Article

Self-interested Low-carbon Growth in Brazil, China, and India

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Abstract

This article examines the issue of whether low-carbon growth might be in the self-interest of Brazil, India, and China. These countries are the largest member countries of the G20 emerging markets (GEMs), and are also members of the BRIC and BASIC grouping of countries. Individually, they are very important to each other in different ways, not least in that emissions in one country have impacts on citizens in another. Combined, their growth and development trajectories over the next decade have important implications for both the long-term prosperity of their own people and those of others around the world.

Keywords

Climate change, low-carbon, Brazil, India, China

Introduction

A number of recent studies and reports have looked at whether there is a collective interest for countries to transition to low-carbon growth. Here, however, we focus on the interests of these three countries individually and as a group. We do not rehearse various well-understood reasons for action on climate change, including improved energy security, energy access, reducing local pollutants, and achieving health benefits. Rather, we explore three underappreciated reasons for self-interested low-carbon growth. The three broad reasons are:

- increase total factor productivity (TFP) and GDP growth rates through increases in energy productivity;
- capture a greater market share in emerging low-carbon sectors, estimated to be worth around US$3 trillion per annum by 2050; and
- reduce the *risk* of *dangerous* changes in the climate.

The analysis is conducted using econometric techniques, market economic analysis, and the application of three large-scale "integrated assessment models" (IAMs) of climate and the economy—RICE, PAGE, and FUND. We also incorporate some recent advances in climate scientific research.

Our key findings in these three areas are as follows:

- Action by the G20 emerging markets (GEMs), led by Brazil, India, and China, is critical to reducing the risk of catastrophic climate change: the maximum damages suffered in all three countries in 2,100 halves in a scenario in which GEMs join developed countries in taking climate action compared to a situation where they take no action. GEM action would, for instance, reduce the risk of devastating floods in Shanghai, the risk of Amazonian dieback, and the risk of significant interruptions to the hydrological cycle in India that could reduce water supplies that are vital to the prosperity of 250 million people.
- In all three countries, increases in energy productivity are correlated with TFP and GDP growth rates. Furthermore, in India and China, initial econometric analysis suggests a *causal* relationship: a 1 percent increase in energy productivity causes an approximately 1 percent increase in TFP in these countries. To our knowledge, this is the first econometric analysis demonstrating the macroeconomic benefits from improved energy efficiency.
- The low-carbon transition offers at least a US$3 trillion per annum global market opportunity, US$2 trillion of which is in passenger vehicles and fuels. The particular strengths and opportunities for each of the three countries differs—for instance, China looks strong across a host of different technologies; Brazil's comparative advantage seems most readily apparent in biofuels, manufacturing associated with biomass and hydro electricity generation while India's in a moderately good and improving position, especially in some low-carbon energy technologies.

The article develops five sets of policy recommendations:

- **Build alliances to reduce catastrophic risks.** It is impossible for one country alone to reduce the risk of significant climate damages within their borders to tolerable levels. In terms of future influence over the global climate, the most important countries for Brazil, China, and India to work with are each other, alongside the USA and EU. Cooperating on low-carbon growth could yield significant benefits to all three countries.
- **Build appropriate infrastructure.** Delaying the transition to a low-carbon economy will lead to investment of billions of dollars into wasted, high-carbon assets that will subsequently have to be scrapped. The costs of delay in the power sector alone may be in the order of US$ tens of billions for India and up to the order of US$200 billion for China. Good economic analysis would appropriately factor in these costs, in order to determine the optimal speed of the transition to low-carbon growth.
- **Invest in energy efficiency.** Increasing energy productivity in certain sectors appears likely to boost international competitiveness. These sectors vary from one country to another. Specifically they are textiles and glass manufacture in China; sawmilling, paper and non-ferrous metals in Brazil and iron and steel and chemical manufacturing in India.
- **Use the market.** Several tens of billions US$ (or more) per annum will be required in investment to move to low-carbon growth. The magnitude and diversity of this challenge means that much of the investment will need to be undertaken in a decentralized way: in many cases, the appropriate role for government is to create the right incentives (e.g., carbon taxes and trading systems) to facilitate behavior by the corporate/private sector.

- **Strengthen low-carbon innovation.** A common feature of all three countries is that current export performance is stronger than innovation activity. Despite some recent improvement, there is still a considerable gap between the number of climate-relevant patents filed by the USA, Japanese and even Korean inventors and those from Brazil, India, and China. While short–medium term success in supplying low-carbon technologies is likely to be possible through the lower cost base typical in each country, these advantages may erode over time. Longer term technological leadership is likely to require successful innovation activity.

The article synthesizes the findings from three complementary country reports. It also extends previous analysis (Hepburn and Ward, 2009) which looked at these themes for the GEMs as a whole.

The article is structured as follows:

- The first section shows how action by the emerging markets as a whole would substantially reduce the risk of some of extreme temperature rises and the importance of these for each of Brazil, India, and China.
- The second section discusses the relationship between energy efficiency and both economic growth and TFP and presents initial new econometric evidence suggesting a statistically significant causal relationship between improving energy efficiency and TFP growth in many countries of the world, including China and India.
- The third section highlights the growth in low-carbon markets that sustained climate action will precipitate and, using new data and analysis, identifies how, to varying degrees, companies in Brazil, India, and China are well positioned to gain substantial market shares in these technologies.
- The fourth section highlights some of the key policy conclusions for each of the three countries.

Climate Risks

Introduction

This section sets out the role that the emerging markets as a whole can play in avoiding the worst impacts of climate change and assesses the economic, social, and political importance of avoiding these impacts for Brazil, China and India. It presents new, probabilistic modeling analysis showing how the likelihood of different temperature increases and sea level rises depends on emerging markets action. Three separate IAMs[1]—RICE, PAGE, and FUND—are employed to demonstrate the impact of emerging market action on potential climate change damages faced by Brazil, India, and China.[2] This modeling analysis is then supplemented by brief case studies demonstrating some of the specific impacts that might be expected in each of the three countries and broader regions in which they are located.

Why Climate Risks Matter?

Insuring against the worst climate risks (in addition to reducing expected damages from "average" climate change) is an important reason for reducing emissions. Despite some progress in recent years, considerable uncertainty remains regarding both the physical impacts of climate change and the damage this might cause. This is both due to uncertainties in climate science and the uncertain future level of economic development of populations bearing the burdens. In these cases, a simple cost-benefit analysis—comparing the expected costs of taking climate action with the expected damages that are avoided—hides the full range of possibilities, so that the worst case (and best case) may not be fully appreciated. In this context, policy makers (and society) may wish to minimize the risk of experiencing the most damaging consequences of climate change. This is similar to the rationale for taking out an insurance policy.

The force of this idea has been increasingly recognized by the academic and policy making communities. Weitzman (2009, 2010) emphasizes the importance of considering the full range of potential impacts of climate change, including the possibility of catastrophic outcomes, when deciding upon how much to reduce emissions. Similarly, the UK's Committee on Climate Change recommends a policy objective which is to limit "the central expectation of temperature rise to 2°C, or as close as possible" and, in addition, it proposes that action is taken "to reduce the risk of extremely dangerous climate change to very low levels (e.g. less than 1%)." Notably, it interprets extremely dangerous climate change as being increases in global temperatures of greater than 4°C.

In this context, it is important to understand the contribution of countries and groups of countries to changing the risks of extreme climate outcomes.

Scenarios and Results

We have used MAGICC—a model used by the IPCC in its most recent Assessment Report—to assess the impacts of three different scenarios[3] of emissions/climate action:

- A business-as-usual scenario, where the recent trends in emissions are projected forward on the basis of GDP forecasts provided by the Centennial Group to 2050 and from 2050–2100 based on forecasts from the climate change modeling literature.
- A developed country action scenario in which developed countries commit to reduce emissions by 80 percent on 1990 levels by 2050.
- A developed country plus GEM[4] action scenario where, in addition to developed country action, GEMs also commit to ensuring that emissions (except from land use change) are at 2005 levels by 2050 and emissions from land use change fall by 50 percent on 2005 levels.

We present the impact of these different emission scenarios in an explicitly probabilistic manner. This allows examination of how action or inaction by different groups of countries reduces the risks of very extreme climate outcomes. The appendix provides more information on how we use the MAGICC model.

Action by the emerging markets significantly reduces the risk of very high temperature increases by 2100. This is shown in Figures 1 (which shows the probability distribution of various temperature increases under each scenario) and 2 (which converts the same data to show the probability of temperature thresholds being exceeded) below.

Action by emerging markets significantly reduces the average expected temperature increases. Figure 1 shows that if emerging markets take action alongside developed countries, then the most likely[5] temperature

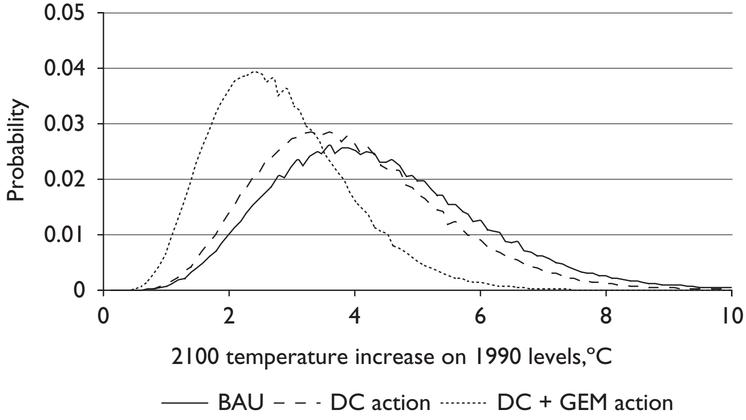

Figure 1. Action by the Emerging Markets Significantly Reduces the Risk of Very High Temperature Increases

Source: Vivid Economics and MAGICC.

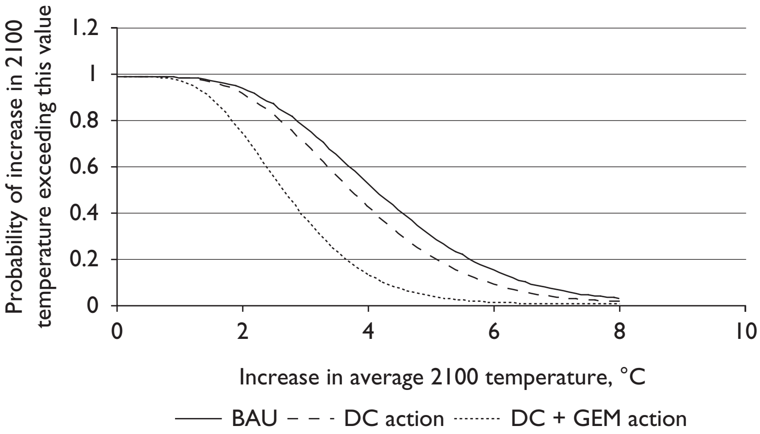

Figure 2. Without Emerging Market Action, There is More Than A 45 Percent Chance of Temperature Increases Greater than 4°C, and an Almost 10 Percent Chance of Temperature Increases Greater than 6°C

Source: Vivid Economics and MAGICC.

increase is 2.4°C (on 1990 levels). This is almost a full degree lower than the most likely temperature increase if only developed countries take action (3.3°C). The median temperature increase is 2.7°C if emerging markets take action alongside developed countries but 3.9°C if they do not.

The results also strikingly show how emerging market action reduces the risks of very high temperature increases. For instance, Figure 2 shows that if only developed countries take action there is as much as a 10 percent probability that temperature increases could exceed 6°C by 2100.[6] By contrast, GEM action, in conjunction with developed countries, virtually assures that temperature increases of 6°C by 2100 are avoided. There is a 45 percent probability of increases in temperature of more than 4°C—often used as a threshold for catastrophic climate damage impacts—if only developed countries take action. Looking at a 2°C temperature increase—a typical threshold for "safe" temperature increases and the temperature increase referred to in the Cancun Agreements—there is a 94 percent chance that this will be exceeded without emerging markets taking action alongside developed countries.

Correspondingly, emerging market action is also required to reduce the likelihood of substantial sea level rise (SLR). This is shown using the same format in Figures 3 and 4 below.[7]

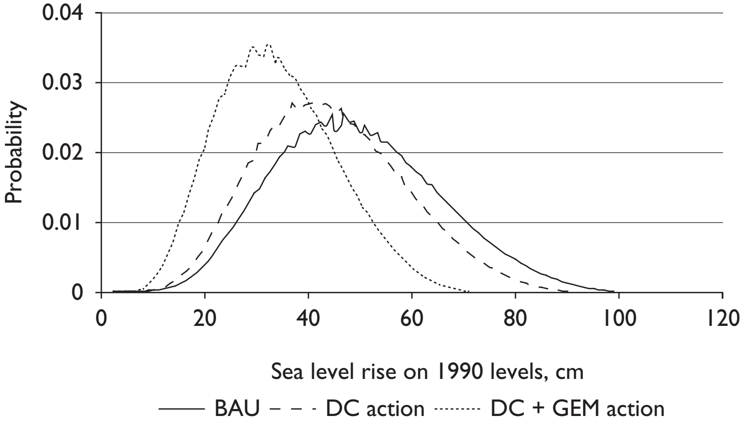

Figure 3. Emerging Market Action Brings Down the Most Likely Increase in Sea Levels by Almost 10 cm

Source: Vivid Economics and MAGICC.

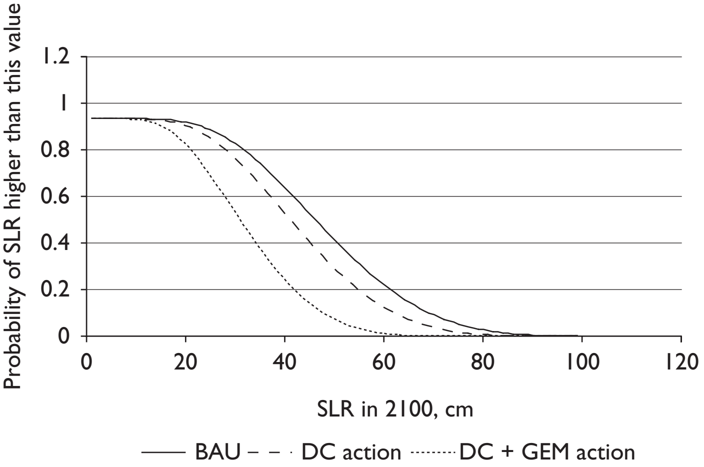

Figure 4. Without GEM Action There is a 33 Percent Chance that Sea Levels could Rise by More than a Meter

Source: Vivid Economics and MAGICC.

The case for GEM action to avoid significant sea level rises is clear. If only developed countries take action then, Figure 4 shows that there is almost a one-third probability of sea level rises of more than 0.5 meter, whereas with GEM action this probability falls to less than 8 percent. Figure 3 also demonstrates how developed country action alone makes only a modest impact to the likelihood of different sea level rises.

Implications

The temperature and sea level rise that are expected to result without emerging market action could have very serious economic and social implications. In this section, we use three separate IAMs—RICE, FUND, and PAGE—to explore the potential impacts of the temperature and sea level rises identified above. These modeling results are supplemented with a number of illustrative case studies that highlight potential specific impacts in each of the key countries.

In all three countries, the models concur that there is a 10 percent risk of losses equivalent to up to 10 percent of GDP by 2100 without action by emerging markets.[8] This is despite significant differences in the modeling assumptions and framework across the three models and consequently on the absolute magnitude of damages anticipated. Some of the key results in relation to the **maximum likely damage** suffered by each country with or without emerging market action are that:[9]

- In China, if developed countries act without emerging markets, then there is a 10 percent risk that damages in 2100 could be as high as 8–10 percent of GDP. This range of damages declines to just 2–4 percent of GDP with GEM action as well.
- In India, the equivalent figures are that without emerging market action, damages could be between 3 percent and 10 percent of GDP, a range which falls to 1 percent to 5 percent with GEM action.
- In Brazil, the range of maximum damages is 2–9 percent of GDP if only developed countries act and 1–4 percent of GDP with GEM action as well.

The results from each of the three models, for each of the three emissions scenarios, are shown in Figures 5 (Brazil), 6 (China), and 7 (India) below.

Although modeling analysis is helpful in identifying the magnitude of potential economy wide damages resulting from climate change, the potential damages caused by climate change can be more readily appreciated from considering some of the specific impacts that may occur in each country and surrounding regions.

In Brazil, without action by the emerging markets, there is a real risk of temperature rises that could precipitate dieback of the Amazonian rainforest. Although contested by some authors, climate change, coupled with localized deforestation, significantly increases the risk of the Amazon rainforest suffering dieback due to changing rainfall probabilities and locations, which induce drought, loss of biomass, and ultimately forest failure. Lenton et al. (2007) predict that dieback will commence if global warming reaches 3–4°C: according to our calculations, as reported above, there is almost a 45 percent probability of temperature increases of 4°C or more by 2100 without emerging market action. This probability falls to just 10 percent with emerging market action. However, delayed emerging market action could still cause significant damage: previous research (Lenton et al., 2009; based on Jones et al., 2009) has shown

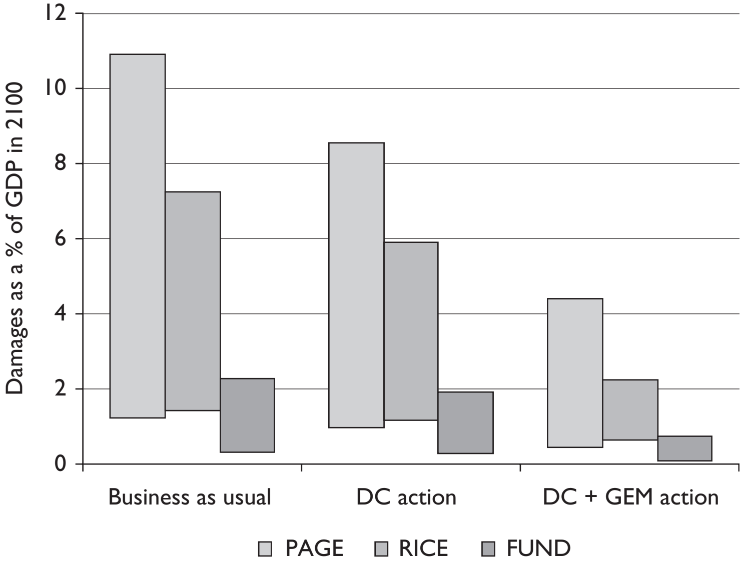

Figure 5. The RICE, FUND, and PAGE Models all Show that Emerging Market Action Substantially Reduces the Climate Damages Faced by Brazil

Source: Vivid Economics based on RICE, FUND, and PAGE.
Note: Each bar shows the 10–90 percent range of the damages expected by each model under each emission scenario

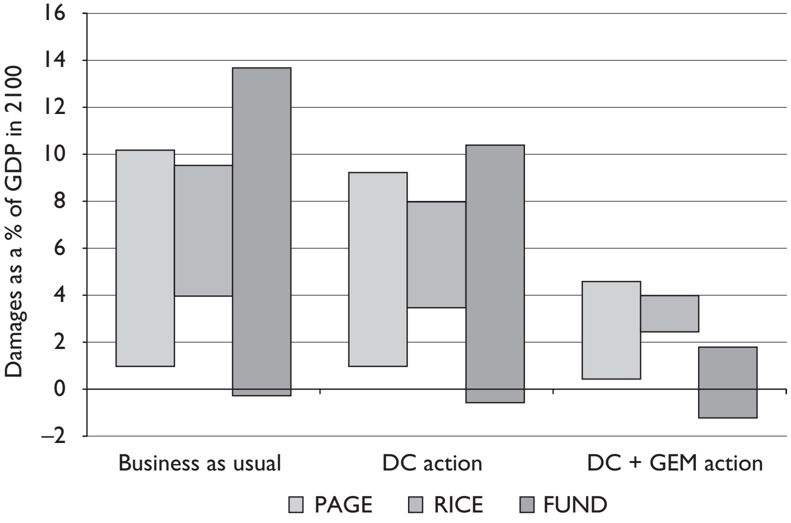

Figure 6. The RICE, FUND, and PAGE Models all Show that Emerging Market Action Substantially Reduces the Climate Damages Faced by China

Source: Vivid Economics based on RICE, FUND, and PAGE.
Note: Each bar shows the 10–90 percent range of the damages expected by each model under each emission scenario.

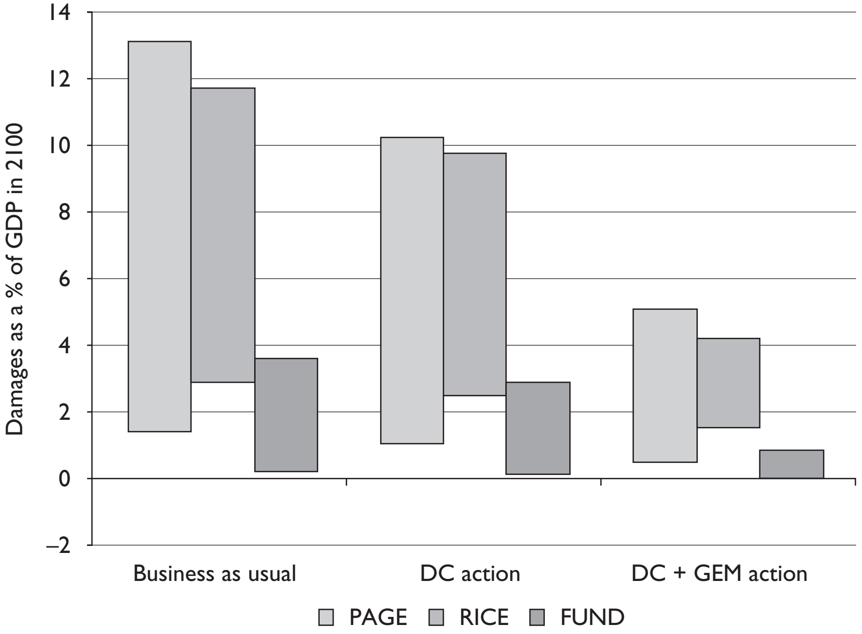

Figure 7. The RICE, FUND and PAGE Models all Show that Emerging Market Action Substantially Reduces the Climate Damages Faced by India

Source: Vivid Economics based on RICE, FUND, and PAGE.
Note: Each bar shows the 10–90 percent range of the damages expected by each model under each emission scenario.

that if emissions proceed along a trajectory broadly consistent with our developed country only action scenario[10] then even by 2030, more than 20 percent dieback could be committed to, while if this trajectory persists until 2050 then 50 percent could be committed to (even though, in both cases, most of the actual dieback would not be seen until beyond these dates).

The consequences of dieback of the Amazonian rainforest would be profound. It is estimated that the Amazonian rainforest is responsible for producing 20 percent of the world's oxygen (World Bank, 2010); it harbors around 20 percent of all of the world's animal and plant species and accounts for almost 20 percent of all of the freshwater input into the world's oceans (Magrin et al., 2007). Moreover, loss of the rainforest could have a further massive destabilizing impact on global emissions. Compared to total global emissions of around 45 GT of CO_2, it is estimated that the total carbon stored in the Amazon rainforest is equal to 436 GT of CO_2 (Soares-Filho et al., 2006). Typically, studies assume that 85 percent of any carbon stored in biomass is lost to the atmosphere when die-back takes place (Lenton, 2009).

In India and the surrounding region, climate change could reduce the flow of Brahmaputra and Indus rivers lowering the feeding capacity of each river basin by around 25–30 million people by as early as 2065 (Immerzeel, 2010). This would occur in a region of the world where political tensions associated with water shortages, as well as concerns over migration, are already high. These results are predicated on a temperature increase for which there is a greater than 75 percent chance of exceeding if emerging markets fail to act but a less than 50 percent chance of exceeding if they do act.[11]

In some coastal cities of China, as well as in other cities in South and South East Asia, climate change will double the number of people exposed to coastal flooding. In each of Shanghai, Dhaka, and Kolkata, the number of people and assets exposed from coastal flooding if sea levels rise by 0.5 m is at least double the number of people who would be exposed without sea level rises. In total, there could be an additional 17 million people in these three cities alone who would be exposed to the risk of coastal flooding in 2070 (Nicholls et al., 2007).[12] Nor, for some countries in the region, would these impacts be confined to specific coastal cities. Dasgupta et al. (2007) conclude that measured both by population exposure and by GDP exposure, Vietnam was the country in the world most exposed to sea level rise with more than 10 percent of its projected GDP and population exposed to sea level rise.[13]

Energy Efficiency and Growth

Introduction

This section provides a preliminary exploration of the idea that using energy more efficiently provides economic benefits. It explores the relationship between energy efficiency and two key, closely related, macroeconomic variables:

- GDP per capita—a measure of the income generated by an economy.
- TFP—a measure of the efficiency by which an economy turns its inputs into output. Over half of economic growth is thought to be explained by increases in TFP (Klenow and Rodriguez-Clare, 1997) with the remainder explained by changes in inputs.

Theoretically, both measures should be expected to be positively related to energy efficiency.[14] In terms of GDP per capita, energy efficiency should reduce expenditure on intermediate energy inputs and therefore increase the amount of revenue available as payment to workers and capital owners. Similarly, because energy efficiency means that fewer energy inputs are required to produce a given amount of output, TFP should increase. However, despite this strong intuitive rationale, to our knowledge, we are not aware that this hypothesis has been explored quantitatively before at the macroeconomic level. Our study represents a first effort to account for this gap.

Our initial results find that there is a positive relationship between energy efficiency and TFP growth and that for TFP, in many countries including China and India, there are good reasons to believe that this relationship is causal, that is, greater energy efficiency increases TFP. This suggests that countries that take action to improve the energy efficiency of their economy should, as well as reducing the risk of long-term catastrophic climate damages (as explored in the previous section), also induce increases in TFP which will lead to higher levels of income per capita. Of course, this is not to say that all climate action can deliver immediate benefits—it is generally recognized that some actions will lead to short-term reductions in GDP[15]—but it does suggest that a significant component of climate action can deliver economic benefits.

Correlations

Figures 8 and 9 below track the relationship between energy efficiency[16] and both TFP (the left hand side figure) and GDP per capita (the right hand side figure) 1960 and 2005 for a selection of key countries: China, India, Brazil, Japan, and the USA. The line gets thicker over time.

A number of observations can be drawn from these figures:

- In both India and China, there is a broadly positive relationship between energy productivity and both TFP and GDP per capita, although the decline in energy productivity between 1990 and 2005 in China is marked.
- In Brazil, in the initial part of the period analyzed, both energy productivity, TFP and GDP per capita increased, but for most of the period, TFP has declined, energy productivity has stabilized but GDP per capita has increased.
- In the USA, energy productivity and GDP per capita have continued to rise throughout the period, but there was a well-documented fall in TFP in the late 1970s[17] during which time energy productivity continued to rise.
- In Japan, in the first half of the period, TFP and GDP per capita increased while energy productivity remained stable, but in the second half of the period, all three variables have improved.

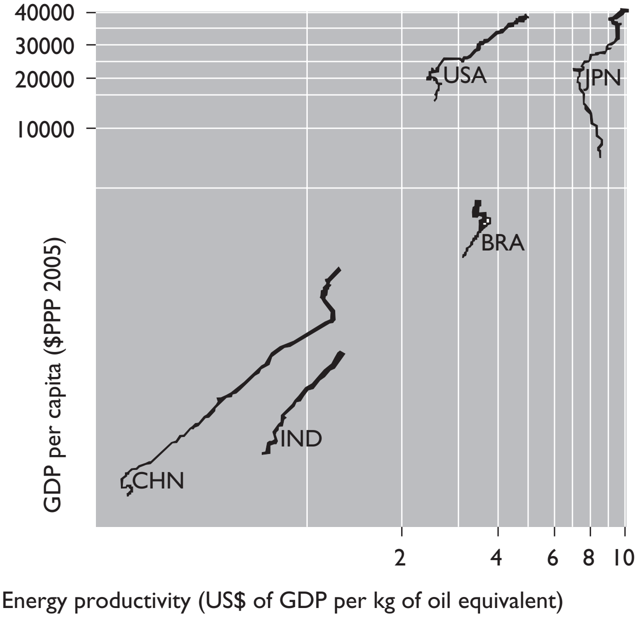

Figure 8. In China, India, Brazil, USA, and Japan, Improvements in Energy Efficiency have Tended to be Associated with Increase in GDP per Capita

Source: Vivid Economics.

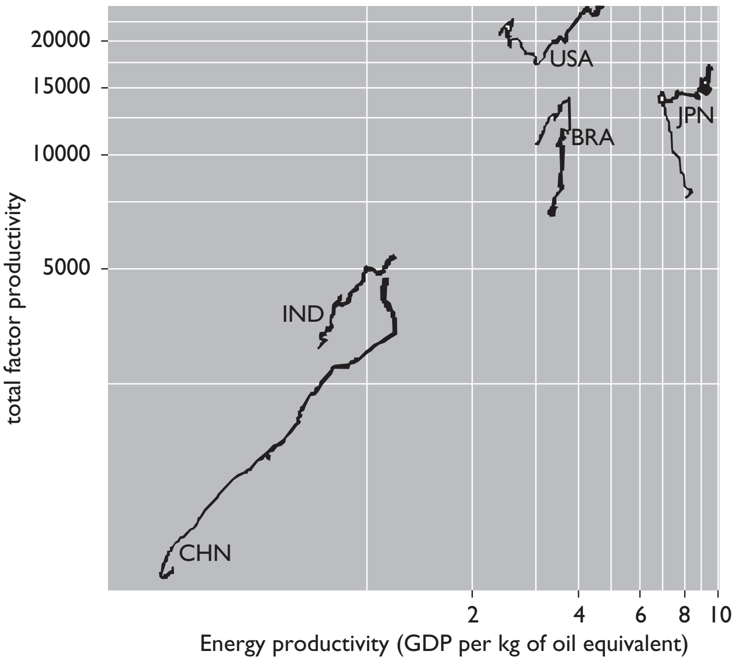

Figure 9. TFP and Energy Efficiency have also Tended to Move in the Same Direction in These Countries

Source: Vivid Economics.

Overall, although there are some notable exceptions, the picture is that TFP, GDP per capita, and energy productivity have tended to move in concert over the period.

Causation

We use econometric techniques to identify whether changes in energy productivity cause changes in these key macroeconomic variables—and also to quantify these impacts. The fact that increases in energy productivity are typically associated with improvements in GDP per capita and TFP does not demonstrate that they help *cause* these improvements. For example, increasing openness to trade will increase TFP as the economy specializes in sectors where it has an advantage, and it may also reduce energy intensity, if the value of output increases due to greater market access while energy use is unchanged. These preliminary econometric results suggest that the relationship between energy efficiency and macroeconomic aggregates is an important area of future research.

Our initial econometric evidence suggests a causal relationship between energy productivity and TFP growth in India and China, as well as the G20 as a whole.[18] Table 1 below shows the results for the key countries of interest as well as for the G20 as a whole. The results can be interpreted as showing the expected percentage change in TFP when energy productivity (GDP per kilogram of oil equivalent) increases by 1 percent. The table shows that in the case of China, a 1 percent improvement in energy productivity would be expected to cause an increase in TFP of 1.1 percent while in India the same productivity improvement would be expected to cause an increase in TFP of 0.8 percent. The results for Brazil also show the same directional impact but the relationship is not statistically significant. The overall G20 results, in line with the Chinese and Indian results, also demonstrate a statistically significant relationship between improvements in energy productivity and TFP growth.

Table 1. In China, India and Across the G20 as a Whole, Improvements in Energy Productivity Cause Increases in TFP

Country	A 1 Percent Improvement in Energy Efficiency Would Increase TFP by...
China	1.1 percent **
India	0.8 percent *
Brazil	2.6 percent
G20 average	1.2 percent **

Source: Vivid Economics.
Note: Asterisk signify statistical significance. * shows significance at 95 percent; ** shows significance at 99 percent.

Policy Implications

While the overall finding that energy efficiency boosts TFP, and hence economic growth, is common to many countries, the sectors where the gains may be largest are likely to differ across countries. To help identify the sectors where the gains from energy efficiency in each of Brazil, China, and India are likely to be greatest, we assess the sectors against three criteria:

- The energy intensity of the sector (where energy cost reductions will be material).
- The international competitiveness of the sector (sectors that are already demonstrating an ability to compete in international markets can be most assured of further gains if they increase their productivity).
- The importance of the sector within the economy (sectors that already make a substantial contribution to a country's output will contribute more to overall economic growth if their productivity improves than smaller sectors).

This analysis revealed that some[19] of the key sectors where policy to improve energy efficiency would be worthwhile include:

- In Brazil, iron and steel, paper production and basic chemical manufacture.
- In China, textiles, glass manufacture and non-metallic mineral products i.e. ceramics.
- In India, iron and steel, basic chemical manufacture, textiles and non-metallic mineral products i.e. ceramics.

This analysis can help to inform ongoing domestic policy initiatives in these three countries. All three countries have already placed a heavy focus on improving energy efficiency as part of their existing climate action programs. Our analysis validates this emphasis and indicates that yet more ambitious targets could yield (further) benefits—within the G20, only Indonesia and Russia had lower energy productivity than India and China.[20] The sectoral analysis could be used to assist in specific policy design. For example, India is currently identifying targets for its energy efficiency certificate trading regime (Perform Achieve and Trade)—in this or subsequent periods, the sector coverage and target setting process could be informed by sectoral analysis such as that presented above.

New Markets

Introduction

A low-carbon world requires radically different technologies: supplying these technologies offers exciting market opportunities for Brazil, India, and China to develop strong industries and acquire technological leadership. In this section, we summarize the key technologies that will be required and their likely market size, identify the current and likely future strengths of companies in each of the three countries in supplying these goods and services and suggest some key domestic policies that might allow companies in these countries to flourish.

The global market to supply low-carbon technologies (low-carbon power, passenger vehicles and fuels and buildings) could be worth at least US$3 trillion per annum by 2050. Moreover, this is likely to underestimate the size of the total market opportunities as it does not include the accompanying networks infrastructure that will be required alongside these investments i.e. in smart grids and electric charging infrastructure for vehicles. To place this in context, the current size of the global pharmaceuticals industry is estimated at around US$800–850 billion per annum (IMS Health, 2010).

While low-carbon power often dominates policy discussion, Figure 10 shows that the largest markets may be in the supply of low-carbon vehicles and fuels. These alone could be worth around US$2.3 trillion in 2050.

In identifying how companies in each of the three countries could seize the opportunities that these markets provide, it is important for policy to avoid picking winners or industrial policy wherever possible. These market opportunities will provide different options for companies in each of Brazil, India, and China (and, indeed, the rest of the world) according to where current and future comparative advantage may rest. We are not advocating that governments attempt to support specific companies or narrowly defined sectors. Furthermore, it is logically not possible for every country to develop strong export industries in all technologies. Rather, if each country (and, more precisely, firms within those countries) considers areas where they have comparative advantage, the greatest global gains from trade are likely to be secured. Therefore, our analysis has focused on trying to identify where the current strengths of each country might lie—by looking at existing export patterns for these technologies—and where future strengths might lie—by looking at patenting activity.

Low-carbon Power

The largest manufacturing markets for low-carbon power technologies currently appear likely to be nuclear energy and wind power. Analysis based on IEA analysis (IEA 2010a)[21] shown in Figure 11 suggests that

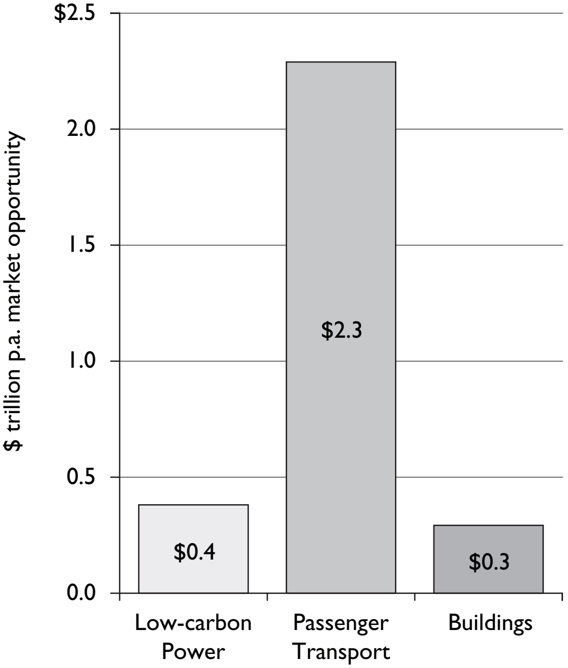

Figure 10. The Global Supply of Low-carbon Technologies in 2050 Could be Worth More than US$3 Trillion

Source: Vivid Economics based on IEA (2010a).

annual investments in these two technologies alone may be almost US$200 million by 2050. This implies substantial growth, especially for nuclear energy, where the annual investment[22] will be almost seven times larger than current levels. Other technologies that will show rapid growth over the period include carbon capture and storage and solar power (where investment flows are estimated to be almost 14 and six times current levels).

China has already demonstrated an impressive capacity to seize these opportunities, but could benefit from greater effort on R&D activity. China has already had considerable success in acquiring these markets: it is, for instance, the world's largest manufacturer of wind turbines and solar PV cells. Moreover, in 2008, Chinese inventors accounted for a larger share of patents than Brazilian and Indian inventors in all low-carbon energy technologies[23] sometimes by a wide margin e.g. in CCS, Chinese inventors accounted for four times the number of patents from Indian investors and eight times the number of Brazilian inventors. However, it is striking that its patenting activity is still substantially lower than the USA, Japan, or indeed Korea: while US inventors registered more than 3,300 patents in key low-carbon energy technologies in 2008, Chinese inventors managed less than 10 percent of this value while its inventors registered less than half the number of patents that Korean inventors patented.[24] The inclusion of a target within the 12th Five Year Plan that R&D spending should reach 2.2 percent of GDP by 2015 indicates that these challenges have been recognized and provides an immediate opportunity to rectify this relatively weak low-carbon innovation performance.

Brazil's low-carbon energy comparative advantage appears to focus most strongly in manufacturing linked to biomass and hydroelectricity. It accounts for around 3 percent of the global value of exports in

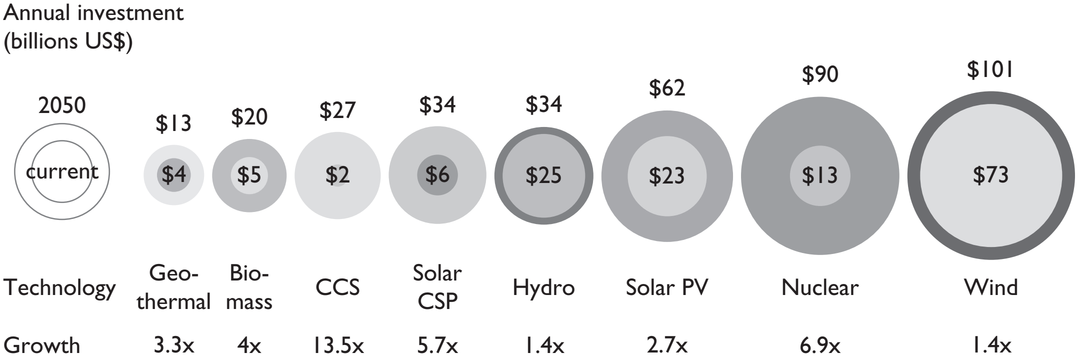

Figure 11. All Low-carbon Power Technologies Could See Growth in Investment of 50 Percent between 2009 and 2050—for Less Mature Technologies the Growth May Exceed 1200 Percent

Source: IEA (2010a), IAEA (2010) and Vivid Economics calculations.

Notes: 2050 data are for IEA BLUE Map scenario (50 percent reduction on 2007 energy-related CO_2 levels by 2050); apart from nuclear, 2009 data are top–down estimates based on IEA (2010a), these estimates are greater but not significantly so than bottom–up estimates from UNEP/SEFI (2010). Current nuclear data are for 2010 and is the product of the capacity installed in 2010, from IAEA (2010), and the average overnight capital cost from IEA (2010b).

both these technologies while in 2008 Brazilian inventors registered more than 2 percent of global patents in products linked to hydroelectricity, substantially more than its share of patents in any other low-carbon energy technology. Some of the key policy options that could be considered to further develop these strengths are to identify and streamline R&D on biomass technologies, to establish independent internationally recognized consultative panels to advise on hydro projects entailing major social/environmental risks and simultaneously bolster institutional capacity of licensing body to overcome slow and costly process of environmental licensing (IIED, 2007; Nexant, 2008; *The Economist,* 2008).

India's position in key low-carbon energy technologies is one of growing strengths across a range of technologies without having achieved global pre-eminence (or indeed parity with China) in any as yet. It has become one of top 25 exporters in all key low-carbon energy technologies in the last 3 years, in some technologies growing rapidly. A number of individual companies have established global reputations in specific technologies, that is, Suzlon in wind turbine manufacture. However, both its export market share and its inventor's share of global patents are, for all technologies, lower than in China. Continued growth in these technologies is likely to rest on effective and efficient implementation of its domestic policies for low-carbon energy deployment coupled with policies that aim to build on India's recognized strengths i.e. demonstrate successful business models of, for example, renewable energy at scale using "frugal innovation/engineering" techniques (replicating the success already achieved in cars, cataract surgery, and computers).

Passenger Transport

The current immaturity, but extremely rapid growth, required in low-carbon vehicles and fuels provides massive opportunities for Brazil, India, and China. In contrast to low-carbon energy production, the current low-carbon passenger transport markets are very underdeveloped. The growth implied by the IEA's analysis is for the liquid biofuels market to grow by more than 20 times, the hybrid passenger market by almost 30 times while electric vehicles are expected to be a larger market than both of these sectors combined, despite currently representing a tiny fraction of global automobile manufacture. This is shown in Figure 12.

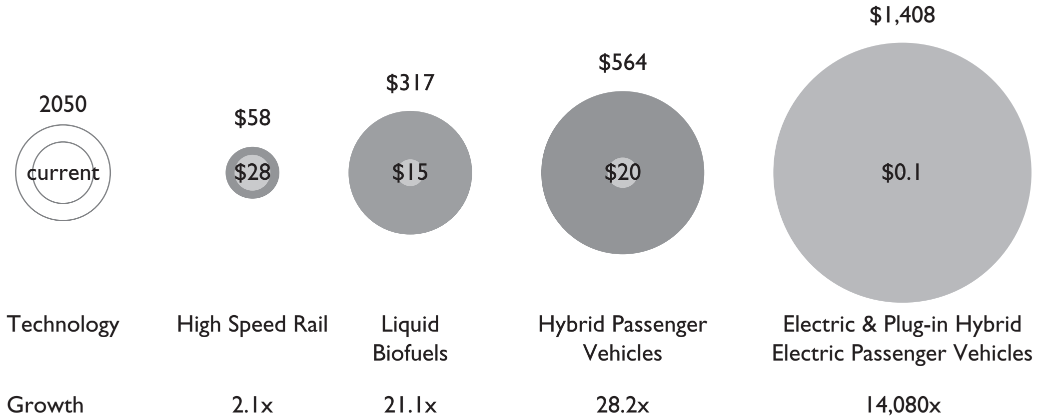

Figure 12. Massive Growth in the Markets for Low-carbon Passenger Vehicles and Fuels will be Required Over the Next 40 Years

Sources: High speed rail: UIC (2010), SCI Verkher (2008), BSL (2009), De Rus (2008), HS2 (2009) & Vivid Economics calculations.

Notes: current investment p.a. is for 2010; future investment p.a. is by 2025, no change in unit investment cost is assumed between 2010 and 2025. Liquid biofuels current p.a. investment: REN21 (2010); data are for 2008. Passenger vehicle current p.a. investment: IEA (2010a), http://www.polk.com/ & Vivid Economics calculations. Biofuels and passenger vehicles p.a. investment by 2050: IEA (2010a) & Vivid Economics calculations.

The Chinese government and Chinese inventors appear to have recognized the massive growth potential of these markets. The 12th Five Year Plan identifies alternative fuelled vehicles as one of seven pillars of the economy, collectively expected to contribute to 15 percent of GDP by 2020 (Ng and Mabey, 2011). This creates a platform from which China can capitalize on some recent successes in this sector: the share of global patents in both biofuels and electric vehicles in 2008 registered by Chinese inventors were greater than for any of the renewable energy sectors discussed above and, again, greater than either Brazil or India. However, despite this relative focus, its patenting efforts still fall well short of those in developed countries. Notably, in 2008, more than 50 percent of global patents for electric vehicles were filed by Japanese inventors.

Brazil has clear opportunities in relation to liquid biofuels where it is already the world's largest exporter. Seizing the growth opportunities provided in this sector is likely to be facilitated by further R&D efforts (despite its export strength in this sector, in terms of filing patents, its inventors lag those in both key developed countries such as the USA and Japan as well as China) as well as defining, implementing, and ensuring quality assurance standards for uniformity in quality of biofuels for export.

The evidence from India suggests less focus has been given to these technologies than is warranted given their massive growth potential. Although India has had some notable early successes in electric vehicle manufacture, such as the Reva, India inventors have filed a negligible proportion of global electric vehicle patents and its biofuels exports are also tiny. That said, in 2008, its share of patents in biofuels did notably increase although it is as yet unclear whether this is the start of a trend.

Buildings

The low-carbon buildings market may be worth around US$300 billion by 2050. As Figure 13 shows, much of market opportunity will be in cooling and ventilation measures as well as refurbishments of building shells. Data on growth relative to the current market are not available.

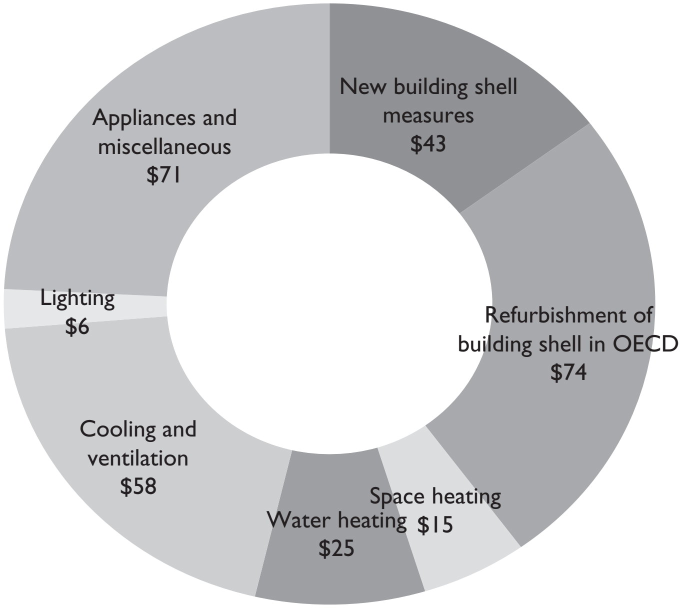

Figure 13. The Market to Supply Low-carbon Technologies to Buildings Could be Worth US$300 Billion p.a. by 2050

Source: IEA (2010a) & Vivid Economics calculations.

China is again extremely well positioned to benefit from this market growth. It currently accounts for more than 55 percent of total global exports of compact fluorescent lamps as well as 9 percent of all insulation products exported and 8 percent of all heat pumps. By contrast, Brazil and India are not currently demonstrating any clear capacity to compete in manufacture and export of these technologies.

Implications

The low-carbon transition offers massive market opportunities for each of Brazil, India, and China. The particular strengths of each country differ—for instance, China looks strong across a host of different technologies; Brazil's comparative advantage seems most readily apparent in biofuels, biomass, and hydro while India's strength is growing especially in some low-carbon energy technologies. Nonetheless, the transition to a low-carbon economy collectively represents an opportunity for each of these countries, and other emerging market economies, to achieve leadership across a range of technologies that will be crucial in the twenty first century.

To seize this opportunity will require specific policy actions in each country but there are also some areas of common ground between each country. The discussion above highlighted some of the specific policies that could help each country maximize its opportunities. However, there are also some actions that are common to all countries. Three of these are identified below.

First, additional domestic action will spur the growth of these global markets. The US$3 trillion opportunity identified in this discussion is predicated on achieving a 50 percent reduction in energy-related CO_2 emissions by 2050. This can only be achieved through emerging markets also taking further action both given their importance to global emissions and also because such action is likely to be necessary to stimulate further emissions reductions by developed countries.

Second, creating the framework and incentive structure for the corporate sector to seize these market opportunities is vital. These market opportunities will be taken, or otherwise, by the corporate sector and, within, Brazil and India, the private sector as traditionally defined. Across the Brazilian and Indian economies as a whole, between 1999 and 2008, 88 percent and 86 percent of all investment was undertaken by the private sector.[25] The pattern is similar in many of the sectors where low-carbon market opportunities are greatest: in the vehicles sector, private sector companies undertake practically all Indian car manufacture; in Brazil more than 80 percent of car manufacture was in the private sector.[26] In China, this picture is complicated by the prevalence of state-owned enterprises but, even here these sometimes operate at arms' length from the state. Given that the vast majority of activity and financing will be undertaken by the corporate sector, the appropriate role for government will be in providing incentives and regulation that directs efforts toward these key new technologies.

Third, each of India, China, and Brazil might consider strengthening their innovation activity in key low-carbon technologies. A common theme in relation to all three countries is that current export performance is stronger than innovation activity. Despite growth, there is still a considerable gap between the number of patents filed by USA, Japanese, and even Korean inventors and those from Brazil, India, and China. While short–medium term success in supplying low-carbon technologies is likely to be possible through the lower cost base typical in each country, these advantages will erode over time and longer term technological leadership will require being at the forefront of innovation activity. The success China has shown, for instance, in building the world's fastest super-computer, will need to be focused on low-carbon technologies by itself as well as by India and Brazil.

Policy Implications

The analysis reveals that, despite the differences between India, China, and Brazil, there are a series of important policy implications which are common to all of the countries. This section draws out five key themes and illustrates them from examples from each of the three countries.

Stimulate Climate Action Within and Outside of Brazil, India, and China

Stronger climate action by developed countries provides large benefits to each of Brazil, India, and China. If developed countries (as well as emerging markets) continue along a BAU emissions trajectory, then the median temperature increase by 2100 will be greater than 4.1°C on 1990 levels (c. 4.5°C on pre-industrial temperatures) and there is a 10 percent probability they could increase by 6.6°C (7.0°C on pre-industrial). This would have profound consequences for each country. Our modeling analysis suggests that temperature increases of this magnitude could lead to damages equivalent to up to 14 percent of GDP in China, 13 percent in India, and 11 percent in Brazil in 2100. Further, without action by developed countries, the substantial export opportunities in the provision of low-carbon goods and services that would otherwise be available for these countries will be lost.

However, action by developed countries will not be sufficient for Brazil, India, and China to avoid the worst damages. Even if developed countries take action, Brazil, India, and China could still suffer damages of between 9 and 10 percent of GDP in 2100 if emerging economies do not also act. However, emerging economy action can halve the likely maximum damages that these countries would suffer. In other words, emerging market action is a very effective insurance policy if the emerging markets wish to ensure that they do not experience catastrophic impacts from climate change.

Given Brazil, India, and China's need for action by both developed and emerging economies, (additional) publicized, and potentially co-ordinated, climate action by the emerging markets, potentially made conditional on further developed country action, could yield substantial dividends. A perceived lack of action by emerging markets is often used as a reason for developed countries failing to take stronger action on climate change. At the same time, other stakeholders within developed countries have recognized the action that emerging markets in general, and China in particular, have begun to implement a low-carbon transition (E3G, 2011) and raised concerns within policy communities that developed countries need to move more quickly. Additional climate action by emerging economies—based, for instance, around the idea mooted by China of ensuring that 2050 emissions are no higher than 2005 emissions—would help remove the excuses for inaction within developed countries. Making a commitment like this conditional on further developed country action would place the onus firmly on developed countries to explain why they were not prepared to make more ambitious commitments.

Make Infrastructure Choices Appropriate for a Low-carbon World

Failure to make infrastructure choices consistent with a low-carbon future could be extremely costly. The IEA (IEA, 2010b) estimates that global electrical generating capacity is set to grow by between 63 and 70 percent between 2008 and 2030 of which 75–80 percent will take place outside of the OECD. This provides a tremendous opportunity for these countries to make infrastructure choices consistent with the requirements of a low-carbon future. The wrong choices, however, could be very costly as greater realization of the risks of climate change in the future, would necessitate the premature scrapping of substantial amounts of high-carbon assets and a short-term requirement for disproportionate resources to be allocated to constructing alternative low-carbon assets.

Infrastructure decisions also need to be made recognizing that even with concerted action by both developed and emerging countries, the climate will change appreciably during the life time of assets that are due to be constructed. Even under the developed country and emerging market action scenario, median temperature increases of 2.7°C on 1990 levels (and 3.1°C on pre-industrial) are forecast by 2100 and increases of 1.2°C (1.6°C) by 2050. Sea levels may rise by 13 cm by 2050 and 32 cm in 2100 in the same scenario. These changes could have substantial impact on the optimal amount, and engineering characteristics, of the infrastructure, especially in coastal areas, which needs to be designed to be resilient to these future changes.

Support Corporate Sector Low-carbon Investment

The low-carbon transition will require substantial new investment most of which will need to be delivered by the private/corporate sector. Typically, it is estimated that low-carbon investment requirements will be between 1 and 2 percent of GDP by 2030 (Stern, 2009) which at current GDP levels would imply investment of US$50–100 billion in China, US$12–25 billion in India, and US$16–32 billion in Brazil (using market exchange rates).

The magnitude and diversity of this challenge means that much of the investment will need to be undertaken in a decentralized way: in many cases, the most appropriate role for government will be to create the right incentive and regulatory framework to facilitate the required behavior by individual firms. For instance, in Brazil and India, only around 12–14 percent of economy wide investment is undertaken by the public sector. The same reasons that keep this percentage relatively low in the economy as a whole (i.e. the public sector's lack of information, in many cases a stronger efficiency incentive within the private sector) will also apply to much of the investment needed for the low-carbon transition. Even in China, where state-owned enterprises are much more prevalent, there has been increasing recognition, as seen for instance in the 12th Five Year Plan, that a more decentralized, incentive-based approach to facilitating investment will be required (Ng and Mabey, 2011). As the scale, challenge and pervasiveness of the low-carbon transition increases, building on this trend will be important.

Given their abundance of low-cost abatement opportunities, embracing flexible market-based mechanisms could be particularly advantageous for each of Brazil, India, and China. In particular, it could result in a significant proportion of investment costs being paid for by developed countries. For instance, Börner et al. (2010) estimate that introducing a market-based mechanism to reduce emissions from deforestation and degradation in Brazil through developed countries purchasing "offsets" could lead to international transfers of around R$15 billion (around US$9 billion at current exchange rates) between 2009 and 2018.[27]

Remove Barriers to Emerging Areas of "Green" Comparative Advantage

To ensure that Brazil, India, and China realize the massive potential provided by the low-carbon transition to achieve technological leadership in key low-carbon technologies, it is vital for each of the countries to identify strengths and weaknesses and the policy actions that can facilitate growth in areas of comparative advantage. Our analysis suggests that these policy actions might include:

- In China, prioritizing R&D spending and innovative activity in low-carbon technologies, so that their current dominance in many low-carbon manufacturing activities persists in the future (especially as developed countries may be more reluctant to make their intellectual property available).
- In Brazil, focusing particularly on biofuels and manufacturing linked to biomass and hydro through stronger innovation; defining, implementing, and ensuring quality assurance standards for uniformity in quality of biofuels for export and bolstering institutional capacity.
- In India, building on rapid growth (despite which its global presence remains small relative to China) in particular through efficient and effective implementation of its domestic low-carbon deployments programs and supporting greater low-carbon innovation effort.

Capture the Benefits of Energy Efficiency

To our knowledge, the report has provided the first econometric analysis demonstrating the immediate macroeconomic benefits available to countries who improve their energy efficiency.

Annex A: Description of the MAGICC Model

The MAGICC model is a simple climate model, described as an "upwelling diffusion energy-balance model" which also incorporates a carbon cycle allowing for system feedbacks (Wigley and Raper, 2001). It is computationally fast, and can represent the output of more complex scientific models, making it suitable for this report.

To generate the probabilistic results presented in this report, we have assumed that three of the key input variables into the model are random variables, as follows:

- The climate sensitivity parameter (which measures the change in temperature for a doubling of CO_2) is assumed to be log-normally distributed with the underlying normal distribution having mean of 1.0986 and standard deviation of 0.5409. This results in the log-normal distribution having a median value three with only a 10 percent probability that the true value is less than 1.5 as discussed in the most recent IPCC report (Meehl et al., 2007).
- The ocean diffusivity parameter, following Ranger et al. (2009), was derived from fitting a log-normal distribution to the range of ocean mixing rates across the range of current global climate models (Table 9.A1 Cubasch et al., 2001). This resulted in the underlying normal distribution having a mean of 0.9055 and standard deviation of 0.5456.
- For the carbon cycle feedback, we assume equal one-third weightings to each of the low, medium, and high options in MAGICC.

MAGICC reports expected temperature increases relative to a 1990 baseline. Implicitly, there has been a 0.4°C increase in global average temperatures between pre-industrial times and 1990. This is consistent with the IPCC 4th assessment report which provides a central case increase in global average temperature from pre-industrial times to 2000–2005 of 0.8°C (within a range of 0.6–1°C) and the results from Brohan et al. (2006)—the most recent relevant study reported in the IPCC report—which estimates that the global average temperature increase per decade from 1979 to 2005 has been 0.268°C. The Brohan et al. (2006) results suggest that there was a 0.4°C temperature increase between 1990 and 2005, implying a further 0.4°C between pre-industrial and 1990.

Annex 2: Econometric Analysis

Calculation of TFP

In economic analysis, the economy at the country level is often modeled by an aggregate production function. A production function is a mathematical relationship which relates output to inputs. The most common measure of output is gross domestic product (GDP); the value of goods and services produced in an economy in a given year. GDP represents the amount of income available for distribution to workers and the owners of firms (note that the owners of firms do not always reside in the same country as the firm).

The production function for a particular country can be written as

$$GDP = AK^{\alpha}(HL)^{1-\alpha}, \tag{1}$$

where K is the value of the capital stock and L the number of hours worked by employees, and H a measure of human capital. The parameter α can be said to represent the technology used and is often assumed to be equal to one-third (Hall and Jones, 1999), an approach we use. The parameter A determines how much output can be achieved for a given amount of capital and labor. It is known as TFP, and is the way in which the conceptual definition of productivity as the ratio of inputs to outputs can be quantitatively expressed.

This framework is used in this report to derive a measure of TFP. We calculate TFP in an analogous fashion to Hall and Jones (1999). In the equation above, measures of the number of years of schooling and the rate of return on schooling are used to calculate H.

Econometric Specification

The relationship between TFP and energy intensity is modeled using the following equation:

$$\ln(TFP)_{i,t} = \alpha_i + \beta_i \ln\left(Energy\ Use \big/ GDP\right)_{i,t} + u_{i,t}$$

where $u_{i,t}$ is an error term and the subscripts i and t refer to countries and years, respectively. The coefficient β_i can be interpreted as the percentage change in TFP observed when there is a 1 percent change in energy intensity (i.e., energy use per unit of GDP). Because the variables in the equation are expressed in natural logarithms, the coefficient $\beta_{i,}$ multiplied by minus one can be interpreted as the percentage change in TFP observed for a 1 percent change in GDP/energy use i.e. energy productivity.

This equation is estimated using instrumental variable techniques. Because TFP is a determinant of GDP, it is likely that GDP will be correlated with any errors in TFP measurement (represented by u in the equation) and this can bias the estimate of β_i. This is known as an endogeneity problem in the econometric literature. In order to account for this, we use the price of diesel and gasoline fuel as instruments and implement standard IV techniques.

In order to be a valid instrument, we require that the instruments are correlated with energy intensity but not with TFP. Prices are often good candidates for such variables, and we use prices as our instruments in this case. The level of fuel prices in the economy will affect energy efficiency, but will not have a direct impact on TFP, and so are appropriate instruments.

Data on energy intensity are missing for Germany, Russia, and Saudi Arabia for some of the time period, and so these three countries are excluded from the analysis; this leaves the remaining 16 G20 countries included in the estimation.

Table A2.1 presents the estimates, along with standard errors, from both an OLS and an IV estimation. Country codes are the international ISO-3 standard. The G20 average was calculated econometrically by restricting the coefficients to be the same for all countries, and so differs from the arithmetic average of the individual country estimates. The table shows that, within the preferred IV results, the only estimates which are statistically significant are in those countries where there is a positive relationship between energy efficiency and TFP i.e. where the coefficient estimates are negative. Table A2.2 provides more information on the variables and data used in the analysis.

Table A2.1. Key Results from the Econometric Analysis of the Relationship between Energy Efficiency and TFP

	OLS Estimates	Standard Error	IV Estimates	Standard Error
ARG	−1.93***	0.36	−2.11	1.24
AUS	−1.54***	0.23	−0.40	0.84
BRA	−1.39**	0.53	−2.59	1.61
CAN	0.01	0.16	−0.97	0.55
CHN	−1.05***	0.04	−1.12***	0.27
FRA	−0.70**	0.25	−0.88	1.25
GBR	−0.66***	0.08	−0.74	0.47
IDN	0.00	0.22	−2.78	1.73
IND	−1.10***	0.17	−0.82*	0.39
ITA	−0.78***	0.18	−1.38	2.91
JPN	−0.80***	0.19	1.13	3.17
KOR	2.24***	0.22	1.10	1.42
MEX	0.17	0.32	0.63	0.75
TUR	1.52***	0.33	−1.02	1.76
USA	−0.18	0.09	−0.79	0.48
ZAF	−0.34	0.19	1.21	1.53
average	−0.73***	1.1.1	−1.17***	1.1.2

Note: Results with * significant at the 5 percent level, ** at the 1 percent level and *** at the 0.1 percent level.

Table A2.2. Data Sources and Definitions

Variable	Definition	Source
Real GDP per capita	Purchasing power parity $	Heston et al. (2009)
Real capital per worker	1.1.3	UNIDO
Energy use	Kilotonnes of oil equivalent	World Bank (2010)
Years of schooling	1.1.4	Barro and Lee (2010)
Pump price of diesel fuel	US$ per liter	World Bank (2010)
Pump price of gasoline fuel	US$ per liter	World Bank (2010)
Rate of return to schooling	percentage increase in wages per year	Hall and Jones (1999)

Notes

1. IAMs are models 'that combine the scientific and economic aspects of climate change in order to assess policy options for climate change'. (Kelly and Kolstad, 1998).
2. Or the regions in which these countries are located.
3. These are the same scenarios that were used in our previous analysis although the results have been updated to take account of the latest Centennial Group economic growth forecasts.
4. The G20 Emerging Markets (or GEMSs) are Argentina, Brazil, China, India, Indonesia, Korea, Mexico, South Africa, and Turkey. These are the G20 countries that do not have legally binding commitments to reduce emissions under Annex B of the Kyoto Protocol and that, in 1990, the base year for the Kyoto Protocol, had a Gross National Income (on an international dollar Purchasing Power Parity basis) of less than US$ 9,000 per capita. All of the other countries of the G20 had a higher GNI per capita in this year.
5. That is modal temperature increase.
6. The Stern Review (2006) notes that temperature increases of 5°C or more "would be equivalent to the amount of warming that occurred between the last ice age and today—and is likely to lead to major disruption and large scale movement of population. Such "socially contingent" effects could be catastrophic, but are currently very hard to capture with current models as temperatures would be so far outside human experience.
7. The SLR estimates are derived from MAGICC. As noted by the IPCC (2007) some recent scientific literature suggests that these models may significantly underestimate possible sea level rises due to land-based ice sheet dynamics. This is discussed more fully in Schubert et al. (2006).
8. These damages estimates include both market and non-market damages (converted into GDP-equivalent impacts) to provide a comprehensive assessment of the impact on human welfare from climate change.
9. These are the damages associated with the 90th centile temperature and sea level rises anticipated with and without emerging market action as reported above (with the exception of PAGE results where the climate model embedded within the model was used to generate temperature and sea level rises, although these were closely calibrated to those temperature and sea level rises generated from MAGICC). In all cases, the results refer to the modeling region in which the country is located although each of India, Brazil, and China represents the largest economies in each of the relevant regions across the different models.
10. This analysis was based on the SRES A2 scenario. According to the IPCC (2007), the best estimate temperature increase for this emission scenario is 3.4°C between 2090–2099 and 1980–1999. By contrast, in our developed country action scenario, the median temperature increase (2100 on 1990) is 3.9°C.
11. Modeling based on A1B emission scenario which is reported to give a most likely temperature increase of 2.8°C (2090–2099 on 1980–1999), IPCC (2007).
12. These results examine exposure to a 1 in a 100 years flood, following a 0.5-m sea rise and 10 percent increase in storm surge height, in 2070, not taking flood defenses into account. The authors describe their exposure metric as a "worst case scenario," citing hurricane Katrina and New Orleans as an example. Alternative results (World Bank/ADB/JICA, 2010) suggest that, in Manila and Bangkok, climate change could result in around one million extra people (20–40 percent of the baseline without the impacts of climate change), being exposed to a 1 in 100-year flood in 2050. These results take into account the impacts of current and planned improvements in flood defenses.
13. These figures are based on sea level rises of one meter.
14. This would not necessarily be the case if a country received substantial income from the production and sale of energy sources.
15. A recent survey of the literature on cost estimates derived from a wide range of integrated assessment models concluded that these models suggest that the global costs of meeting a 2°C climate goal are likely to be between 1% and 5% of GDP (Bowen and Ranger, 2009). There is little work to date on what the costs for GEMs specifically might be. The 2°C goal is more ambitious than the scenarios presented in section 3 which implies that the costs associated with achieving these scenarios would be lower.

16. We measure energy efficiency as its inverse i.e., GDP per kilogram of oil equivalent so that a higher number implies a higher efficiency performance.
17. For example, Lynde and Richmond (1993).
18. Econometric analysis of the relationship between energy efficiency and GDP per capita has not been undertaken as the typical definition of energy efficiency at the macroeconomic level, and the approach adopted in this analysis, is GDP per kilogram of oil equivalent input. Consequently, any econometric analysis would have GDP as both an independent and dependent variable meaning that any results could be spurious.
19. The constraints imposed by integrating data from different sources means that these lists should not be considered exhaustive.
20. Further, India and China's energy productivity was only 40 percent of Korea's: a country which is often cited as a country with a low-carbon growth strategy that these countries could seek to emulate.
21. This analysis is based on the IEA Blue scenario which provides one pathway for achieving a 50 percent reduction in energy consumption emissions by 2050 on 2005 scenarios. This pathway is generated through application of a modeling approach that estimates the lowest cost of delivering the stated objective.
22. More specifically, given the long lead times in nuclear investment, the annual increases in capacity connecting to the grid expressed in monetary terms.
23. Except Brazilian inventors in hydropower technologies.
24. The need for greater R&D effort in these low-carbon technologies has been recognized in a number of detailed reports into renewable energy technologies in China. See, for instance, Li and Ma (2009).
25. Firms plus households. Data for China are not available. Data taken from UNSTAT, National Accounts Official Country Data.
26. When there is shared public–private ownership, output is allocated pro-rata to ownership stake.
27. This is based on an offset price of around R$7/tonne (based on credit prices on CCX with typical discount (39 percent) applied because of potential temporary nature of emission savings) and identifying where this price would incentivise reduced deforestation, as well as taking into account lost benefits from no longer undertaking deforestation. Higher credit prices would obviously result in greater flows. The study also shows that alternative options for structuring the payment i.e., by hectare of avoided deforestation would result in (substantially) lower flows.

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