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EXPECTING THE UNEXPECTED: MACROECONOMIC VOLATILITY AND CLIMATE POLICY

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Expecting the Unexpected:

Macroeconomic Volatility and Climate Policy*

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ABSTRACT

To estimate the emissions reductions and costs of a climate policy, analysts usually compare a policy scenario with a baseline scenario of future economic conditions without the policy. Both scenarios require assumptions about the future course of numerous factors such as population growth, technical change, and non-climate policies like taxes. The results are only reliable to the extent that the future turns out to be reasonably close to the assumptions that went into the model.

In this paper we examine the effects of unanticipated macroeconomic shocks to growth in developing countries or a global financial crisis on the performance of three climate policy regimes: a globally-harmonized carbon tax; a global cap and trade system; and the McKibbin-Wilcoxen hybrid. We use the G-Cubed dynamic general equilibrium model to explore how the shocks would affect emissions, prices, incomes, and wealth under each regime. We consider how the different climate policies tend to increase or decrease the shock's effect in the global economy and draw inferences about which policy approaches might better withstand such shocks.

We find that a global cap and trade regime significantly changes the way growth shocks would otherwise be transmitted between regions while price-based systems such as a global carbon tax or a hybrid policy do not. Moreover, in the case of a financial meltdown, a price based system enables significant emissions reductions at low economic cost whereas a quantity target base system loses the opportunity for low cost emission reduction reductions because the target is fixed.

1. Introduction

The global financial crisis, a looming global recession, and deep turmoil in credit markets drive home the importance of developing a global climate architecture that can withstand major economic disruptions. A well-designed global climate regime and the attendant domestic implementation policies undertaken by participating countries need to be resilient to large and unexpected changes in economic growth, technology, energy prices, demographic trends, and other factors that drive costs of abatement and emissions. Ideally, the climate regime would not exacerbate macroeconomic shocks, and would possibly buffer them instead, while withstanding defaults by individual members. Because climate policy must endure indefinitely in order to stabilize atmospheric concentrations of greenhouse gases, all sorts of shocks will occur at some stage in the policy's existence. Anticipating such shocks may mean rejecting policies that might reduce emissions reliably in stable economic conditions but would be vulnerable to collapse—with consequent deterioration in environmental outcomes—in volatile conditions.

Macroeconomic volatility is the practical manifestation of an issue that has received considerable attention in the theoretical literature on the design of environmental policies: uncertainty about the costs and benefits of reducing emissions.[1] In particular, macroeconomic shocks can cause the cost of regulation to be much higher or lower than anticipated. Unexpectedly stringent and costly regulations may become political lightning rods. Recent world events, for example, highlight the fact that economic surprises can subject governments to enormous pressures to relax or repeal taxes or other policies perceived to impede economic growth. For a climate policy to survive future shocks, therefore, it must have dynamic consistency: it must be optimal for each government to

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[1] See, for example, Weitzman (1974), Roberts and Spence (1976), Pizer (1997), McKibbin and Wilcoxen (1997), Pezzey (2003), von Below, D. and T. Persson (2008).

continue to enforce the policy even when confronted with sharp departures from the conditions expected when the governments undertook the commitments. All else equal, a climate regime that exacerbates downward macroeconomic shocks or depresses the benefits of positive macroeconomic shocks would be more costly and less stable than a system that better handles global business cycles and other volatility.

The stability of the policy has important environmental implications for two reasons. First, collapse of the policy could set back progress on emissions reductions for years. Second, decisions of economic actors depend on their expectations of future policy, and this dependency affects the performance of the policy itself.[2] In the case of climate change, a system that is more robust to shocks, and is thus more likely to persist, would increase the expected payoffs of investments in new technologies and emissions reductions relative to a system that is less robust. In particular, a system of rigid and ambitious targets may seem the most environmentally rigorous approach, but if the rigidity decreases the probability the agreement would be ratified, or reduces compliance, or limits long term participation, households and firms will take that into account in their investment decisions. They will invest too little in abatement and alternative energy technologies, causing the system to be less effective in practice that one with more flexibility. If governments try to compensate for low credibility by imposing more a stringent target, they could inadvertently worsen the incentives for investment by further reducing the program's credibility. This all points to the central importance of establishing a regime that is credibly robust to changing economic conditions.

This paper uses the G-Cubed model to explore how shocks in the global economy propagate differently depending on the design of the climate policy regime. G-Cubed divides

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[2] Finn E. Kydland and Edward C. Prescott make this point in "Rules Rather than Discretion: The Inconsistency of Optimal Plans," *The Journal of Political Economy*, Vol. 85, No. 3 (Jun., 1977), pp. 473-492. The University of Chicago Press.

the world economy into ten regions: the U.S., the E.U., Japan, Australia, the rest of the OECD, Former Soviet Union states, China, India, other developing countries, and oil exporting developing countries.[3] We examine two kinds of shocks relevant to recent experience: (1) a positive shock to economic growth in China, India, and other developing countries, and (2) a sharp decline in housing markets and a rise in global equity risk premiums, causing severe financial distress in the global economy. We analyze the effects of each shock on key economic indicators for the first decade after the shock occurs. We compare the results from the three climate regimes and draw inferences about which approaches may offer participants the strongest incentives to sustain participation in the regime in the context of these economic disruptions.

The three regimes we consider are a system of targets and timetables, a globally coordinated tax on carbon, and a hybrid of the two. The "target and timetables" approach we consider is a system of internationally tradable permits for carbon emissions. The globally-coordinated carbon tax sets a common price on carbon in each economy, with each government collecting revenue within its national boundary. The hybrid is a system of national long term permit trading systems with a globally-coordinated maximum price for permits in each year.[4]

In each scenario, we hold climate and broader economic policy rules constant. The fiscal deficit of each economy is held at its baseline level, as are tax rates, so changes in tax revenues will result in corresponding changes in government spending. The behavior of each region's central bank follows a region-specific Henderson-McKibbin-Taylor rule with a weight on output growth relative to trend, a weight on inflation relative to trend and a weight on exchange rate volatility.[5] The weights vary across countries with industrialized economies

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[3] The model is summarized in Appendix A and described more fully in McKibbin and Wilcoxen (1998).

[4] The hybrid we consider is based on McKibbin and Wilcoxen (1997, 2002a).

[5] See Henderson and McKibbin (1993) and Taylor (1993).

focusing on controlling inflation and output volatility, and developing countries placing a large weight on pegging the exchange rate to the US dollar.

We find that although the climate regimes appear to be similar in their ability to reduce carbon emissions efficiently, they differ importantly in how they affect the transmission of economic disturbances between economies. In particular, a quantity target with an annual cap global emissions can cause unexpectedly high growth in one country to reduce growth in other economies if the rise in the global carbon price caused by higher growth has a larger negative impact on other economies than the transitional spillover of growth through trade. This effect is absent in the price-based regimes of the global carbon tax and the Hybrid. We believe this change in the transmission of growth has important implication for international relations. Second, in the case of the global financial crisis we find that the quantity target approach misses an opportunity for significant additional low-cost emissions reductions. The global carbon tax and the Hybrid both enable a significantly larger emissions reduction for the same cost due to slower economic activity. On the other hand, the cap system is counter-cyclical: carbon prices fall as the world economy slows, which acts to dampen the economic slowdown.

We discuss each climate policy system in more detail in Section 2 below. Section 3 reviews key sources of uncertainty in the design of climate policy and describes the particular shocks we introduce into the model. Section 4 reviews the results, and Section 5 concludes, with particular emphasis on the policy relevant insights from the study.

2. Alternative climate policy regimes

Analysts have offered a wide range of alternative frameworks for international climate policy upon the expiry of the Kyoto Protocol in 2012.[6] Each of these approaches has advantages and disadvantages with respect to stability in the face of shocks. Some propose an agreement similar to the Kyoto Protocol with targets and broader participation. Frankel (2007) explains that targets could be indexed to economic growth so that parties do not face unanticipated stringency with strong economic growth or benefit from international allowance sales when their reductions are a result of downturns and rather than determined climate action. Bodansky (2007) argues that targets and timetables have proven to be politically untenable for those who sat out the Kyoto Protocol and that the successor agreement should be more flexible. For example, the agreement could include an explicit range of domestic actions that parties could take including taxes, efficiency standards, and indexed targets, with the mix chosen at the discretion of each party. Some combination of targets and timetables for industrialized countries and more flexible provisions for developing countries could emerge as parties seek to expand participation and China and India resist hard national targets.

An agreement that is tailored at least to some extent to different countries' national circumstances is likely. Nonetheless, analysis of more analytically tractable policies is useful. Analysts have paid particular attention to an international system of binding emissions caps, like the Kyoto Protocol, that reaches a specified target with certainty (at least in principle) and a system of agreed price signals on greenhouse gas emissions, such as a harmonized carbon tax, which promises a certain level of effort but leaves emissions levels uncertain. For example, Nordhaus (2006) and others find that a price signal approach reduces the risk of inadvertent stringency and is likely to be more efficient than a system of hard caps in the context of uncertainty over both the costs and benefits of abatement.

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[6] See for example, *Architectures for Agreement, Addressing Global Climate Change in the Post-Kyoto World*, Joseph Aldy and Robert Stavins eds., Cambridge University Press, 2007.

A less-explored characteristic of both systems is how and whether they create political constituencies with incentives to sustain the system.[7] Any serious domestic climate policy will have important distributional implications, and transfers that involve organized sub-groups are particularly likely to affect the political dynamics of the program. Such transfers could become increasingly important as the stringency of the climate policy increases, particularly if marginal abatement costs do not fall over time. For example, a carbon tax contributing to general government revenue could generate increasingly strong political pressure for its repeal or relaxation as the tax rate rises. This could be true even if the tax is fully revenue neutral because as the effect on energy prices becomes increasingly salient, energy-intensive stakeholders would organize against it. A climate tax in which the revenues are earmarked for particular purposes may develop the same sort of constituency that other special interest tax provisions do, and the political contention would then be between recipients of the revenue and those on whom the tax falls.

A cap and trade system in which all the allowances are in the hands of private actors, such as electric utilities, produces a constituency with a strong financial stake in perpetuation of the policy, which may help counteract objections from those who bear the costs of abatement, such as electricity consumers. A cap and trade with annual allowance auctions and revenue recycling would run some of the same political risks as a climate tax that funds the general treasury, with the exception that holders of banked allowances and private futures and options contracts on emissions allowances would have an incentive to preserve their asset values.

A hybrid policy first proposed by McKibbin and Wilcoxen (1997) and discussed in detail in McKibbin and Wilcoxen (2002a, 2002b) could combine the best features of taxes and tradable permits. We describe the approach in some detail here because it would address

[7] For a discussion of this topic, see McKibbin and Wilcoxen (2002a, 2002b).

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 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. The total emissions rights conveyed by the permits would be less than or equal to the country's target emissions in each year. Refinements of this approach could achieve greater reductions over time, for example by gradually reducing the allowed emissions each permit conveys or by creating a set of finitely-lived permits with varying dates of expiration. Once distributed, the long-term permits could be traded among firms, or bought and retired by environmental groups.

In addition to the long term permits discussed above, the government would agree to sell annual permits for a pre-set but increasing fee. 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. The system provides clear financial incentives for emissions reductions, but the unlimited supply of annual permits means that no particular emissions target is guaranteed. As long as sufficiently few long-term permits are sold such 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.

The hybrid policy described above is strictly a domestic policy, without international trading in emissions rights. However, an international system of coordinated approaches, for example with common prices for annual permits, would be feasible. This approach would focus negotiations around the price of annual permits across and within participating countries. The treaty could also limit the maximum number of long-term emissions rights a participating country could issue, and individual countries could choose to distribute fewer. For example, parties that prefer a carbon tax could distribute no long-term permits at all.

The hybrid policy has many of the advantages of any system of agreed domestic measures. Importantly, because the permit markets under this policy are separate between countries, shocks to one permit market do not propagate to others. Accession by a new participant has no effect on the permit markets operating in other countries. And if a participating country withdraws from the agreement or fails to enforce its hybrid policy, permit markets in other countries are unaffected.

3. Sources of uncertainty and shocks

Many uncertainties affect the optimal climate policy and the willingness of individual countries to undertake binding international commitments. A key uncertainty is the cost of complying with any given commitment, making it risky for a country to agree to a hard target that may later prove to be infeasible. Uncertainty in economic growth, energy prices, and the development and cost of abatement technologies all contribute to uncertainty in costs.[8] Because these factors are not necessarily correlated, together they could amplify or attenuate the overall stringency of the program. For example, higher than expected macroeconomic growth would increase the stringency of a given cap, but if accompanied by the development of technologies with lower than expected abatement costs, the net effect of these dual shocks could be modest. But at its core, the targets and timetables approach requires each participant to achieve its national emissions target regardless of the cost of doing so. Even if the targets are indexed to factors correlated with the feasibility of the target, the basic approach does not bound costs.

The history of the Kyoto Protocol shows that ambitious targets do not necessarily produce the intended reductions. Countries facing potentially high costs either refused to

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[8] For a range of estimates of the costs of complying with the Kyoto Protocol, see Weyant, ed. (1999). Other studies include Bohringer (2001), Kemfert (2001), Buchner et al. (2002), Loschel and Zhang (2002), International Monetary Fund (2008). Literature surveys appear in the Intergovernmental Panel on Climate Change (2001, 2007).

ratify the protocol, such as the United States, or have so far failed to achieve an emissions level consistent with their 2008 to 2012 targets. The latter group is not necessarily out of compliance with the protocol since it may be possible for those countries to acquire allowances from other protocol participants before the end of the commitment period. However, countries that are on track to reduce emissions to match their assigned amounts have been aided by 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 Soviet economy in the early 1990's. This suggests that despite sincere intentions of those countries that ratified the Kyoto Protocol, the targets negotiated in 1997 did not fully anticipate the economic expansion of the ensuing years.

The uncertainty each country faces around its own growth matters, but in a global economy—and particularly with international allowance trading—other countries' growth matters, too. For example, even if a country perfectly predicts its own economic performance, higher than expected growth in another major economy could induce inadvertent stringency by increasing the demand for tradable permits globally. To quantify this effect and others, in Section 4 we explore what happens if China, India, and other developing countries experience unexpectedly high levels of growth during the tenure of a climate policy. We compare and contrast the impacts of this shock in a regime of harmonized global price on carbon and a global cap and trade system.

The experiment is highly pertinent to recent growth trends in Asia. As an example of how difficult it is to project the future even over short periods, Figure 1 (from McKibbin Wilcoxen and Woo, 2008) shows projections for Chinese energy consumption from the *2002 International Energy Outlook* and the *2007 International Energy Outlook*. The surprising fact is that for the future years that were overlapping in both reports, in every case China's projected energy consumption in the *low*-growth scenario in the 2007 report was above the projected energy consumption in the *high*-growth scenario in the 2002 report. The 2002 high-growth forecast for 2020 was 102.8 quadrillion BTU and the 2007 low-growth forecast for 2020 was 106.6 quadrillion BTU: that is, the updated low-growth forecast was 3.8 quadrillion BTU *above* the original low-growth forecast. The change in the "reference case" forecast emphasizes how much expectations have changed: the 2002 "reference case" forecast was 84.4 quadrillion BTU in 2020, and the 2007 "reference case" forecast was 112.8 quadrillion BTU in 2020 – an upward revision of 33.6 percent. Even more important, carbon dioxide emissions in 2005 were 50% higher than the forecast for 2005 made in 2002. The surge in energy use since 2002 is obvious from the figure, and it resulted from a number of factors including rising GDP growth since 1998 as well as a rise in the energy intensity of GDP. The shift in the energy intensity of the Chinese economy was due to a number of factors driving structural change including: increased electrification; greater energy demand from manufacturing; greater energy demand by households; and greater use of cement and steel as infrastructure spending has risen. The growth surprise we model is similar to that experienced by China over this period.

We examine a second pertinent shock in Section 4. To model a financial crisis roughly of the magnitude of one unfolding in the fall of 2008, we impose an unexpected fall in the return to housing in each economy, with the largest drop occurring in the United States. We add to this an exogenous rise in the equity risk premium in all sectors in all economies. Together, the shocks causes a substantial financial crisis including a sharp fall in equity markets, declines in household wealth, a sharp contraction in consumption, a jump in the required rate of return on investment, and a sharp decline in investment. These adjustments lead to a global recession.

4. Methodology and Results

In this section we use a global economic model called G-Cubed to explore the uncertainty in costs for different countries. Table 1 summarizes the G-Cubed model and

Appendix A provides additional details.[9] G-Cubed 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.

We begin by generating a baseline projection with an emissions reduction path as set out in detail in McKibbin and Wilcoxen (2008).[10] Along this path we consider three regimes. The first is a global cap and trade system for carbon dioxide emissions. Under this policy, we assume that each country is allocated permits based on its emissions trajectory expected before the growth shock. The second regime is an optimal global carbon tax calculated to give the same global emissions as the cap and trade system. The third regime is the McKibbin Wilcoxen Hybrid which also has a common global price for carbon but is implemented at the national level.

All three regimes are normalized so that they start with the same carbon prices in each economy and the same global emissions outcome. We assume in each case that the regimes are in place when the shocks hit.[11] We solve the model under each regime with and without the unexpected shocks and examine the differences between the paired simulations. Under the shocks presented here, the global carbon tax and the Hybrid are both carbon taxes at the margin, so for clarity we report a single set of results under the heading "Price-Based Policy."[12] In contrast, the cap and trade system is listed as "Permit System."

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[9] See McKibbin and Wilcoxen (1998) for a complete description. The version of G-Cubed used in this paper is 80J.

[10] See McKibbin, Pearce and Stegman (2007) for a discussion of the importance of structural change in undertaking long term projections.

[11] This approach was chosen to illustrate how each shock affects the global economy under each regime. Clearly this is not a reflection of current state of global climate policy.

[12] The carbon tax and the Hybrid policy would not be equivalent under a more severe shock to the world economy. If the shock were sufficiently damaging, the demand for emissions permits in one or more countries might drop low enough that no annual permits would be sold in that country. In that case, carbon prices would vary across countries and the Hybrid would

The main difference between the price-based policies and the cap and trade permit system is that the latter is less flexible: in the face of unexpected shocks, the rigid constraint on emissions drives sharp changes in carbon prices, which cause corresponding changes in other variables. Under the price-based systems, in contrast, the carbon price remains fixed at its announced trajectory and emissions can adjust.[13]

have some of the counter-cyclical properties of a pure permit system. In the results presented here, however, the demand for permits is large enough that at least a few annual permits are sold under all circumstances.

[13] Under the Hybrid, fluctuations in economic conditions cause swings in the sales of annual permits.

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

4.1 Developing country growth shock

As mentioned in Section 3, one of the scenarios we consider is an unexpected rise in growth rates in developing countries (China, India, and LDCs in the model). The particular shock we analyze is an unexpected increase in labor productivity growth of three percent per year for 16 years, after which growth returns to baseline rates. Only growth rates return to the baseline: the three economies are permanently larger.

Results for a range of variables for all countries are included in Table 2, which shows percentage deviations from baseline for years 1, 5 and 10 for both the growth shock discussed in this section and the risk shock to be discussed below. Also shown are the differences in percentage deviation between the permit and price systems. Figure 2 shows the change in key economic variables in China due to the shock under two different climate regimes: a global permit trading system ("Permit System", shown by squares), and a price system ("Price", shown by triangles). The rise in productivity expands the effective supply of labor to each economy, rapidly increasing output in each sector and therefore raising GDP. At the same time, the increase in labor productivity raises the marginal product of capital sharply across the Chinese economy. This increase in the return to capital causes a large rise in private investment of close to twenty percent. The higher investment is financed partly from capital inflows (hence the trade balance worsens) and partly from higher savings, hence consumption take a number of years to rise to the permanently higher level. The lagged adjustment of consumption captures an important historical feature of the Chinese economy. In G-Cubed, the People's Bank of China is modeled as placing a large weight on the exchange rate in its reaction function and small weights on the deviation in growth from trend and the deviation of inflation from the target. To prevent the exchange rate from appreciating, the bank cuts interest rates. There is an initial spike in inflation due to strong demand and the loosening of monetary policy. Carbon emissions rise significantly due to the increase in energy use from higher GDP growth. Under a global cap on emissions, the rise in developing country growth causes the global price of carbon to rise (see the rows labeled "Carbon Price, US$, Permits" under the "Growth Shock" columns in Table 2) which acts as a slight brake on the growth of all other countries, even including China. This is particularly true for China because it has a low marginal abatement cost: the GDP outcome for China when a binding global carbon target is in place is slightly smaller than when China only has a fixed carbon price. Obviously in the case of a fixed carbon price, emissions rise above the target in the baseline. There is not much flexibility to adjust energy inputs in the short run but in the long run there is substitution away from carbon-intensive activities as the expected future carbon price rises. Although growth is only marginally lower, the emissions pathway over time is significantly different under the two climate policy regimes. This illustrates that expectations about future carbon prices and the credibility of the policy regime can make a big difference in the ability of economies to reduce carbon emissions without large effects on economic growth.

The strong growth of developing countries transmits positively to other countries directly via trade flows with developing countries and indirectly through higher global wealth and increased trade flows more generally. The benefits of productivity growth in one country are also transmitted through international capital flows responding to the return to capital. Capital achieves a higher rate of return in rapidly growing economies and the resulting capital flows raise incomes globally. Developing countries that have the productivity boom (China, India and LDCs) experience higher growth under a price-based system than a permit system because marginal abatement costs do not rise and slow activity in the former climate regime. The effect of a cap in depressing the benefits of the positive growth shock is largest in countries to which the growth is most prone to spill over. Figure 3 shows detailed results for the United States from higher growth in developing countries. (Table 2 shows results for all countries.) As capital flows out on the United States toward higher returns in developing countries, the US trade balance improved slightly and the US capital stock initially falls along with consumption due to the global re-allocation of capital. As developing countries grow further, this effect eventually reverses due to higher global incomes. In the short term, the monetary rule in the model used to represent the behavior of the Federal Reserve causes interest rates to fall, both because growth is initially lower in the US but also because cheaper goods from developing countries lowers US inflation.

When a global carbon constraint is present, the transmission of the shock is supplemented by the rise in the global carbon price (see Table 2). In the longer run, higher carbon prices reduce the positive effect of higher developing country growth on the US. In the short run, relatively lower developing country growth reduces the amount of capital that flows out of the United States and dampens the negative transmission of the shock for about the first three years.

Figure 4 shows the results for GDP for all Annex 1 countries and Figure 5 shows the GDP outcomes for all non-Annex 1 countries. It is important to observe that the positive effects of high growth in developing countries on the industrialized economies are very different when a quantity constraint is imposed on global carbon emissions. For example, in the United States, after ten years GDP is approximately 0.1% higher under the permit policy but would be 0.4% higher under a price-based policy. For some countries (Australia, ROECD, Former Soviet Union and OPEC) a shock hitting a system with a hard emissions cap raises abatement costs so much that the added costs outweigh the benefit from trade and financial spillovers. For those countries, the shock lowers GDP under a cap but raises GDP under a price based system.

Results for carbon emissions under both the permit and price regimes are shown in Figures 6 and 7. The difference between these regimes in terms of responsiveness to the shock is very clear. Higher emissions in developing countries under a global target require lower emissions in all other countries in order to meet the global emissions cap. Interestingly because China is a country with lower marginal abatement costs, its emissions are constrained as well in order to accommodate the growth in other developing countries and India.

These results clearly demonstrate that hard targets for emissions at the global level can amplify uncertainties even when international permit trading is allowed. Such uncertainties could be 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.

4.2 Rise in global risk: a financial crisis

The second shock we consider is a global financial crisis. We represent the crisis as a rise in the equity risk premium in all sectors in all countries. It increases by ten percent in the first year and then declines by one percent per year until year six. From year six on, the risk premium is five percent above baseline forever. In addition we introduce a permanent fall in the productivity of housing in all countries. The reduction is five percent in all countries other than the US and ten percent in the US. This is intended to capture a housing bubble bursting.[14]

Figure 8 contains the results for a number of key variables for the United States. Note that this shock is relatively symmetric across all countries in contrast to the growth shock, which was only occurring in the developing world. The rise in risk and the fall in housing productivity lead to a portfolio reallocation away from equities and housing into government bonds in all countries. This drives up bond prices and drives down real interest rates. Housing prices and equity prices drop sharply. The required return to capital rises sharply when the risk premium is taken into account. With a given capital stock, the actual return to capital is too low after the shock and thus investment collapses (eventually driving the marginal product higher as the capital stock shrinks). Consumption drops sharply because of the sharp decline in real wealth resulting from sharply lower equity prices and sharply lower housing prices. Because the housing shock is larger in the United States, capital also flows out of the United States to other countries and hence the US trade balance improves. With the large shifts in aggregate demand, US GDP falls by four percent—a recession in terms of economic growth. GDP remains below baseline for the decade, although growth rates gradually return to trend after five years and rise above trend for another five years. The monetary reaction

[14] See McKibbin and Stoeckel (2006).

function in the model indicates a central bank cut in interest rates of 225 basis points despite a rise in inflation because the output loss is substantial.

The collapse in economic activity leads to a sharp decline in carbon emissions when a price-based system is in place. Under the permit trading system, emissions do not change but carbon prices fall. Within the US, this means that less abatement occurs under the permit policy than under the price-based system. After five years, the difference is five percent of baseline emissions, a large amount of abatement foregone. Note that the difference to US GDP under the alternative climate regimes is very small, which means that an opportunity to cut emissions at much lower economic cost is lost under a global cap relative to a global price based system.

Figures 9 and 10 show the change in carbon emissions under the two climate regimes. The price-based regimes deliver much larger emission cuts for little additional economic cost over time. The global quantity target regime delivers the same emissions reduction as planned along the baseline before the shocks hit but the price of carbon falls significantly (see the "Risk Shock" columns in Table 2). This has secondary effects on the induced technological innovations that would be required to reduce future emissions at low cost. It is likely that if this actually occurred, the credibility of the cap regime would be undermined due to the inflexibility in the originally negotiated global emissions target.

5. Summary and Conclusions for Policy

The global financial crisis of 2008 has a starkly emphasized a number of important lessons for the design of global and national climate policy. These lessons need to be considered explicitly during international negotiations on a new treaty to succeed the Kyoto Protocol after its 2008-2012 commitment period.

The first lesson is that any policy framework whose costs or benefits depend strongly on forecasts of the future state of the world or national economic conditions is likely to fail because the forecast is likely to be wrong. Countries committing to targets and timetables for emissions reductions are committing to a policy with highly uncertain costs. A global climate framework needs to endure even in the face of the wide variety of shocks that will undoubtedly occur over the coming decades. Thus there must be a mechanism built into the framework that directly addresses the issue of cost uncertainty. Otherwise, it will be much harder to negotiate a broad agreement, and the agreement may be vulnerable to collapse under adverse future shocks.

The second lesson is that it is critical to get the global and national governance structures right. There must be a clear regulatory regime in each country and a transparent way to smooth out excessive short-term volatility in prices. A system that enables or even encourages short term financial speculation in climate markets may collapse at huge expense to national economies. A hybrid system provides many of the advantages of a permit system while limiting opportunities for speculation through the annual permit mechanism. It provides a strong mix of market incentives and predictable government intervention.

The third lesson is that since shocks in one part of the world will certainly occur, the global system needs to have adequate firewalls between national climate systems to prevent destructive contagion from propagating local problems into a system-wide failure. A global cap and trade system, or alternative systems such as Stern (2006) or the Garnaut Review (2008), would be extremely vulnerable to shocks in any single economy. A system based on national hybrid policies, on the other hand, would be explicitly designed to partition national climate markets and limit the effects of a collapse in climate policy in one part of the world on climate markets elsewhere.[15]

This paper has explored these issues by examining the effects of shocks that have actually occurred in the past decade: a surprising surge of economic growth in developing

[15] For further discussion of the advantages of this point see McKibbin and Wilcoxen (2002, 2004, 2008).

countries and a global financial crisis. Quantity-based approaches such as a global permit trading regime tend to buffer some kinds of macroeconomic shocks: carbon prices rise and fall with the business cycle. However, price-based approaches such as a global carbon tax (levied at the national level) or a McKibbin Wilcoxen Hybrid would provide stronger firewalls to prevent adverse events in one carbon market from causing a collapse of the global system.

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.

References

Aldy, J. and R. Stavins (eds) (2007), *Architectures for Agreement: Addressing Global Climate Change in the Post-Kyoto World*, Cambridge University Press, pp185-208.

Bagnoli, P. McKibbin W. and P. Wilcoxen (1996) "Future Projections and Structural Change" in N. Nakicenovic, W. Nordhaus, R. Richels and F. Toth (ed) *Climate Change: Integrating Economics and Policy*, CP 96-1 , Vienna: International Institute for Applied Systems Analysis, 181-206.

Blanchard O. and S. Fischer (1989) *Lectures on Macroeconomics* MIT Press, Cambridge MA.

Bodansky, Daniel (2007), "Targets and timetables: good policy but bad politics?" in Joseph E. Aldy and Robert N. Stavins, *Architectures for Agreement: Addressing Global Climate Change in the Post-Kyoto World*, Cambridge University Press, pp57-66.

Buchner B., C. Carraro and I. Cersosimo (2002) "Economics Consequences of the U.S. Withdrawal from the Kyoto/Bonn Protocol," *Climate Policy*, 2, pp273-292.

Bohringer, C. (2001), "Climate Policies from Kyoto to Bonn: from Little to Nothing?" ZEW Discussion Paper No. 01-49, Mannheim.

Castles, I and Henderson, D. (2003) "The IPCC Emission Scenarios: An Economic-Statistical Critique", *Energy & Environment*, 14 (2&3): 159-185

Energy Information Agency (2007) "*International Energy Outlook*", Department of Energy, Washington DC.

Frankel, Jeffrey (2007), "Formulas for quantitative emission targets," in Joseph E. Aldy and Robert N. Stavins, *Architectures for Agreement: Addressing Global Climate Change in the Post-Kyoto World*, Cambridge University Press, 31-56.

Garnaut Review (2008), Garnaut Climate Change Review Interim Report, February.

Henderson, D.W., and W. McKibbin (1993), "A Comparison of Some Basic Monetary Policy Regimes for Open Economies: Implications of Different Degrees of Instrument Adjustment and Wage Persistence," *Carnegie-Rochester Conference Series on Public Policy*,39, pp 221-317.

Intergovernmental Panel on Climate Change (2001), *Climate Change 2001*, 3 vols., Cambridge: Cambridge University Press.

Intergovernmental Panel on Climate Change (2007) *Climate Change 2007: Synthesis Report*, Cambridge University Press, Cambridge.

International Monetary Fund (2008), World Economic Outlook, April.

Kemfert, Claudia (2001), "Economic Effects of Alternative Climate Policy Strategies," Environmental Science and Policy, vol 5, issue 5, pp367-384.

Löschel, A. and Z.X. Zhang (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*, Vol. 138, No. 4, pp. 711-746.

McKibbin W. J., D. Pearce and A. Stegman (2007) "Long Term Projections of Carbon Emissions*" International Journal of Forecasting*, vol 23, pp637-653.

McKibbin W. J. and A. Stoeckel (2006), "Bursting of the US Housing Bubble," www.EconomicScenarios.com, Issue 14, October, 8 pages.

McKibbin W.J. and D. Vines (2000) "Modeling Reality: The Need for Both Intertemporal Optimization and Stickiness in Models for Policymaking" *Oxford Review of Economic Policy* vol 16, no 4.

McKibbin W. and P. Wilcoxen (1997), "A Better Way to Slow Global Climate Change" *Brookings Policy Brief* no 17, June, The Brookings Institution, Washington D.C. .

McKibbin W. and P. Wilcoxen (1998) "The Theoretical and Empirical Structure of the G-Cubed Model" *Economic Modelling* , 16, 1, pp 123-148

McKibbin, W. J. and P. J. Wilcoxen (2002a), *Climate Change Policy After Kyoto: A Blueprint for a Realistic Approach*, Washington: The Brookings Institution.

McKibbin, W. J. and P. J. Wilcoxen (2002b), "The Role of Economics in Climate Change Policy," *Journal of Economic Perspectives*, 16(2), pp.107-130.

McKibbin W.J. and P.J. Wilcoxen (2004) "Estimates of the Costs of Kyoto-Marrakesh Versus The McKibbin-Wilcoxen Blueprint" *Energy Policy* vol. 32, no. 4.Elsevier, pp467-479.

McKibbin W. and P. Wilcoxen (2007) "A Credible Foundation for Long Term International Cooperation on Climate Change" in Joseph Aldy and Robert Stavins (eds), *Architectures for Agreement: Addressing Global Climate Change in the Post-Kyoto World*, Cambridge University Press, pp185-208.

McKibbin W.J., Wilcoxen P. and W. Woo (2008), "Can China Grow and Help Prevent the Tragedy of the CO2 Commons" in Garnaut, R. Song L. and W. T. Woo (Editors)(2008) *China's Dilemma: Economic Growth, the Environment and Climate Change,* Asia Pacific Press, the Brookings Institution Press, and Social Sciences Academic Press (Forthcoming).

Nordhaus, William (2006), "After Kyoto: Alternative Mechanisms to Control Global Warming," *American Economic Review,* vol. 96, no. 2, May 2006, pp. 31-34.

Nordhaus, William (2007), "To Tax or Not to Tax: The Case for a Carbon Tax," *Review of Environmental Economics and Policy*.

Obstfeld M. and K. Rogoff (1996*) Foundations of International Macroeconomics* MIT Press, Cambridge MA.

Pezzey, J (2003) "Emission taxes and tradable permits: a comparison of views on long run efficiency". *Environmental and Resource Economics,* vol. 26, no. 2. pp329-342.

Pizer, W.A. (1997), "Prices vs. Quantities Revisited: The Case of Climate Change," Resources for the Future Discussion Paper 98-02, Washington: Resources for the Future.

Roberts, M. J., and A. M. Spence (1976), "Effluent Charges and Licenses under Uncertainty," *Journal of Public Economics*, 5, 193-208.

Stern, N. (2006), Stern Review: Report on the Economics of Climate Change. Cambridge University Press, UK.

Taylor, J. B. (1993), Discretion Versus Policy Rules in Practice. Carnegie-Rochester *Carnegie-Rochester Conference Series on Public Policy* 39, 195-214.

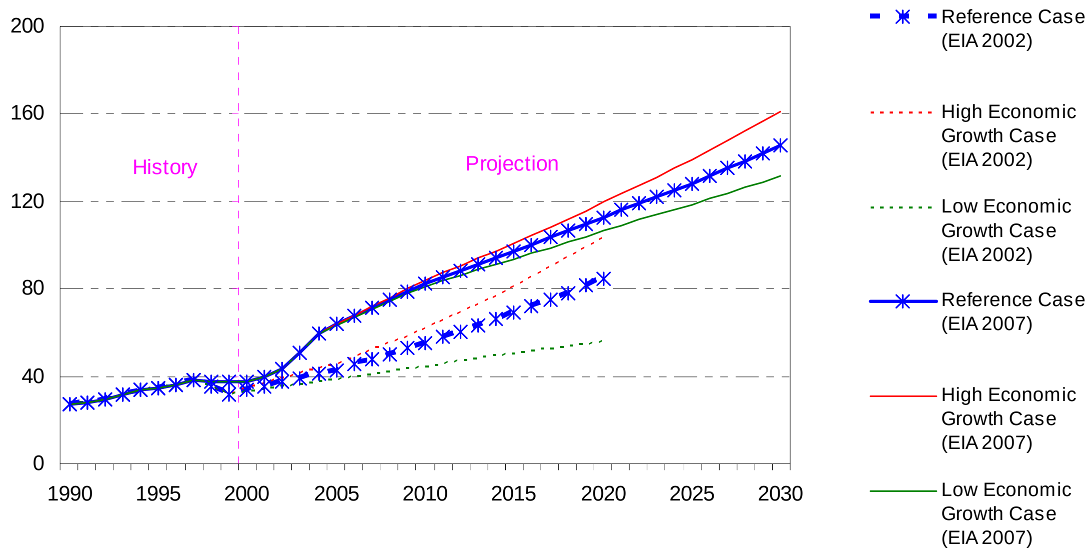
von Below, D. and T. Persson (2008), Uncertainty, Climate Change and the Global Economy. Institute for International Economic Studies, Stockholm University (mimeo)

Weitzman, M. L. (1974), "Prices vs. Quantities," *Review of Economic Studies*, 41, 477-91.

Weyant, John (ed.) (1999), "The Costs of the Kyoto Protocol: A Multi-model Evaluation," *The Energy Journal*, Special Issue.

Figure 1: Comparison of projections of energy consumption for China

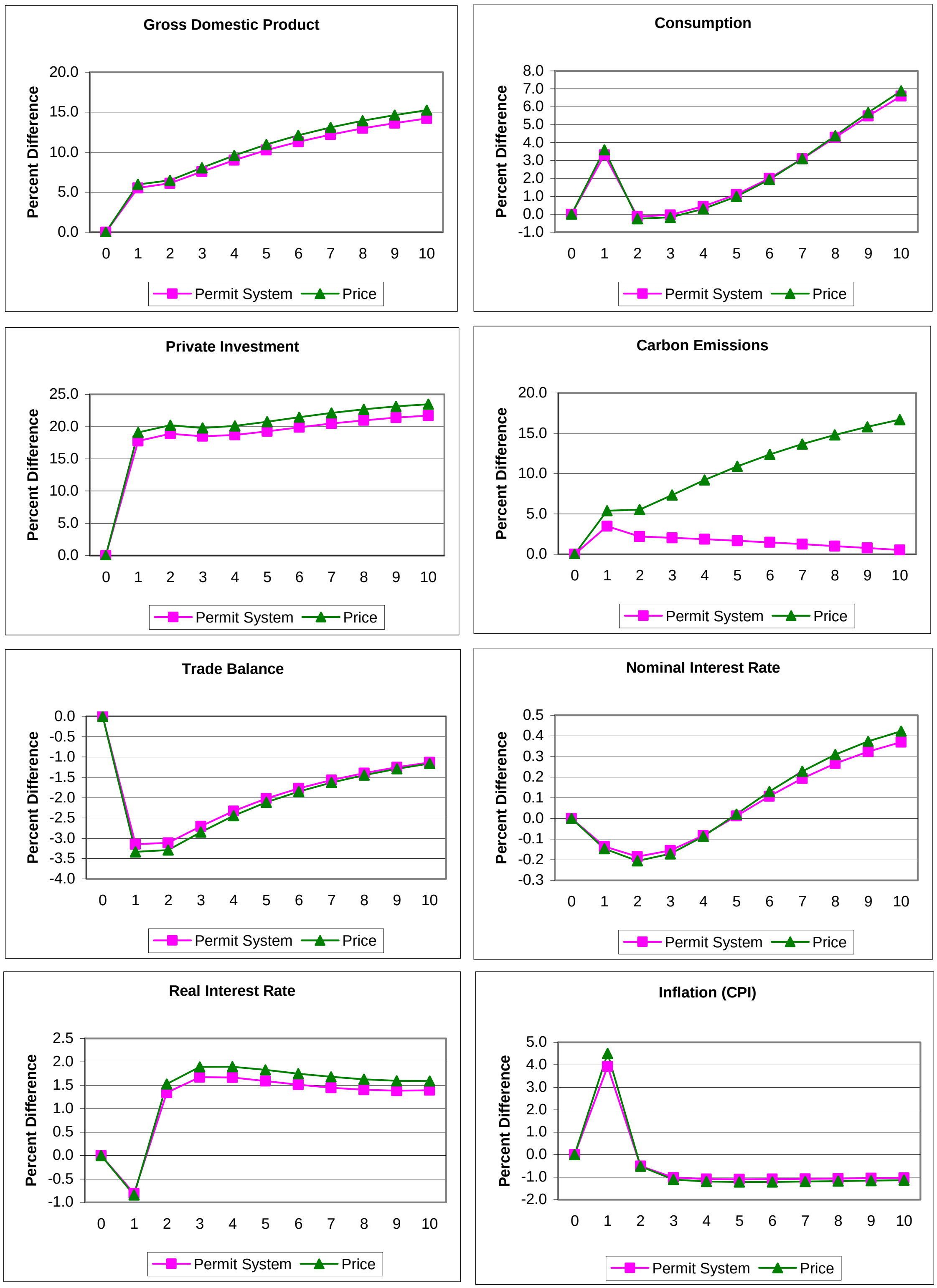
(Quadrillion Btu)



Note: The base years for projections reported in EIA 2002 and 2007 are 1999 and 2004, respectively.
Source: Energy Information Administration / International Energy Outlook 2002 and 2007

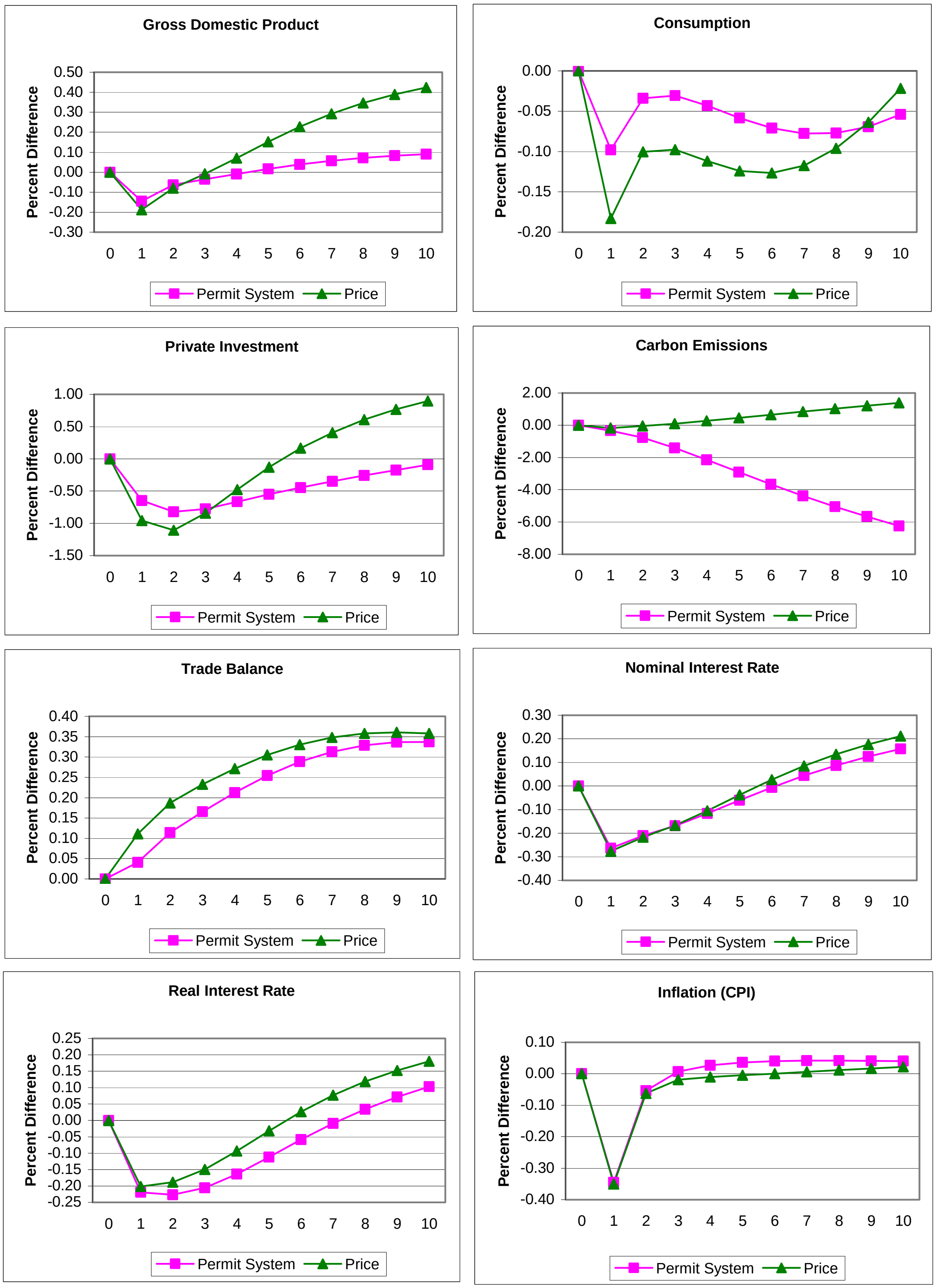
Source: Figure 1 in McKibbin Wilcoxen and Woo (2008)

Figure 2: Economic conditions in China under a growth shock



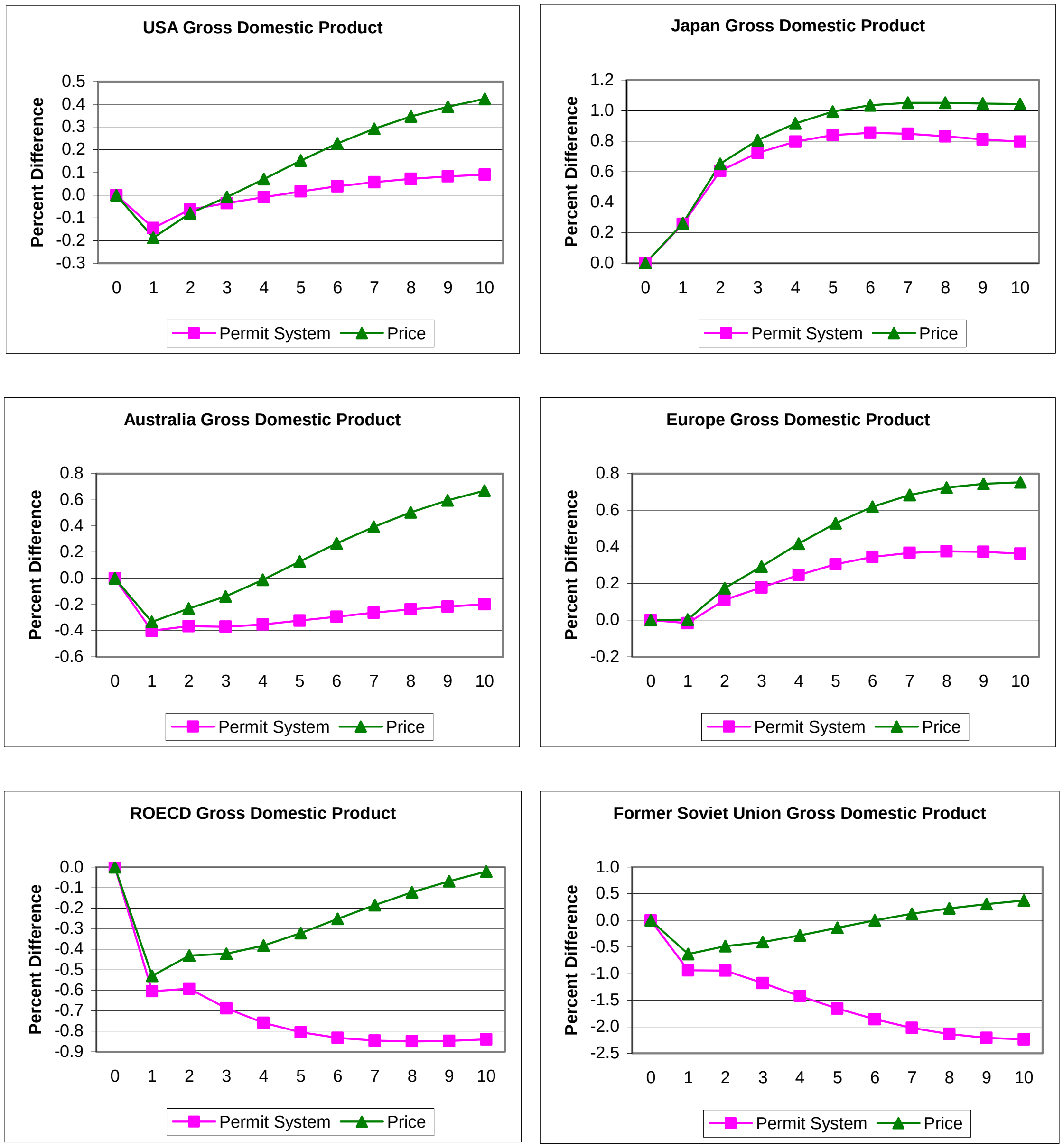
Source: G-Cubed Model version 80J

Figure 3: Economic conditions in the US under a growth shock



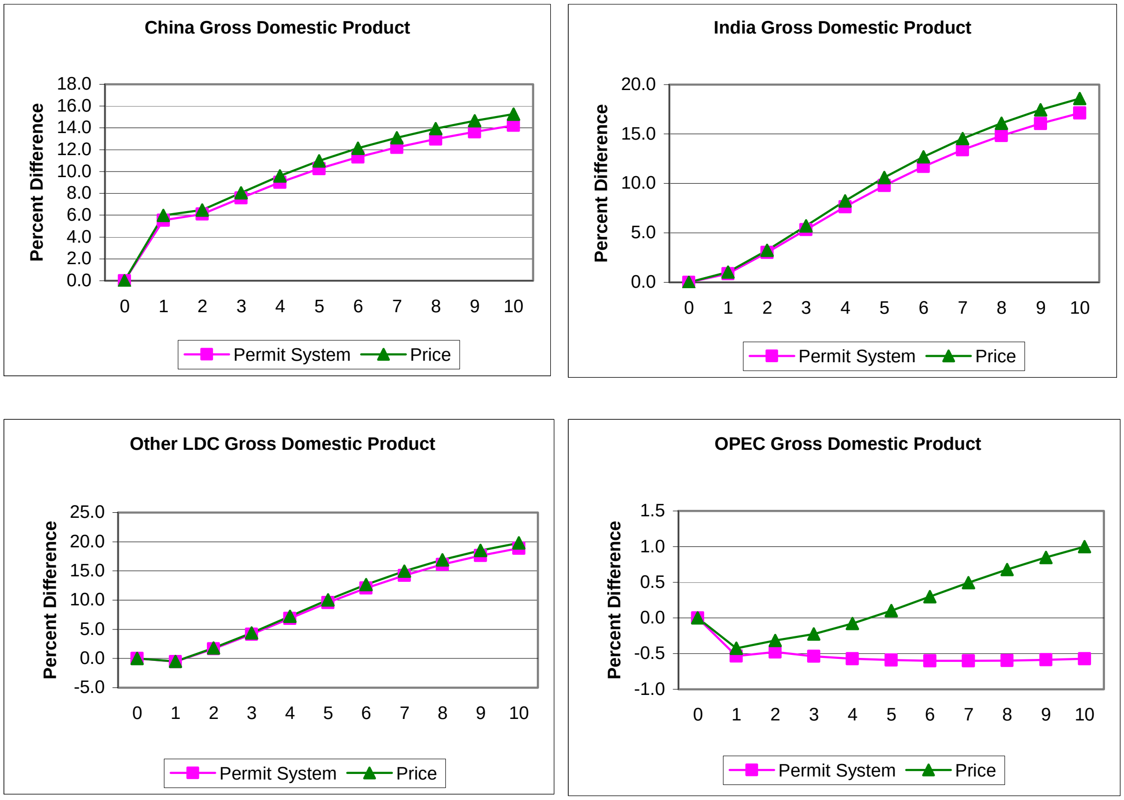
Source: G-Cubed Model version 80J

Figure 4: Gross domestic product under a growth shock, Annex 1 countries



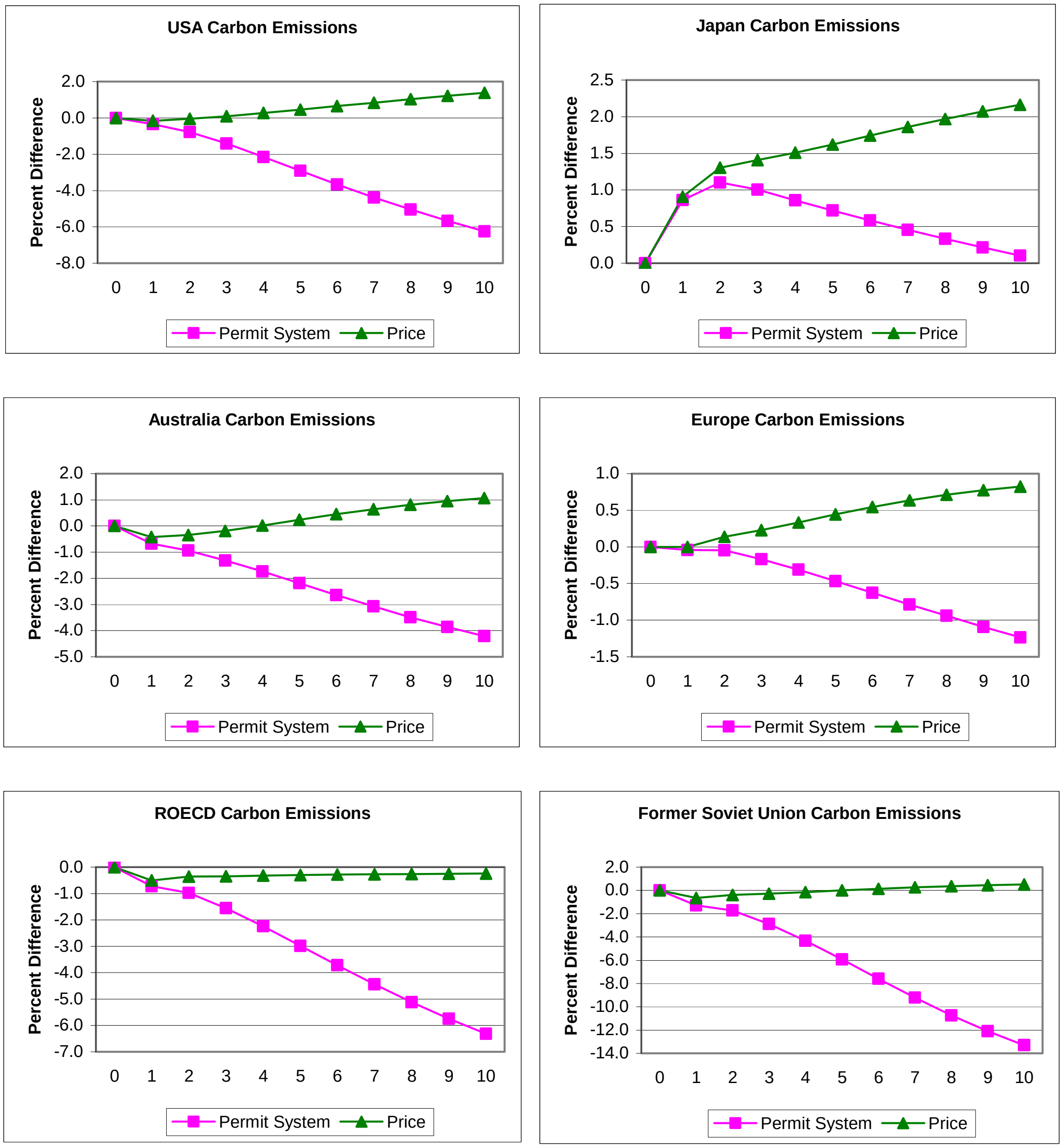
Source: G-Cubed Model version 80J

Figure 5: Gross domestic product under a growth shock, developing countries



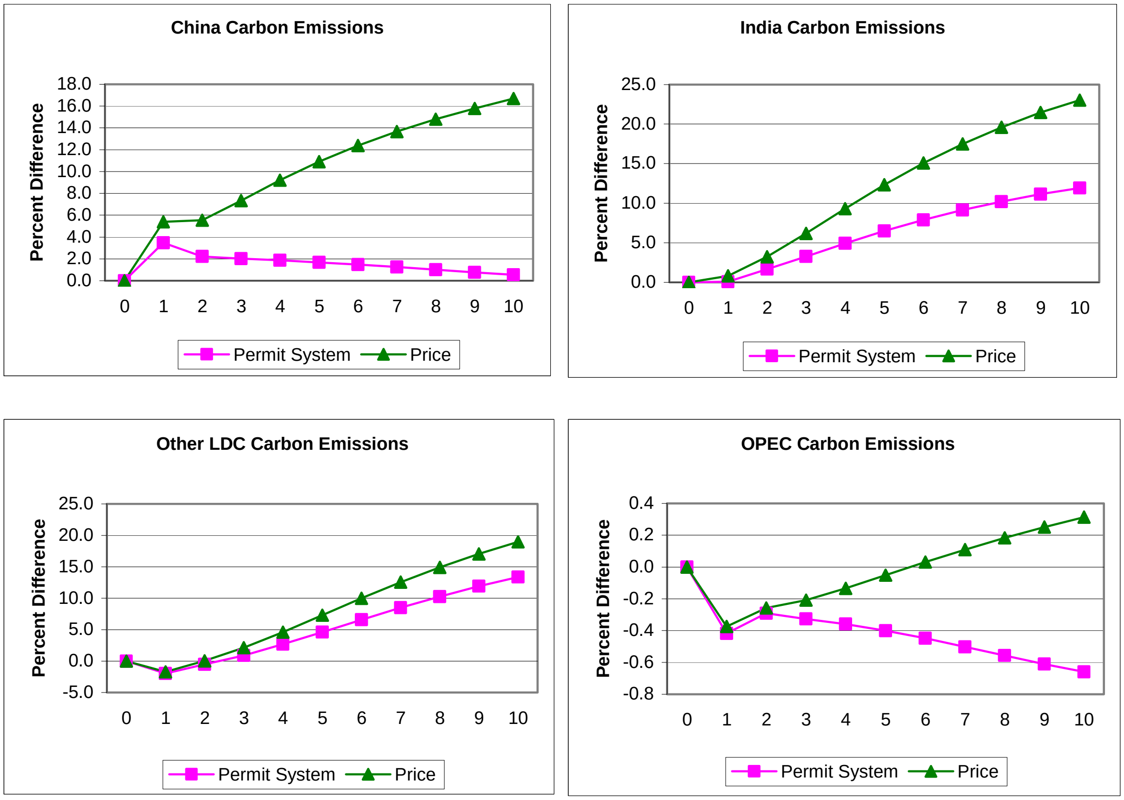
Source: G-Cubed Model version 80J

Figure 6: Carbon emissions under a growth shock, Annex 1 countries



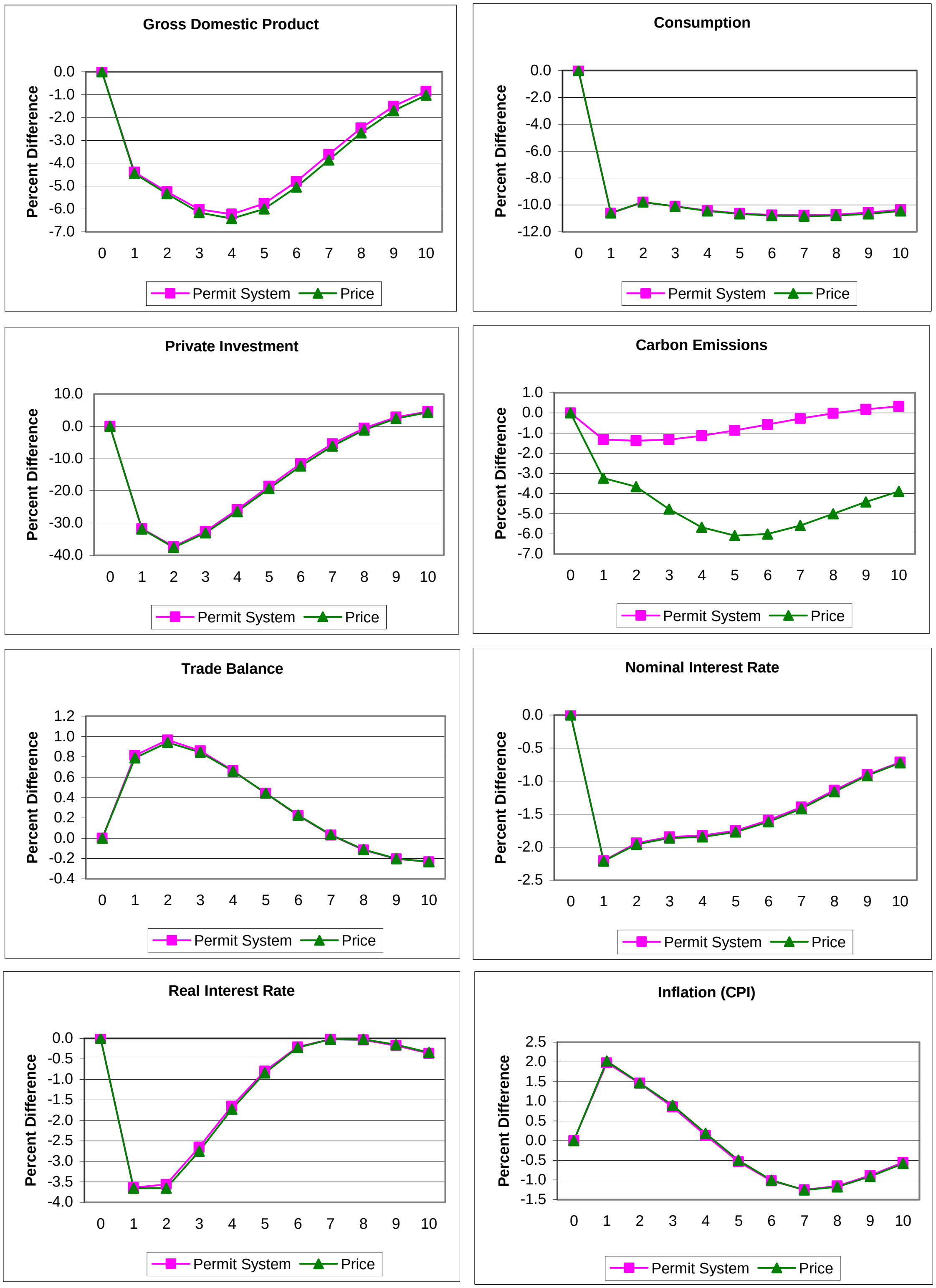
Source: G-Cubed Model version 80J

Figure 7: Carbon emissions under a growth shock, developing countries



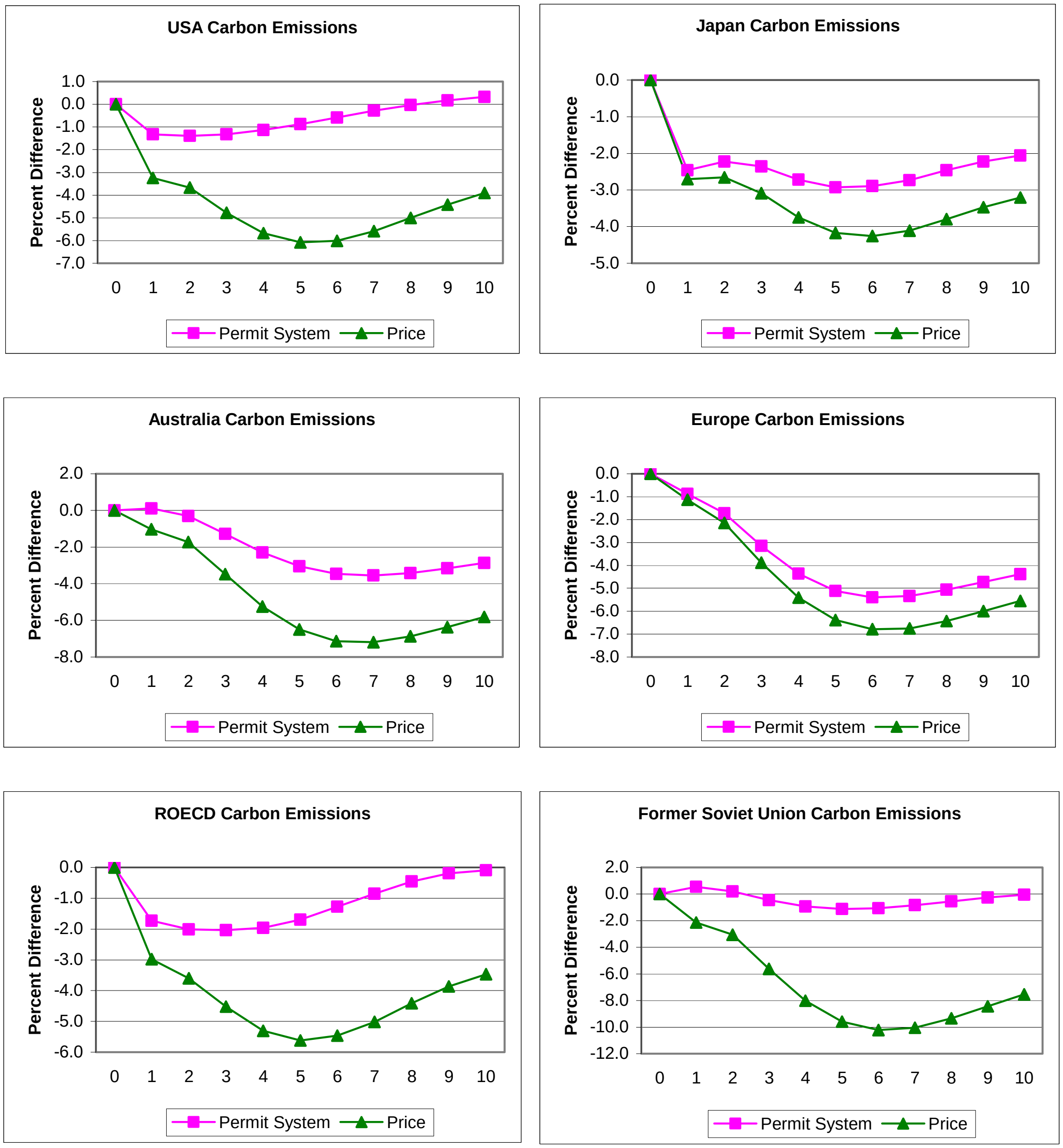
Source: G-Cubed Model version 80J

Figure 8: Economic conditions in the US under a risk shock



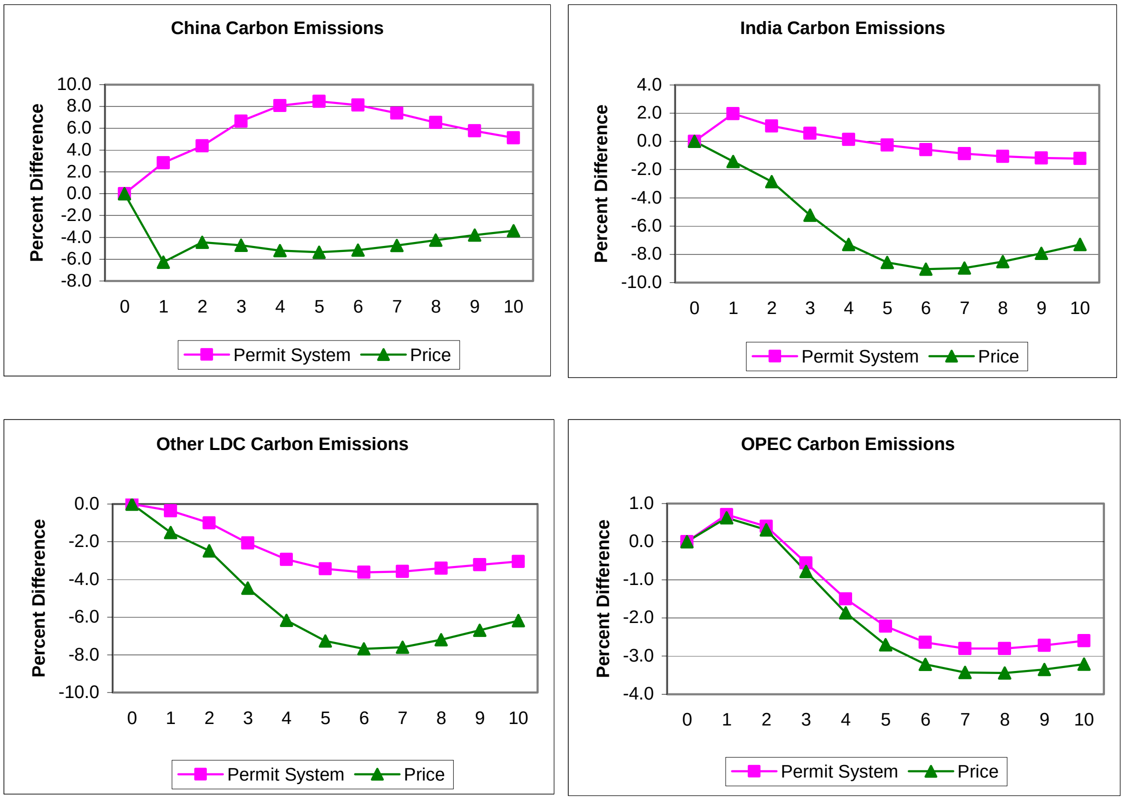
Source: G-Cubed Model version 80J

Figure 9: Carbon emissions under a risk shock, Annex 1 countries



Source: G-Cubed Model version 80J

Figure 10: Carbon emissions under a risk shock, developing countries



Source: G-Cubed Model version 80J

Table 2: Results by region

United States							
Variable	Policy	Growth Shock			Risk Shock		
		1	5	10	1	5	10
GDP	Permits	-0.1	0.0	0.1	-4.4	-5.8	-0.9
	Prices	-0.2	0.2	0.4	-4.4	-6.0	-1.0
	Difference	0.0	-0.1	-0.3	0.1	0.2	0.2
GNP	Permits	0.0	0.1	0.2	-4.1	-5.5	-0.6
	Prices	-0.1	0.3	0.5	-4.2	-5.8	-0.8
	Difference	0.0	-0.1	-0.3	0.0	0.2	0.2
Consumption	Permits	-0.1	-0.1	-0.1	-10.6	-10.6	-10.3
	Prices	-0.2	-0.1	0.0	-10.6	-10.7	-10.4
	Difference	0.1	0.1	0.0	0.0	0.0	0.1
Investment	Permits	-0.6	-0.6	-0.1	-31.7	-18.6	4.5
	Prices	-1.0	-0.1	0.9	-31.9	-19.3	4.3
	Difference	0.3	-0.4	-1.0	0.2	0.7	0.2
Carbon Emissions	Permits	-0.3	-2.9	-6.2	-1.3	-0.9	0.3
	Prices	-0.2	0.5	1.4	-3.2	-6.1	-3.9
	Difference	-0.2	-3.4	-7.6	1.9	5.2	4.2
Trade Balance	Permits	0.0	0.3	0.3	0.8	0.4	-0.2
	Prices	0.1	0.3	0.4	0.8	0.4	-0.2
	Difference	-0.1	-0.1	0.0	0.0	0.0	0.0
Current Account	Permits	0.1	0.4	0.5	1.1	0.7	0.0
	Prices	0.2	0.4	0.5	1.1	0.7	0.0
	Difference	-0.1	-0.1	0.0	0.0	0.0	0.0
Carbon Price, US$	Permits	0.7	5.2	10.9	-4.0	-8.0	-5.7
	Prices	0.0	0.0	0.0	0.0	0.0	0.0
	Difference	0.7	5.2	10.9	-4.0	-8.0	-5.7

Table 2: Results by region, continued

Japan							
Variable	Policy	Growth Shock			Risk Shock		
		1	5	10	1	5	10
GDP	Permits	0.3	0.8	0.8	-2.5	-4.3	-1.8
	Prices	0.3	1.0	1.0	-2.5	-4.4	-1.9
	Difference	0.0	-0.2	-0.2	0.0	0.1	0.1
GNP	Permits	0.2	0.8	0.9	-2.9	-4.6	-2.2
	Prices	0.2	1.0	1.1	-2.9	-4.8	-2.3
	Difference	0.0	-0.2	-0.3	0.0	0.2	0.1
Consumption	Permits	0.1	0.3	0.6	-4.8	-3.7	-4.9
	Prices	0.1	0.2	0.6	-4.8	-3.7	-5.0
	Difference	0.0	0.0	-0.1	0.0	0.0	0.1
Investment	Permits	3.4	2.9	1.0	-18.2	-11.2	-4.2
	Prices	3.6	3.4	1.6	-18.4	-11.6	-4.4
	Difference	-0.2	-0.5	-0.6	0.2	0.3	0.2
Carbon Emissions	Permits	0.9	0.7	0.1	-2.5	-2.9	-2.1
	Prices	0.9	1.6	2.2	-2.7	-4.2	-3.2
	Difference	0.0	-0.9	-2.1	0.2	1.2	1.1
Trade Balance	Permits	-0.5	0.0	0.5	-0.1	-0.6	0.0
	Prices	-0.5	0.1	0.5	-0.1	-0.6	0.0
	Difference	0.0	0.0	0.0	0.0	0.0	0.0
Current Account	Permits	-0.4	0.2	0.7	-0.7	-1.1	-0.3
	Prices	-0.4	0.2	0.8	-0.8	-1.2	-0.4
	Difference	0.0	0.0	-0.1	0.0	0.0	0.0
Carbon Price, US$	Permits	0.7	5.2	10.9	-4.0	-8.0	-5.7
	Prices	0.0	0.0	0.0	0.0	0.0	0.0
	Difference	0.7	5.2	10.9	-4.0	-8.0	-5.7

Table 2: Results by region, continued

Australia							
Variable	Policy	Growth Shock			Risk Shock		
		1	5	10	1	5	10
GDP	Permits	-0.4	-0.3	-0.2	-1.4	-4.8	-2.9
	Prices	-0.3	0.1	0.7	-1.6	-5.4	-3.3
	Difference	-0.1	-0.5	-0.9	0.2	0.6	0.5
GNP	Permits	-0.3	-0.2	0.0	-0.8	-4.6	-2.7
	Prices	-0.3	0.3	0.9	-1.0	-5.1	-3.2
	Difference	-0.1	-0.4	-0.8	0.2	0.5	0.4
Consumption	Permits	-0.4	-0.3	-0.1	-4.1	-2.9	-4.1
	Prices	-0.4	-0.3	-0.2	-4.1	-2.8	-4.2
	Difference	0.0	0.1	0.0	0.0	-0.1	0.1
Investment	Permits	-1.8	-2.8	-1.2	-16.8	-28.6	-7.2
	Prices	-1.1	0.1	1.8	-17.7	-31.3	-8.2
	Difference	-0.7	-2.9	-2.9	0.9	2.7	0.9
Carbon Emissions	Permits	-0.7	-2.2	-4.2	0.1	-3.0	-2.9
	Prices	-0.4	0.2	1.1	-1.0	-6.5	-5.8
	Difference	-0.2	-2.4	-5.3	1.1	3.5	2.9
Trade Balance	Permits	0.3	0.5	0.4	-0.3	0.1	-0.1
	Prices	0.2	0.4	0.4	-0.3	0.1	-0.1
	Difference	0.1	0.1	0.0	0.0	0.0	0.0
Current Account	Permits	0.4	0.7	0.7	0.2	0.4	-0.1
	Prices	0.3	0.6	0.6	0.2	0.4	-0.1
	Difference	0.1	0.1	0.1	0.0	0.0	0.0
Carbon Price, US$	Permits	0.7	5.2	10.9	-4.0	-8.0	-5.7
	Prices	0.0	0.0	0.0	0.0	0.0	0.0
	Difference	0.7	5.2	10.9	-4.0	-8.0	-5.7

Table 2: Results by region, continued

Europe							
Variable	Policy	Growth Shock			Risk Shock		
		1	5	10	1	5	10
GDP	Permits	0.0	0.3	0.4	-2.0	-6.6	-3.7
	Prices	0.0	0.5	0.8	-2.0	-6.8	-3.8
	Difference	0.0	-0.2	-0.4	0.0	0.2	0.2
GNP	Permits	0.0	0.4	0.5	-2.1	-6.7	-3.7
	Prices	0.0	0.6	0.9	-2.1	-6.9	-3.8
	Difference	0.0	-0.2	-0.4	0.0	0.2	0.2
Consumption	Permits	-0.1	0.1	0.3	-4.4	-4.7	-5.9
	Prices	-0.1	0.1	0.4	-4.4	-4.7	-6.0
	Difference	0.0	0.0	-0.1	0.0	0.1	0.1
Investment	Permits	0.4	0.5	-0.3	-21.0	-29.0	-7.7
	Prices	0.7	1.6	0.9	-21.3	-29.8	-8.1
	Difference	-0.3	-1.1	-1.2	0.3	0.8	0.4
Carbon Emissions	Permits	0.0	-0.5	-1.2	-0.9	-5.1	-4.4
	Prices	0.0	0.4	0.8	-1.1	-6.4	-5.6
	Difference	0.0	-0.9	-2.1	0.3	1.3	1.2
Trade Balance	Permits	0.0	0.2	0.4	0.0	0.2	0.1
	Prices	0.0	0.2	0.4	-0.1	0.2	0.1
	Difference	0.0	0.0	0.0	0.0	0.0	0.0
Current Account	Permits	0.0	0.3	0.5	-0.2	0.1	0.1
	Prices	0.0	0.3	0.6	-0.2	0.0	0.1
	Difference	0.0	0.0	0.0	0.0	0.0	0.0
Carbon Price, US$	Permits	0.7	5.2	10.9	-4.0	-8.0	-5.7
	Prices	0.0	0.0	0.0	0.0	0.0	0.0
	Difference	0.7	5.2	10.9	-4.0	-8.0	-5.7

Table 2: Results by region, continued

Rest of the OECD							
Variable	Policy	Growth Shock			Risk Shock		
		1	5	10	1	5	10
GDP	Permits	-0.6	-0.8	-0.8	-3.0	-4.1	-1.4
	Prices	-0.5	-0.3	0.0	-3.2	-4.7	-1.7
	Difference	-0.1	-0.5	-0.8	0.2	0.6	0.4
GNP	Permits	-0.5	-0.4	-0.3	-3.9	-4.8	-1.6
	Prices	-0.4	0.1	0.5	-4.1	-5.4	-2.0
	Difference	-0.1	-0.5	-0.8	0.2	0.6	0.3
Consumption	Permits	-0.6	-0.5	-0.7	-5.7	-4.3	-4.6
	Prices	-0.5	-0.5	-0.5	-5.7	-4.3	-4.7
	Difference	0.0	0.0	-0.1	0.1	0.1	0.1
Investment	Permits	-4.8	-9.7	-5.0	-24.6	-23.7	-5.1
	Prices	-3.7	-5.5	-1.5	-26.1	-27.1	-5.7
	Difference	-1.1	-4.1	-3.5	1.5	3.4	0.6
Carbon Emissions	Permits	-0.7	-3.0	-6.3	-1.7	-1.7	-0.1
	Prices	-0.5	-0.3	-0.2	-3.0	-5.6	-3.5
	Difference	-0.2	-2.7	-6.1	1.2	3.9	3.4
Trade Balance	Permits	0.7	0.9	0.6	0.2	-0.1	0.3
	Prices	0.5	0.7	0.5	0.3	-0.1	0.3
	Difference	0.1	0.2	0.1	-0.1	-0.1	0.0
Current Account	Permits	0.7	1.2	1.1	-0.7	-0.9	0.0
	Prices	0.6	1.1	1.0	-0.7	-0.9	0.1
	Difference	0.1	0.1	0.1	0.0	0.0	0.0
Carbon Price, US$	Permits	0.7	5.2	10.9	-4.0	-8.0	-5.7
	Prices	0.0	0.0	0.0	0.0	0.0	0.0
	Difference	0.7	5.2	10.9	-4.0	-8.0	-5.7

Table 2: Results by region, continued

Former Soviet Union							
Variable	Policy	Growth Shock			Risk Shock		
		1	5	10	1	5	10
GDP	Permits	-0.9	-1.7	-2.2	-1.7	-6.0	-3.2
	Prices	-0.6	-0.1	0.4	-2.2	-7.6	-4.4
	Difference	-0.3	-1.5	-2.6	0.5	1.7	1.2
GNP	Permits	-1.0	-1.4	-1.6	-1.7	-6.2	-3.3
	Prices	-0.6	0.0	0.7	-2.2	-7.8	-4.4
	Difference	-0.3	-1.4	-2.3	0.5	1.6	1.1
Consumption	Permits	-0.9	-0.5	-0.9	-3.2	-3.3	-4.1
	Prices	-0.8	-0.6	-0.5	-3.4	-3.5	-4.6
	Difference	-0.1	0.0	-0.4	0.3	0.2	0.6
Investment	Permits	-10.0	29.7	73.9	-21.4	53.9	55.4
	Prices	-5.3	6.6	1.4	-28.2	75.3	75.3
	Difference	-4.7	23.1	72.5	6.7	-21.4	-19.9
Carbon Emissions	Permits	-1.3	-5.9	-13.3	0.5	-1.1	-0.1
	Prices	-0.6	0.0	0.5	-2.1	-9.6	-7.5
	Difference	-0.6	-5.9	-13.8	2.7	8.5	7.5
Trade Balance	Permits	0.9	1.4	1.1	-1.0	-0.4	0.1
	Prices	0.7	1.0	0.8	-0.7	-0.1	0.1
	Difference	0.3	0.4	0.3	-0.2	-0.3	0.0
Current Account	Permits	0.9	1.6	1.7	-1.0	-0.5	-0.2
	Prices	0.7	1.2	1.2	-0.7	-0.2	-0.1
	Difference	0.3	0.5	0.6	-0.2	-0.3	-0.1
Carbon Price, US$	Permits	0.7	5.2	10.9	-4.0	-8.0	-5.7
	Prices	0.0	0.0	0.0	0.0	0.0	0.0
	Difference	0.7	5.2	10.9	-4.0	-8.0	-5.7

Table 2: Results by region, continued

China							
Variable	Policy	Growth Shock			Risk Shock		
		1	5	10	1	5	10
GDP	Permits	5.5	10.3	14.2	-5.4	-3.7	-2.1
	Prices	6.0	11.0	15.3	-5.9	-4.5	-2.5
	Difference	-0.4	-0.7	-1.0	0.5	0.8	0.5
GNP	Permits	5.6	10.0	13.9	-5.4	-3.7	-2.1
	Prices	6.0	10.7	14.9	-5.9	-4.5	-2.6
	Difference	-0.4	-0.7	-1.0	0.5	0.8	0.5
Consumption	Permits	3.3	1.1	6.6	-6.3	-2.5	-3.7
	Prices	3.6	1.0	6.9	-6.5	-2.6	-4.2
	Difference	-0.3	0.1	-0.3	0.3	0.1	0.4
Investment	Permits	17.8	19.3	21.7	-13.8	-5.6	-2.7
	Prices	19.1	20.7	23.5	-15.4	-6.9	-3.1
	Difference	-1.3	-1.5	-1.8	1.6	1.4	0.4
Carbon Emissions	Permits	3.5	1.7	0.5	2.8	8.5	5.1
	Prices	5.4	10.9	16.7	-6.3	-5.4	-3.4
	Difference	-1.9	-9.2	-16.2	9.1	13.8	8.5
Trade Balance	Permits	-3.1	-2.0	-1.1	0.6	-0.4	0.1
	Prices	-3.3	-2.1	-1.2	0.8	-0.3	0.1
	Difference	0.2	0.1	0.0	-0.2	0.0	0.0
Current Account	Permits	-3.0	-2.4	-1.8	0.6	-0.3	0.1
	Prices	-3.2	-2.5	-1.9	0.8	-0.3	0.1
	Difference	0.2	0.1	0.1	-0.1	0.0	0.0
Carbon Price, US$	Permits	0.7	5.2	10.9	-4.0	-8.0	-5.7
	Prices	0.0	0.0	0.0	0.0	0.0	0.0
	Difference	0.7	5.2	10.9	-4.0	-8.0	-5.7

Table 2: Results by region, continued

India							
Variable	Policy	Growth Shock			Risk Shock		
		1	5	10	1	5	10
GDP	Permits	0.9	9.8	17.1	-1.3	-5.5	-4.2
	Prices	1.0	10.6	18.6	-1.5	-6.4	-4.9
	Difference	-0.2	-0.8	-1.5	0.2	0.9	0.8
GNP	Permits	0.9	9.7	16.9	-1.3	-5.6	-4.2
	Prices	1.0	10.6	18.4	-1.5	-6.5	-5.0
	Difference	-0.2	-0.8	-1.5	0.2	0.9	0.8
Consumption	Permits	-1.2	-0.1	5.4	-3.1	-3.3	-5.0
	Prices	-1.2	-0.2	5.8	-3.1	-3.4	-5.4
	Difference	0.0	0.1	-0.4	0.0	0.1	0.4
Investment	Permits	9.3	30.0	35.5	-11.5	-15.9	-7.3
	Prices	10.3	32.8	38.9	-12.8	-18.4	-8.4
	Difference	-1.0	-2.7	-3.4	1.2	2.5	1.1
Carbon Emissions	Permits	0.1	6.5	11.9	2.0	-0.3	-1.2
	Prices	0.8	12.3	23.0	-1.4	-8.6	-7.3
	Difference	-0.7	-5.9	-11.1	3.4	8.3	6.1
Trade Balance	Permits	-0.3	-0.8	-0.6	-0.5	-0.1	0.0
	Prices	-0.3	-0.9	-0.7	-0.5	0.0	-0.1
	Difference	0.0	0.1	0.1	0.0	0.0	0.0
Current Account	Permits	-0.3	-1.0	-1.1	-0.5	-0.1	0.0
	Prices	-0.3	-1.0	-1.1	-0.5	0.0	0.0
	Difference	0.0	0.1	0.0	0.0	-0.1	0.0
Carbon Price, US$	Permits	0.7	5.2	10.9	-4.0	-8.0	-5.7
	Prices	0.0	0.0	0.0	0.0	0.0	0.0
	Difference	0.7	5.2	10.9	-4.0	-8.0	-5.7

Table 2: Results by region, continued

Other Developing Countries							
Variable	Policy	Growth Shock			Risk Shock		
		1	5	10	1	5	10
GDP	Permits	-0.6	9.6	18.9	-1.2	-5.7	-3.7
	Prices	-0.5	10.1	19.8	-1.4	-6.3	-4.1
	Difference	-0.1	-0.5	-0.9	0.2	0.6	0.5
GNP	Permits	-0.6	9.5	18.4	-1.2	-5.9	-3.8
	Prices	-0.5	10.1	19.4	-1.4	-6.5	-4.3
	Difference	-0.1	-0.5	-0.9	0.2	0.6	0.4
Consumption	Permits	-2.7	-2.7	1.1	-3.3	-3.1	-4.4
	Prices	-2.8	-2.8	1.3	-3.3	-3.1	-4.5
	Difference	0.0	0.1	-0.1	0.0	0.0	0.2
Investment	Permits	3.6	71.0	64.4	-15.1	-33.7	-10.0
	Prices	4.5	74.5	67.2	-16.3	-36.8	-11.0
	Difference	-0.9	-3.5	-2.9	1.2	3.2	1.0
Carbon Emissions	Permits	-2.0	4.6	13.4	-0.4	-3.4	-3.0
	Prices	-1.7	7.3	19.0	-1.5	-7.3	-6.2
	Difference	-0.3	-2.7	-5.6	1.2	3.8	3.1
Trade Balance	Permits	1.2	-0.5	-1.2	-1.2	-0.4	0.0
	Prices	1.2	-0.5	-1.2	-1.2	-0.4	0.1
	Difference	0.0	0.0	0.1	0.0	0.0	0.0
Current Account	Permits	1.1	-0.9	-2.2	-1.2	-0.7	0.0
	Prices	1.1	-0.9	-2.2	-1.2	-0.6	0.0
	Difference	0.0	0.0	0.0	0.0	0.0	0.0
Carbon Price, US$	Permits	0.7	5.2	10.9	-4.0	-8.0	-5.7
	Prices	0.0	0.0	0.0	0.0	0.0	0.0
	Difference	0.7	5.2	10.9	-4.0	-8.0	-5.7

Table 2: Results by region, continued

OPEC							
Variable	Policy	Growth Shock			Risk Shock		
		1	5	10	1	5	10
GDP	Permits	-0.5	-0.6	-0.6	0.2	-5.9	-6.0
	Prices	-0.4	0.1	1.0	-0.1	-6.8	-6.9
	Difference	-0.1	-0.7	-1.6	0.3	0.9	0.9
GNP	Permits	-0.5	-0.5	-0.4	0.1	-5.9	-6.0
	Prices	-0.4	0.2	1.2	-0.2	-6.8	-6.9
	Difference	-0.1	-0.7	-1.5	0.3	0.8	0.9
Consumption	Permits	-0.7	-0.1	0.2	-2.7	-3.1	-4.0
	Prices	-0.6	-0.3	0.2	-2.9	-3.1	-4.1
	Difference	0.0	0.1	0.0	0.1	0.0	0.1
Investment	Permits	-4.9	8.7	5.1	-9.9	67.0	66.8
	Prices	-3.5	0.6	-13.7	-12.2	74.5	75.2
	Difference	-1.4	8.1	18.8	2.3	-7.5	-8.4
Carbon Emissions	Permits	-0.4	-0.4	-0.7	0.7	-2.2	-2.6
	Prices	-0.4	-0.1	0.3	0.6	-2.7	-3.2
	Difference	0.0	-0.3	-1.0	0.1	0.5	0.6
Trade Balance	Permits	0.4	0.5	0.3	-1.0	0.3	0.4
	Prices	0.3	0.5	0.4	-1.0	0.2	0.4
	Difference	0.0	0.0	-0.1	0.0	0.1	0.0
Current Account	Permits	0.4	0.6	0.5	-1.0	0.1	0.2
	Prices	0.3	0.6	0.6	-1.1	0.0	0.1
	Difference	0.0	0.0	-0.1	0.0	0.1	0.0
Carbon Price, US$	Permits	0.7	5.2	10.9	-4.0	-8.0	-5.7
	Prices	0.0	0.0	0.0	0.0	0.0	0.0
	Difference	0.7	5.2	10.9	-4.0	-8.0	-5.7

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