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Greenhouse abatement policy: insights from the G-cubed multi-country model†

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The third meeting of the Conference of the Parties of the Framework Convention on Climate Change held in Japan last December was a lost opportunity to set a realistic policy framework for addressing climate change in the coming decades. A number of countries proposed targets for greenhouse emissions, to be reached by a target date. The outcome was a range of different targets for each country. Analysis with the G-cubed multi-country model suggests that fixed targets are a costly way to address climate change. The extent of potential cost suggests the agreement will eventually fail. A better way to address climate change is to focus on uniformity in policy instruments that deliver differentiated outcomes rather than focus on differentiated policy settings.

1. Introduction

The current debate on greenhouse gas emissions is of fundamental importance for the future direction of the Australian economy. Carbon dioxide is the major greenhouse gas and a major source of carbon dioxide emissions is the burning of fossil fuels. Australia has been endowed with large reserves of fossil fuels and, reflecting this endowment, the Australian economy is very fossil fuel-intensive in energy production as well as exports. Because of this reliance on fossil fuels, as well as a range of other factors such as the potential for relatively high future population growth, Australia is particularly vulnerable to any global action on abating greenhouse gas emissions.

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Some people believe that not taking action to curb the rising emissions of greenhouse gases will be very expensive for human well-being in future years. On the other hand, there are those who believe that a fundamental shift in the economic structure of the world economy away from its current reliance on fossil fuels for energy production will lead to substantial economic and social costs during a transition period that could last many decades. Even if these costs are deemed to be worthwhile, there is a continuing debate about how the burden of adjustment should be shared among countries. A crucial aspect of this debate is that, whether policies are adopted, their eventual consequences are highly uncertain. Unfortunately, policy decisions need to be made by governments and decisions need to be made by households and firms in making their future investment plans. It is important that these decisions are not made in an information vacuum.

In the Australian debate there is a widely held view that the outcome for Australia depends on whether or not the Australian government does or does not sign the agreement currently being negotiated under the UN Framework Convention on Climate Change (UNFCCC). An often neglected issue is that the Australian economy will be affected independently of the position taken by its government. This is, first, because Australia is small in the global economy and, second, because Australia relies on global markets for carbon-intensive goods to generate income. These markets are subject to action under international agreements signed by the governments of other countries. Global economic models can and have been used to evaluate the implications for Australia of a range of global and domestic policy actions and clearly illustrate the interdependencies not only of greenhouse emissions but of policy actions in individual countries.

Economic models are just one of many sources of information that can be brought to bear on the greenhouse problem. Like models in any discipline, economic models are simplifications of reality. Nonetheless, they do have a number of important advantages. Despite a range of criticisms and well documented limitations, large-scale economic models do provide information and basic insights that it would be folly to ignore. For example, a key feature of such economic models is that they embody economists' attempts to model the reactions of human beings based on observed empirical evidence. Incorporating human behaviour into any projection of the future is crucial. The world economy in 1997 is far from a simple scaling of the world in 1947 and it is unlikely that anyone in 1947 could have foreseen the world we now live in. Yet the current debate on greenhouse gases regularly involves speculation over an horizon of at least 50 years into the future. Abstractions notwithstanding, global economic models, such as G-cubed, provide the best available input into economic policy-making in these circumstances.

An overview of the debate in Australia can be found in Department of Foreign Affairs and Trade (1997). The purpose of the current article is to summarise what we have learnt from the G-cubed multi-country model of relevance to the greenhouse policy debate. Section 2 gives an overview of how economic models can contribute to the greenhouse policy debate. Section 3 gives a outline of the key features of the G-cubed multi-country model and how it has been used in the climate change debate. The main insights from the modelling project are summarised in section 4. Section 5 summarises concrete policy proposals that have emerged from research with the model. A conclusion is presented in section 6.

2. The role of an economic model in the greenhouse debate

Economic models have an important role to play in the greenhouse debate because they embody knowledge, both theoretical and empirical, that has been accumulating for many decades. This is knowledge about the way individuals react to changing circumstances and the way these responses manifest in various markets. Such models are built on a range of identities which must hold always independently of the assumed behaviour of individuals. If nothing else, this provides a consistency check on the wide range of assumptions that are involved in a question such as greenhouse policy.

An economic model provides a framework for asking 'what if' questions about how economies respond to a change in a forcing variable whether it is a drought, an increase in OPEC oil prices or a domestic or foreign government policy change. These responses can be traced through the economy by modelling the behaviour of households, firms, government and institutions and how they interact in markets. It is foolish to think we can use these models to predict the future beyond a few years with any precision, however. This is partly because of the abstractions they embody but also because the future is inherently unpredictable due to forces not captured in the models. Their usefulness is in addressing questions about what the key driving variables will be in determining the future, as well as the effects of alternative policies on possible futures. In other words, the models help us understand how much a variable of interest, such as national income, is likely to change as a result of a change in a policy instrument, technology or the global environment. Models are used most usefully as frameworks for thinking about the future, frameworks that are transparent and subject to empirical evaluation based on recent experience and observed empirical relationships.

Economic models provide a very effective way to move away from future analysis based solely on trend extrapolation. An example of why formulating policy based on extrapolation of trends can be a problem is clearly illustrated by the oil price shocks of the 1970s. In Bagnoli, McKibbin and Wilcoxen (1996) it is shown that GDP, energy use and carbon dioxide emissions for the United States and Japan rose in parallel from 1965 to 1973, implying that energy use per unit of GDP was relatively constant. When oil prices rose, however, energy use per unit of GDP began to fall significantly. During the subsequent period, therefore, energy use grew a lot more slowly than GDP. American and Japanese energy users substituted away from energy when oil prices where high; they conserved energy.

A couple of insights from this example are crucial for thinking about greenhouse policy. One is that it is clear that economies can be highly responsive to changes in relative prices, even over fairly short periods of time. This response is reflected on the demand side through changes in consumption patterns and on the supply side through changes in the structure of economies. Second, it shows that extrapolative projections that would have been made in 1972 would very quickly have proved completely wrong because of significant unforeseen events. Thus, any prediction of the future is clearly a conditional projection. Third, adjustment to surprises can be very costly (in terms of lost output) since, in the short to medium term, physical capital is difficult to move between sectors of the economy and workers cannot be retrained quickly. In the short run, any sharp change in policy intended to abate greenhouse gases is likely to be costly.

Ultimately, however, the usefulness of economic models is not so much in the numerical magnitudes they produce (although these are very useful in placing debates in context) but in improving our understanding of the key underlying mechanisms that determine any set of numbers.

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

The G-cubed multi-country model was developed by McKibbin and Wilcoxen (1992b) and has been updated in McKibbin and Wilcoxen (1995). It is a dynamic intertemporal general equilibrium model (DIGEM). It combines the approach taken in the earlier research of McKibbin and Sachs (1991) in the McKibbin Sachs Global model (MSG model) with the disaggregated, econometrically estimated, intertemporal general equilibrium model of the US economy by Jorgenson and Wilcoxen (1991).

G-cubed has been constructed to contribute to the current policy debate on environmental policy and international trade with a focus on global warming policies, but it has many features that will make it useful for answering a range of issues in environmental regulation, microeconomic and macro-economic policy questions. It is a world model with substantial regional disaggregation and sectoral detail. In addition, countries and regions are linked through trade and financial markets. G-cubed offers a strong foundation for analysis of both short-run macro-economic policy issues and long-run growth prospects. Budget constraints are imposed on households, governments and nations (the latter through accumulations of foreign debt). To accommodate these constraints households and firms are assumed to use the model to generate forecasts of future economic performance and use these projections in their planning of consumption and investment decisions. The response of monetary and fiscal authorities in different countries can have important effects in the short to medium run which, given the long lags in physical capital and other asset accumulation, can be a substantial period of time. Overall, the model is designed to provide a bridge between computable general equilibrium (CGE) models that typically ignore the adjustment path between equilibria, and macro-economic models that typically ignore individual behaviour and the sectoral composition of economies. Details on this integration and how G-cubed bridges the gap between CGE and traditional macro-econometric models can be found in McKibbin (1993).[1]

[1] The G-cubed model has been funded by a range of direct funding and through consultancies. Direct development funds have been made available from: Korea Foundation (1994–96); The World Bank (1991); the Brookings Institution (1990–present); United States Environmental Protection Agency (1990–present); United States National Science Foundation (1993–present); United States Department of Agriculture (1996–present); and McKibbin Software Group Inc (1990–present). It has been used for a range of studies including reports for: Australian Economic Planning Advisory Council; Australian Department of Foreign Affairs and Trade; Australian Department of Environment, Sports and Territories; Australian Mining Industry Council; Centre for International Economics; and the Australia Institute. Overseas studies include papers and reports for: Japanese Economic Planning Agency; United Nations University; United Nations (Department for Policy Coordination and Sustainable Development).

A range of researchers are currently involved in model development at: the Australian National University; the Brookings Institution, Washington, DC; Canadian Department of Finance; Centre for International Economics (Canberra); Harvard University; University of Texas at Austin; United States Environmental Protection Agency; United States Department of Agriculture; and McKibbin Software Group Inc (Texas and Canberra).

The G-cubed model is routinely used in a range of model comparison exercises: Brookings Institution Global Model Comparison Project (since 1992); Stanford University Energy Modeling Forum; Economic Modeling Bureau of Australia Model Comparison Project; United Nations Global Modeling Forum for Sustainable Development; United Nations University Project on Global Change; Institute for Applied Systems Analysis (IIASA) Annual Workshop on Global Climate Change; IPCC Model Comparison Project throughout 1997; DEST Model Comparison (1995).

Table 1 Summary of main features of G-cubed

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

Table 2 Overview of the G-cubed model

Regions	*Sectors*
United States	Energy:
Japan	electric utilities
Australia	gas utilities
New Zealand	petroleum refining
China	coal mining
Rest of the OECD	crude oil and gas extraction
Oil Exporting Developing Countries	
Eastern Europe and the former Soviet Union	
Other Developing Countries	
	Non-Energy:
	mining
	agriculture, fishing and hunting
	forestry/wood products
	durable manufacturing
	non-durable manufacturing
	transportation
	services

G-cubed is still in the process of development but it is already a large model. In its current form it contains over 6 000 equations and 110 intertemporal costate variables. Its key features are summarised in table 1, while its country and sectoral breakdown is summarised in table 2. The disaggregation shown enables the user to capture the sectoral differences in the impact of alternative environmental policies.

Each economy or region in the model consists of several economic agents: households, the government, the financial sector and firms in the twelve production sectors listed in table 2. The behaviour of each type of agent is modelled. Each of the twelve sectors in each country in the model is represented by a single firm in each sector which chooses its inputs and its level of investment in order to maximise its stock market value subject to a multiple-input production function (defining technological feasibility) and a vector of prices it takes to be exogenous. For each sector, output is produced with inputs of capital, labour, energy, materials and a sector-specific resource. The nature of the sector-specific resource varies across sectors. For example, in the coal industry it is reserves of coal, in agriculture and forestry/wood products it is land which is substitutable between these two sectors.

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

The capital stock in each sector changes according to the rate of fixed capital formation and the rate of geometric depreciation. It is assumed that the investment process is subject to rising marginal costs of installation, with total real investment expenditures in each sector equal to the value of direct purchases of investment plus the per unit costs of installation. These per unit costs, in turn, are assumed to be a linear function of the rate of investment. One advantage of using an adjustment cost approach is that the adjustment cost parameter can be varied for different sectors to capture the degree to which capital is sector-specific.

Households consume a basket of composite goods and services in every period and also demand labour and capital services. Household capital services consist of the service flows of consumer durables plus residential housing. Households receive income by providing labour services to firms and the government, and from holding financial assets. In addition, they also receive transfers from the government. The household decision involves predicting expected future income from all sources as well as current income. This information, together with the relative prices of different goods and services, then determine the pattern of consumption spending over time and the pattern of spending across the available goods.

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

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

In summary, the G-cubed model embodies a wide range of individual behaviours and empirical regularities in a 'general equilibrium' framework. These complex interdependencies are then solved out over a 100-year horizon. It is important to stress that the term general equilibrium is used here to signify that as many interactions are possible are captured, not that the economy is in a full market clearing equilibrium at each point in time. Although it is assumed that market forces eventually drive the world economy to a long-run steady state equilibrium, unemployment does emerge for long periods due to different labour market institutions in different economies.

4. Key insights from studies using the G-cubed model

Since 1992, application of the model to greenhouse policy has had two strands. The first is the generation of global economic projections and exploring the sensitivity of these projections to a variety of assumptions. The second has focused on evaluating the impacts of a variety of policy changes on these projections.

4.1 Baseline issues

In a study for the United Nations University, Bagnoli, McKibbin and Wilcoxen (1996) found that, in a future horizon of 30 years, the assumptions about structural change are crucial for understanding the energy intensity of various economies. Using the model, the authors made two projections of the world economy from 1990 to 2020. The first assumed that all sectors in the economy experienced the same rate of technical change as the economy as a whole. This rate differed across economies, however, with developing economies growing more quickly than developed economies. The second set of assumptions was that the differences in sectoral technical change followed the historical pattern, scaled so that each economy had the same average economy-wide GDP growth rate as the first scenario.

The result was a dramatically different degree of energy intensity in the 2020 world economy. Countries had approximately the same GDP growth rates in both scenarios (by assumption) but energy use was totally different. In the second scenario, economy-wide energy per unit of GDP fell by around 1 per cent per year. Importantly, however, this did not reflect what energy modellers call 'autonomous energy efficiency improvement' (AEEI). This reflected only the changing structure of economies over time in response to relative price changes induced by different sectoral rates of technical change. Thus the carbon taxes required for carbon emission stabilisation in the second scenario were close to 50 per cent less than those for the first scenario.

This study made the point that a simple projection of GDP growth was insufficient to determine the carbon emission path because it was what happened at the sectoral level that was important for future emissions and not the aggregate path of the economy. This is not to say that GDP growth is irrelevant but what matters is the source of that growth.

The other issue that emerged in this study and other related studies is that small changes in growth over twenty or more years can have enormous effects on the levels of variables like income or greenhouse gas emissions. Compounding is not a new discovery but the extreme range of possible outcomes from small changes in growth rates is always a sobering reminder of the degree of uncertainty we are dealing with. In particular, there is associated empirical support for the argument that many economic variables have a unit root or a stochastic trend and therefore no tendency to return to a predictable trend. If this is correct, or even approximately correct, then any standard errors we would calculate to give a statistical measure of our uncertainty of future projections would quickly approach infinity.

4.2 Policy issues

Australian studies which apply the G-cubed model to examine carbon taxes include McKibbin (1994), McKibbin and Pearce (1993, 1995, 1996) and McKibbin, Pearce and Stoeckel (1994). These studies all highlight the result that a surprise carbon tax in Australia leads to a significant reduction in real economy-wide output with the greatest losses occurring in the short run. In addition, any tax that aims at stabilising carbon dioxide emissions at a constant absolute level would have to be continually increasing. The underlying baseline emissions of carbon dioxide rise into the indefinite future primarily due to population growth in Australia. These studies also show that a global tax on production of fossil fuels is preferable for Australia compared to a global tax on the use of these fuels, primarily because Australia is a large coal exporter and with a tax on production the revenue from the tax is kept in Australia rather than being collected by the consuming country. These studies show that Australia will bear a disproportionately large burden should an international agreement be reached that targets each country's emissions at 1990 levels. This is because of Australia's reliance on fossil fuels for energy generation, for export revenue and because Australia has the highest projected rate of population growth in the OECD.

The global applications of the G-cubed model have been more varied. Carbon taxes are examined in McKibbin and Wilcoxen (1992a, 1992b, 1993a, 1993b, 1993c, 1994). These studies show that the adjustment of capital flows is important for the impact of carbon taxes. An increase in the price of energy inputs makes goods produced using energy relatively more expensive in world markets. The conventional view is that the current account of an energy importing country would deteriorate as a result of a carbon tax. We showed, on the contrary, that the current account could improve if the revenue from the tax was used to reduce the fiscal deficit. The rise in saving and fall in investment could easily lead to an improvement in the overall current account balance reflecting a capital outflow. The composition of the trade account would reflect the relative rise in energy costs but the economy-wide general equilibrium effect could go the other way.

McKibbin and Wilcoxen also showed that the way in which the revenue from a carbon tax is used can have important consequences for the costs of the carbon abatement policy. If the revenue is used to reduce another tax in the economy, then the costs of abatement can be reduced. For example, in the United States, if the revenue is used to reduce the fiscal deficit, there can be a fall in interest rates which stimulates economic growth and reduces the costs of the carbon abatement. This does not work in Australia because we are small in global capital markets and have very little impact on world interest rates. Nonetheless, the revenue could be used to reduce taxes on capital and thereby help to offset the negative effects of a carbon abatement policy.

The trade implications of environmental policy are the focus of papers by McKibbin and Wilcoxen (1993b, 1995). These papers show that changes in environmental policy are unlikely to lead to major changes in trade flows through international relocation of industry. This is because the costs of environmental policy are generally small relative to the cost of relocating production facilities. This does not mean that environmental policies lead to small losses in economic output, but the policies are unlikely to be fully offset by substitution towards goods that are not subject to the same environmental regulation. In the context of US policy for global warming, the papers above have shown that the reduction in US emissions also reduces global emission (except for an offset of around 10 to 20 per cent due to the aforementioned substitution effects). A key insight from this research was that a significant part of energy use is for domestic transportation. Transportation services are largely non-traded and therefore unlikely to move overseas.

As part of the Energy Modelling Forum/IPCC/UNU conference in Tokyo in March 1997, it was found that many popular 'permit trading' scenarios in the G-cubed model could not be run because of the instability such a permit trading system would cause in the global trade system. The main problem was the extent of stabilisation proposed in the scenarios which implied very high prices for emission permits. This resulted in wild fluctuations in real exchange rates as part of the process by which resources are allocated in the permit trading system. This has been discussed by McKibbin and Wilcoxen (1997). It suggests that there is a fundamental flaw in the global emission permit trading schemes frequently proposed. The problem is that permit trading systems would generate large transfers of wealth between countries. Supporters of a permit system regard this as an advantage because it would allow developed countries to compensate developing countries for reducing their emissions. Results from the G-cubed model suggest that a plan such as this would put enormous stress on the world trade system. A developed country importing permits would see its balance of trade deteriorate substantially. This would lead to substantial volatility in exchange rates and would create distortions in the world trade system.

Equally serious problems would be created for developing countries. Massive exports of permits would lead to exchange rate appreciation and a decline or collapse in traditional exports. In the international economics literature this is known as the 'Dutch disease' or in Australia as the 'Gregory thesis'. It occurs because the granting of permits has an impact on the wealth of the receiving countries which changes their consumption patterns and comparative advantage. These issues are generally ignored in the debate because permits are assumed to be the same as carbon taxes in the sense that the permit price is a uniform carbon tax across all countries. It is our finding, however, that once the wealth effects of the permit are taken into account, as they are in the G-cubed model, the simplistic equivalence of a uniform carbon tax and an emission permit breaks down.

5. Practical policies suggested by the model research

In Anderson and McKibbin (1997), it was found using the G-cubed model, that the distortions in global coal markets (particularly in Europe, Japan and China), if removed, could reduce global carbon dioxide emissions by close to 8 per cent relative to those that otherwise would be experienced. This is close to the reduction in global emissions that would eventuate by 2010 if all Annex I countries targeted emissions to 1990 levels (McKibbin, Pearce and Stoeckel 1994). This research suggests that policies aimed at other goals such as trade liberalisation can have important implications for greenhouse emissions and could be a useful step towards addressing the climate change issue.

In McKibbin and Wilcoxen (1997), an alternative was proposed to the much discussed global permit trading system. The alternative begins to address the greenhouse problem but without causing the disruption a conventionally advocated permit system could cause. An international agreement to set up a system combining emissions permits and fees at the national level is proposed. Each country would be allowed to distribute emissions permits equal to its 1990 emissions (or some more recent levels). The permits could be given away, auctioned, or distributed in any other way the government of each country saw fit. Each government would also agree to sell additional permits for a specified fee, say, US$10 dollars per ton of carbon. Firms within a country would have to have emissions permits equal to the amount of emissions they produce. They could buy the permits from other firms or from the government for the stated fee. Under this system firms would have an incentive to reduce emissions whenever they could do so for less than US$10 per ton. Because the total supply of permits is not fixed, the policy does not guarantee precisely how much abatement will be done. However, it does ensure that whatever abatement is done will be done at minimum cost. Moreover, firms always have an incentive to reduce further, either to avoid having to pay the fee or in order to be able to sell excess permits. Because the government can give the base block of 1990 permits away for free, the permit/fee policy is politically quite different from a simple tax on carbon emissions, an alternative policy that has often been proposed. The exemption for 1990 emissions would lower the cost of the policy to industry in the United States by well over ten billion dollars relative to a carbon tax of the same magnitude. This would make the policy much more palatable to industry.

A national permit/fee policy would be a modest but concrete step forward in protecting the environment from excessive climate change. It will not necessarily stabilise world carbon emissions but it will certainly reduce them below where they would be in the absence of any policy, or in the presence of a stronger but unimplemented policy. It would also provide valuable information about how much abatement can be done at low cost and how expensive it would really be to stabilise emissions. There is much debate about how easily emissions might be reduced: many economists believe that it will be quite costly but others argue that emissions can be reduced substantially at low cost. A modest emissions fee would do a lot to show which group is right.

The permit/fee policy also gives governments a built-in incentive to monitor and enforce the treaty. The revenue raised through fees would be available for a variety of purposes: to reduce budget deficits, lower personal income taxes or shore up social insurance programs. This would give governments enough incentive to enforce the policy so that little or no international monitoring would be needed.

Finally, the permit/fee system is flexible. The fee can be adjusted as needed when better information becomes available on the seriousness of climate change and the cost of reducing emissions. Also, it would be easy to add countries to the system over time: those interested in joining would only have to adopt the policy domestically; no international negotiations would be required. In fact, many of the permit/fee system's practical advantages arise because it is really more like an internationally coordinated system of domestic policies than an international policy in the usual sense.

6. Conclusions

Economic models have a valuable role to play in the policy debate on greenhouse gas abatement not because of the numbers they generate *per se* but because they can help us understand the potential weaknesses and costs of alternative policies. There are also a range of economic models available, each of which can provide insights particular to the type of issue that the model was designed for. There will never be an all-encompassing model that can answer every question. For any given policy issue a range of models should be used to give a range of insights and some measure of the range of possible quantitative outcomes for any given policy change. It is important that models be used sensibly. In the past, disenchantment with models has generally occurred because they were used to give the definitive answer to certain questions. It is inevitable that using models this way will be counterproductive because the future will never be as a model predicts.

Used properly, economic models provide a range of insights that are crucial for formulating policy. In working with the G-cubed model alone two proposals have been developed that we believe would allow the world to begin to address the issue of greenhouse gas abatement at low cost and with the flexibility required when there is so much uncertainty. This research suggests that no agreement based on country-specific targets that ignore the differential nature of economies can successfully emerge. The political and economic implications of existing official proposals including the Kyoto agreement prevent this. Until policy-makers move away from explicit and unrealistic targets and timetables and towards uniformity in policy instruments that yield differential emission outcomes, substantial progress will not be made. Any agreement, including the recently negotiated Kyoto outcome, based on existing official proposals that have explicit emission targets will most likely collapse within a few years because its foundations are fundamentally flawed.

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