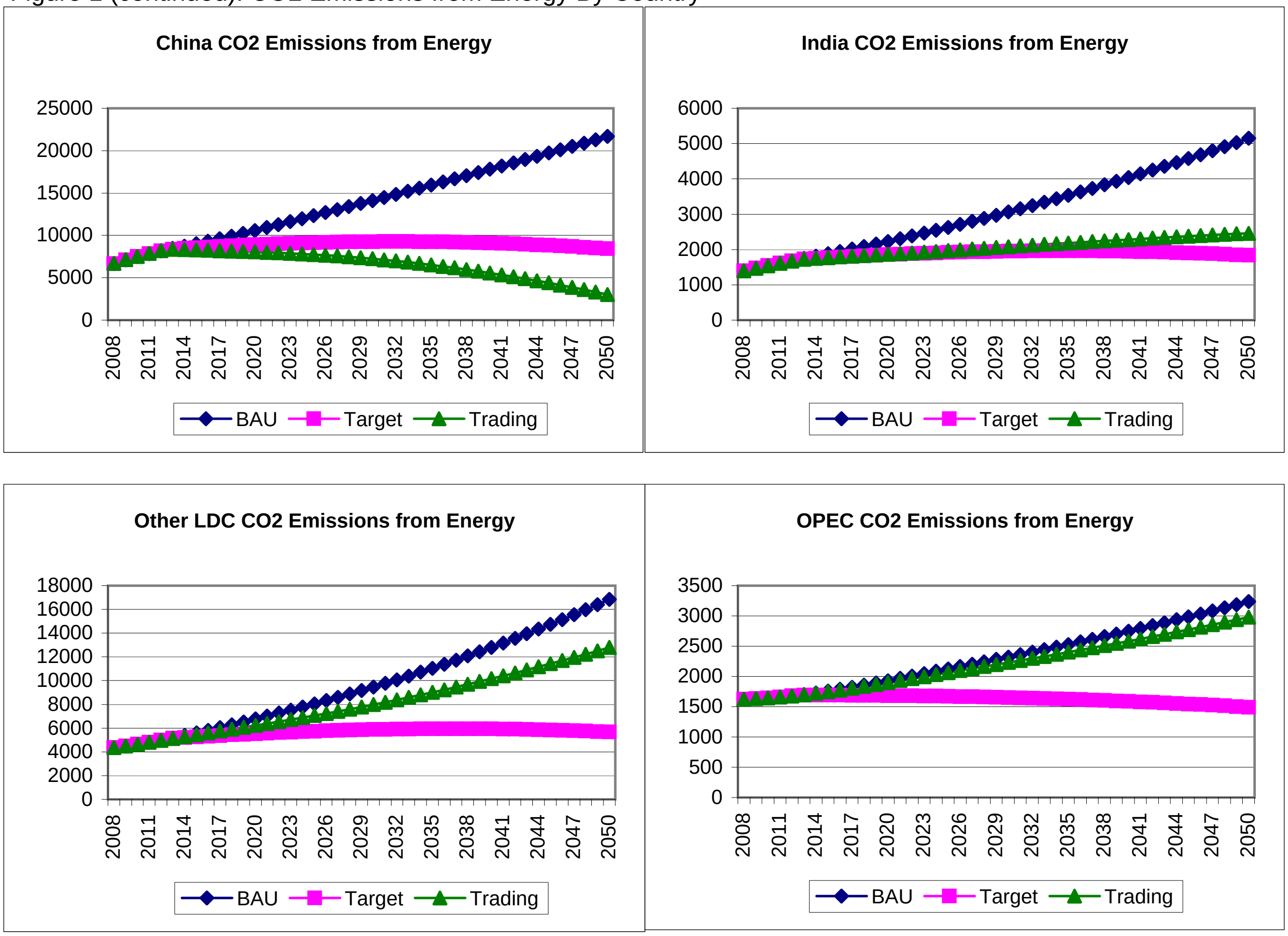


Figure 2: Carbon Prices by Country

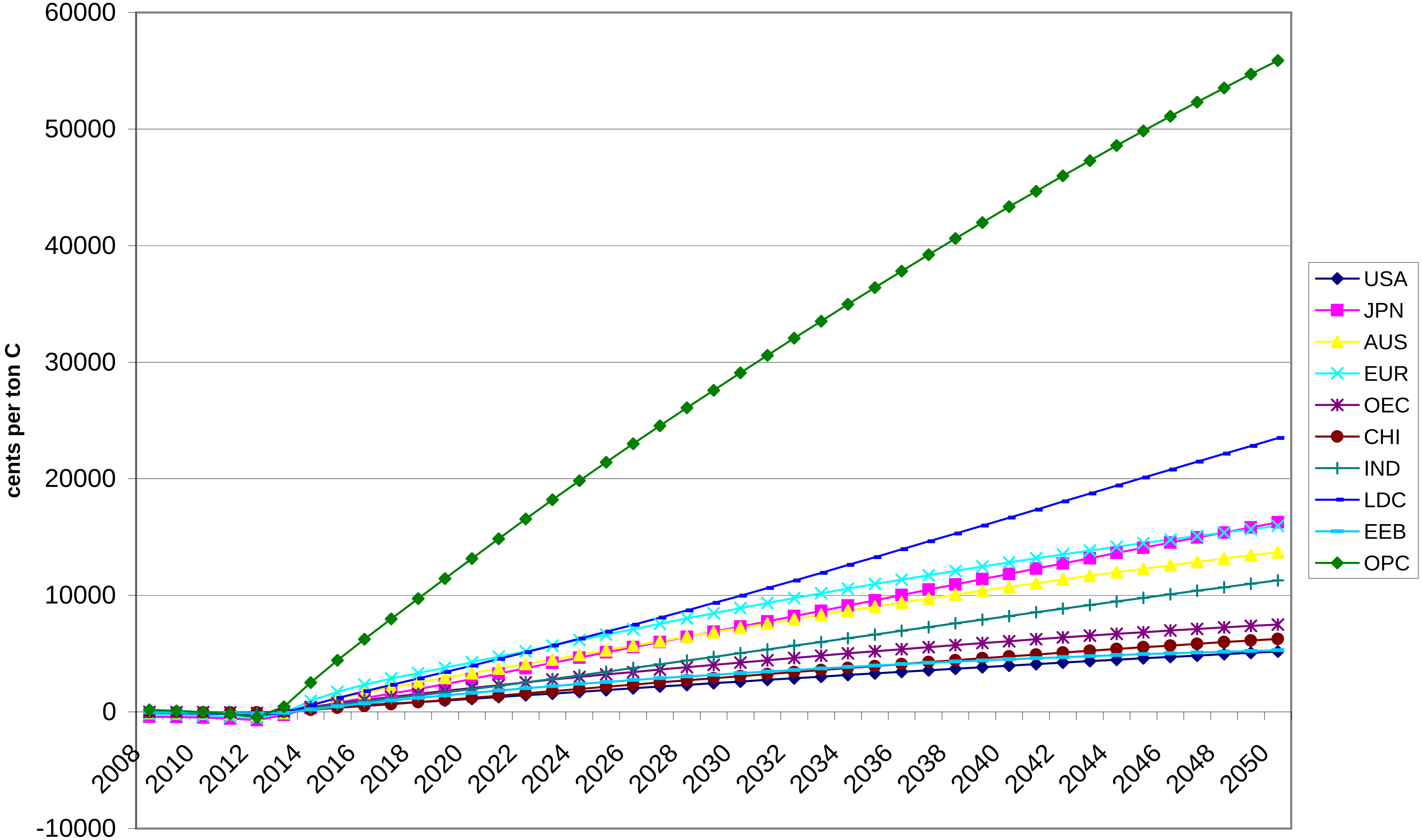


Figure 3: GDP Change from Country Target versus global permit trading with BAU allocation

Figure 3 (continued): GDP Change from Country Target versus global permit trading with BAU allocation

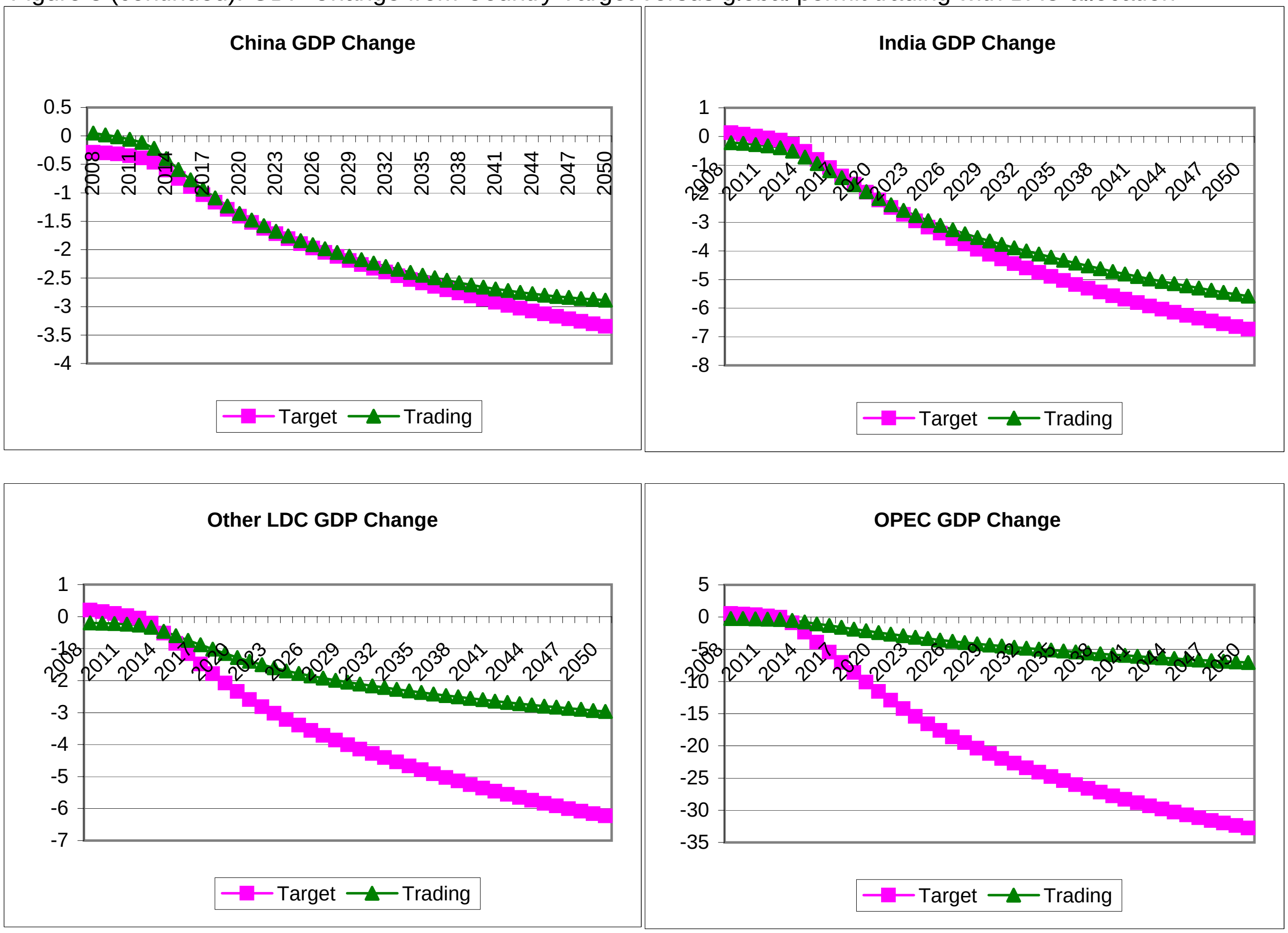


Figure 4: GNP Change Under Permit Trading - BAU versus per Capita Allocation

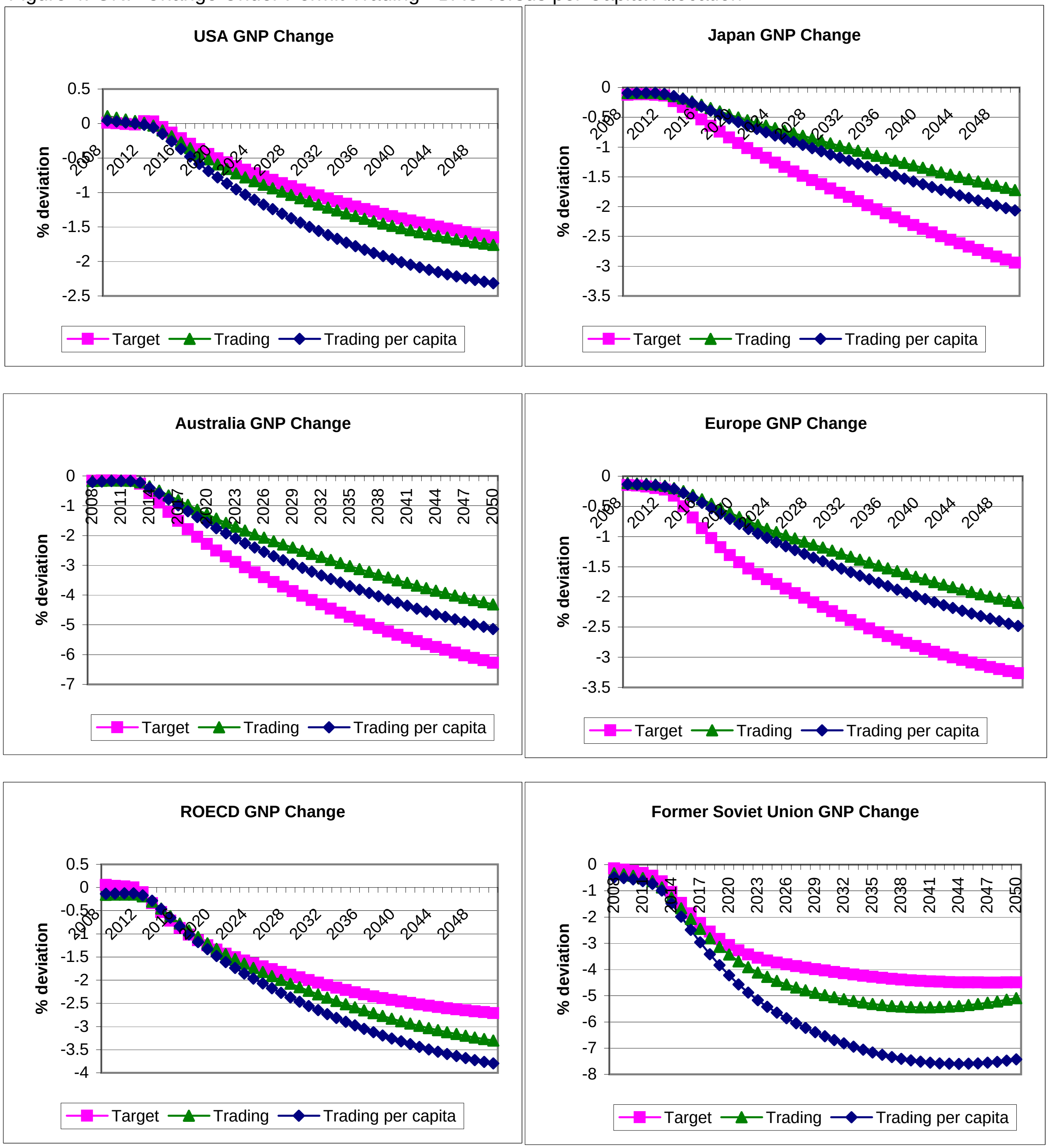


Figure 4(continued): GNP Change Under Permit Trading - BAU versus per Capita Allocation

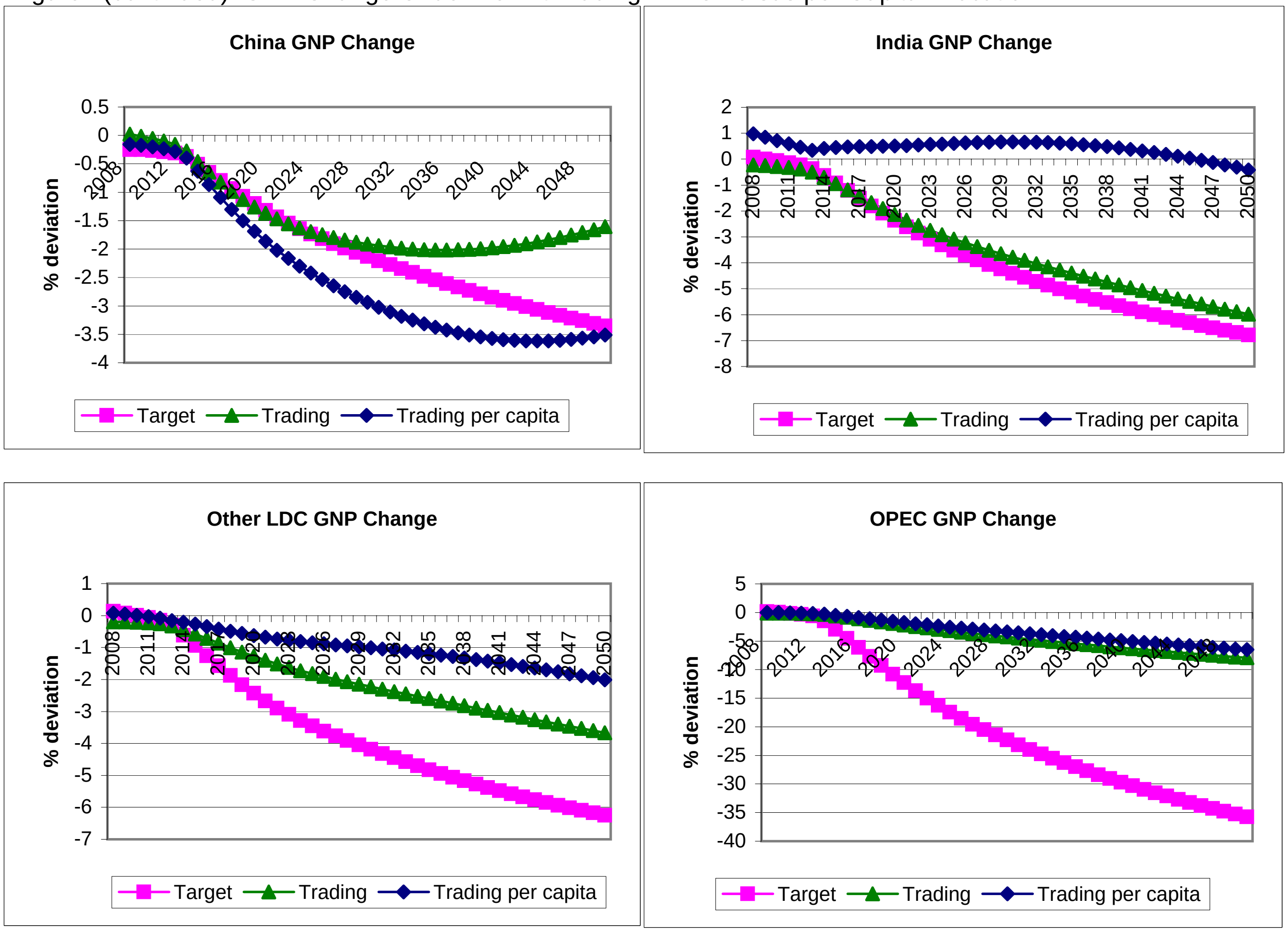


Figure 5: GDP Change from Developing Country Growth Under a Price Versus a Quantity target

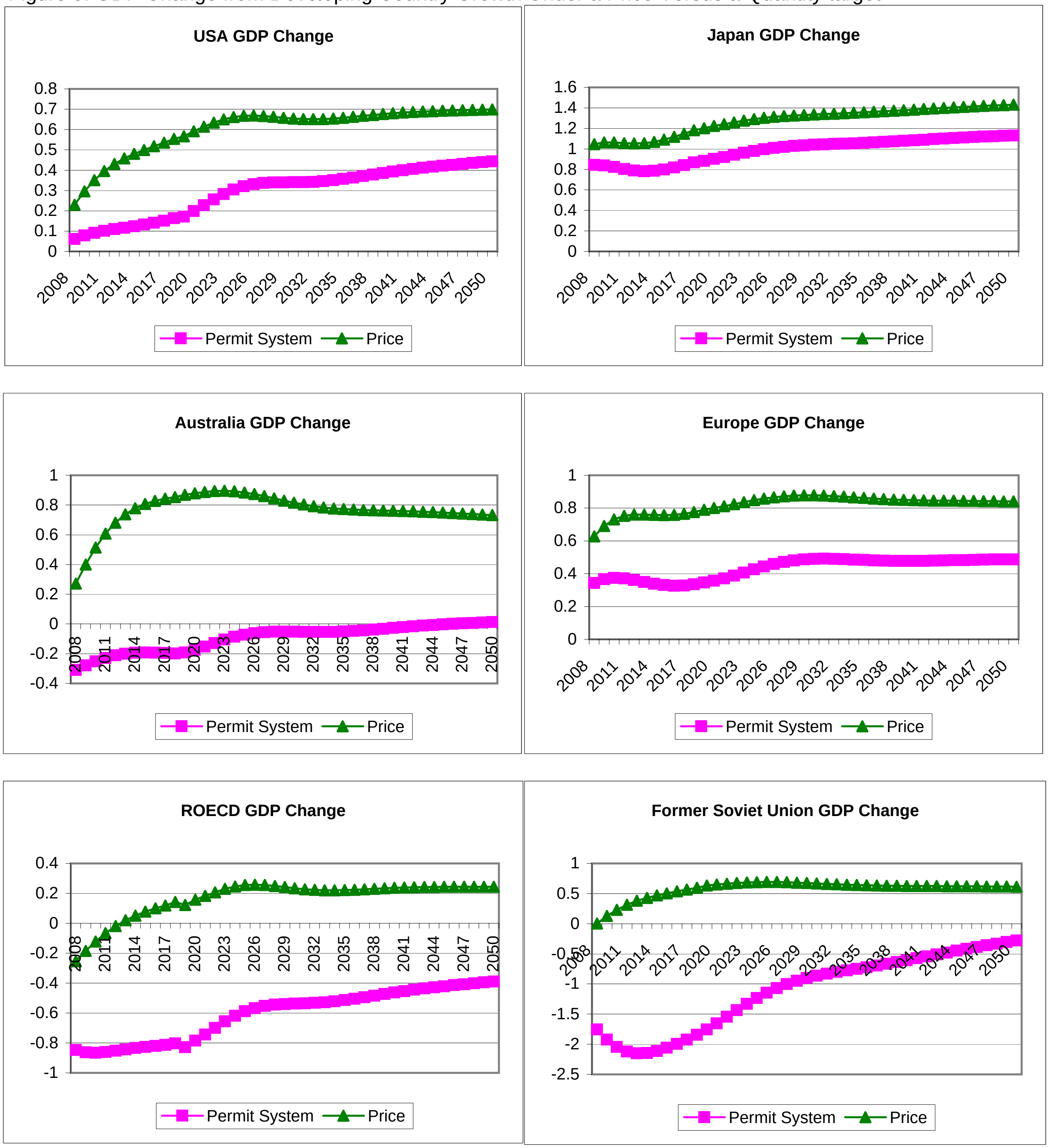


Figure 5(conitnued) : GDP Change from Developing Country Growth Under a Price Versus a Quantity Target

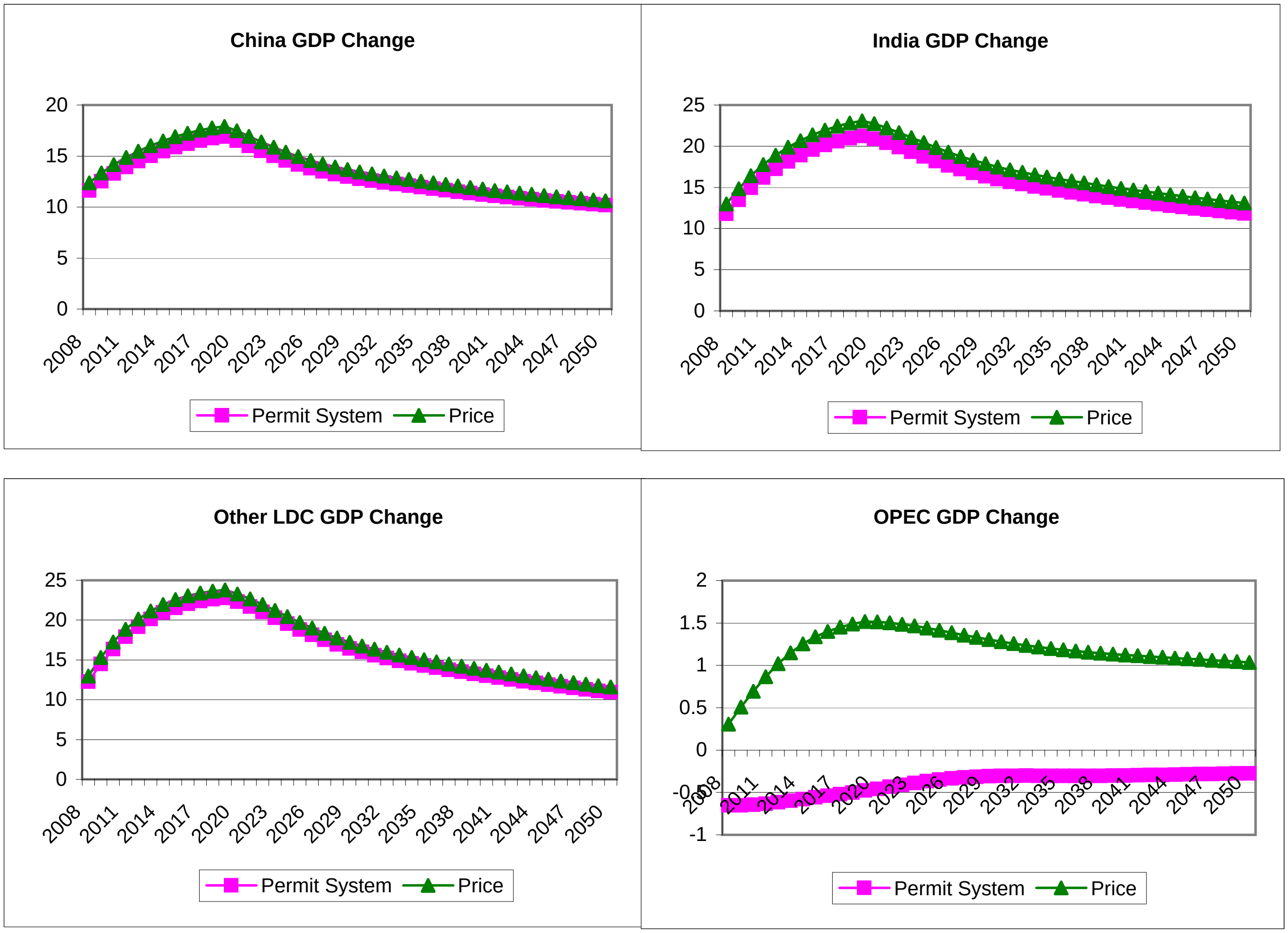


Figure 6: CO2 Emissions from Energy By Country under BAU and high innovation

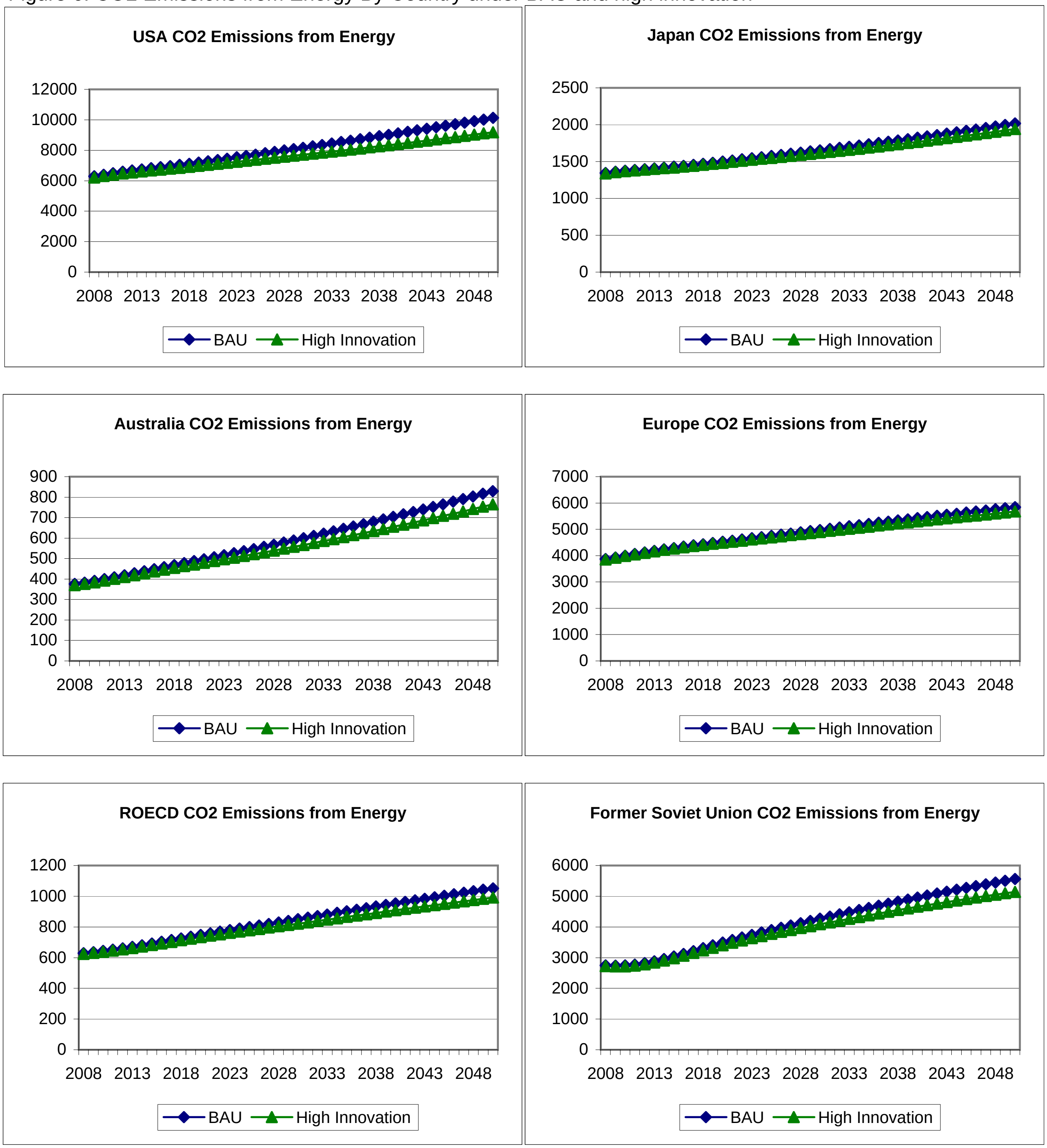


Figure 1 (continued): CO2 Emissions from Energy By Country