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Energy and Development in Emerging Countries

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Energy and Development in Emerging Countries

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Summary

Energy is an important component of the economy and is a fundamental factor of production. In general we expect is use to grow in some relation to growth in economic activity. Empirically we see a closer relationship (higher E/GDP elasticity) in emerging economies where the energy intensive stage of development is still in process. Traditional fossil energy sources remain the least cost source of providing many or most energy services but present an environmental challenge. Managing the growth of energy use and its impact on the environment is a central challenge of "green growth." Examples of the interactions of energy development in China are used to provide a deeper understanding of these links.

Keywords : Energy, emerging countries, climate change, China, CO_2 emissions, green gross, modelling.

JEL Classification : D58, O13, Q53, Q54.

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I. Introduction

Energy is a crucial factor of production in any economy and its use in households can be essential for heating, cooling, and cooking as well as providing a range of energy services that make life easier and free people from burdensome and repetitive tasks. At the macroeconomic level analysts have spoken of decoupling economic growth and energy use because of both environment concerns related to energy use as well as at times the adequacy of energy resources. "Decoupling" energy use and economic growth only enters the lexicon because of the, at least perceived, strength of the relationship. From a production standpoint we often imagine sectors to exhibit constant returns to scale, with a doubling of output leading to a doubling of all inputs. At the macro-economy level the result is a turnpike theory-type conclusion where all sectors grow at the rate of the overall economy, and hence the energy sector should grow at the rate of the economy. This is counter to observations for much of the world especially developed countries, where the energy use per unit of GDP has declined consistently at a rate of 1% per year or more. Moreover, over a decades to a century real energy costs have declined, and so price induced substitution is not a explanation for the energy sector growing slower—rather it would suggest the energy sector should grow faster than the economy as a whole if that were the main factor driving our use trends.

From a consumption-side view of the world, we are familiar with the idea of luxury and necessity goods, where necessity goods have an income elasticity of less than one, and luxury goods more than one. Is energy a necessity or a luxury? In reality it has elements of both. Depending on one's climate some form of space conditioning is a near-necessity as is energy for cooking. So at some level these seem like necessary goods that, as income grows, would become a smaller share of expenditure. But energy use is complementary to many goods that have a luxury element: larger homes, more mobility (autos, air travel), more appliances, and more goods in general. In fact, in the US economy on order of ½ of the CO_2 emissions associated with our consumption pattern is due to indirect energy consumption—that is the embodied energy in the goods we buy that may be produced elsewhere in the US economy or abroad. And when we look at the production of different sectors for the US, a big surprise is that recreation services are among the more energy intensive consumption goods. The observation that the energy sector grows slower than the economy as a whole suggests that overall perhaps the income elasticity of demand for energy (direct and embodied) is less than 1.0. And, if we look across countries we tend to see growth in the energy sector in poorer countries relative to GDP closer to 1, whereas it is significantly less than 1.0 in more developed countries. It suggests a pattern of growth being relative energy intensive in early periods of development, and less energy intensive in later periods—the apparent energy-intensive nature of recreation notwithstanding.

Technical change is the other candidate to explain the long-standing (more than 100 year) trend in falling energy intensity in much of the developed world. This doesn't offer particular insights into why changes in E/GDP are near one in some countries, and so an income elasticity that falls with growth still seems part of the explanation. Just why productivity growth would be naturally biased towards being energy saving is not obvious. Energy is a small share of production costs (on order 5% or much less) and so hardly an input to focus on, and if anything mechanization and such would seem to be substituting energy for human labor. The best explanation is that making things smaller and lighter reduces the need for inputs generally and also lead to less energy use as a (mostly small) side benefit. Energy is the caboose rather than the engine of productivity growth.

If energy were simply a produced good, like automobiles, buildings, appliances, or machines, then we would be much less concerned about its supply. Of course it differs because it is a basic factor in all activities in the economy—energy, whether from human or bullock power, or from advanced sources such as nuclear or solar photovoltaic, is essential. And it is not produced so we can only harness the energy resources nature provides, and so we naturally worry about whether nature's provision is adequate to meet our expanding needs. The general observation is that regardless of the resource, in purely quantitative terms energy resources are enormous. Most of the energy we utilize is one way or another based on the sun, whether it is wind, hydro-electricity, solar, biomass, or fossil fuels. The exceptions are geothermal and nuclear. Leaving these aside, the earth is bathed in solar energy each year that is orders of magnitude greater than that we use in the economy. In fact, my colleague, and co-director of the Program I run at MIT, has calculated that the radiative imbalance we have created with greenhouse gases is alone contributing energy to the earth system that is many times global energy consumption. While concerns about depletion of fossil fuels arise from time to time and we hear about impending "peak oil" these "end of the world as we know it" projections have not materialized. A proper resource accounting tells why: the actually amounts of coal, methane, and petroleum substances in the earth's crust are equal to hundreds of years at least of current world consumption. The recent innovation in recovering shale gas and shale oil illustrates this point. And if that is not enough companies have their eyes on the massive amounts of natural gas hydrates either in permafrost regions or in off-shore deposits. Resource quantity is not the problem—unfortunately for environmental problems like climate change—instead it is the cost of utilizing these vast resources, either renewable or depletable fossil energy resources. We are generally moving energy around with heat pumps to concentrate (heating) or disperse (cooling) energy, releasing stored energy when needed, or transforming from heat to power or vice versa depending on our specific application.

In the remaining sections of the paper I want to first sketch out a world development picture and its implications for energy use and climate change with a focus on emerging economies, then speak briefly about the issue of "green growth"—how we might reconcile economic growth and energy use, and finally give some examples of very concrete explorations of energy-economy-environment issues drawing on our work in China.

II. The Global Energy Evolution and Emerging Economies

I draw from work that applies a global integrated system model, the MIT IGSM, to understand the evolution regional and world economies and implications for energy, land use, the economy, and the environment (SOKOLOV et al., 2005). The economic model component is a applied multi-sector, multi-region general equilibrium model of the world economy (PALTSEV, et al., 2005). The updated version of the model as applied here is described in REILLY et al. (2012), including the supplemental material available on the journal web site. The projections are described in MIT (2014) with greater detail on the projections at http://globalchange.mit.edu/research/publications/other/special/2014Outlook, including regional detail for the USA, Europe (EU-27 plus Norway, Switzerland, Iceland, Lichtenstein), China, India, Mexico, Brazil, Russia, Canada, Japan, Australia/New Zealand, Africa, Dynamic East Asia Economies, Other Latin America, Middle East, Rest of Europe, Rest of Asia. For presentation purposes I focus on 3 broad groups, the *Developed* regions (USA, Europe, Japan, Canada, Japan, Australia/Zealand), an approximation of the *Other G20* given our aggregation (China, India, Brazil, Mexico, Dynamic East Asia) and *Other Developing* economies. For purposes of discussion, let us consider that the *Other G20* and *Other Developing* are emerging economies.

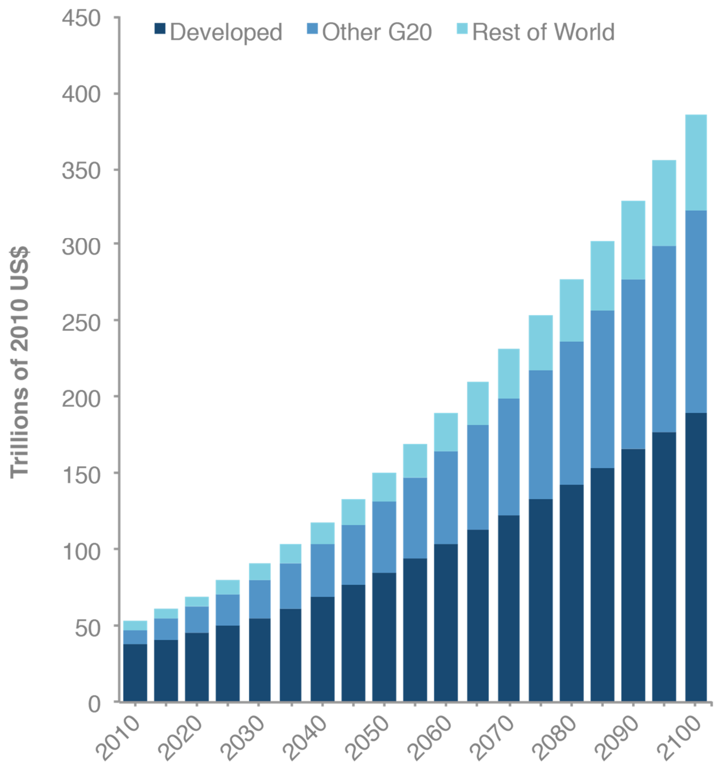

Figure 1: GDP, 2010-2100 for *Developed*, *Other G20*, and *Other Developing*, labeled Rest of the World.

Population projections are from the UN's 2012 Revision (UN, 2013), and while the focus is on the longer term, recent and near term economic growth is calibrated to recent data and forecasts of the International Monetary Fund (IMF, 2013). After that growth reflects the judgment of the authors of the report. The UN population projections show nearly stable population levels in *Developed* countries, growth slowing and population levels declining after 2050 in the *Other G20*, with growth in the *Other Developing* region continuing through the century. World population reaches 10.8 billion by the end of the century. The projected economic growth is more rapid in *Other G20* (3.9%, 2.9%) and *Other Developing* (3.3%, 2.8%) than in the traditionally *Developed* countries (2.1%, 1.8%)—rates in parentheses are annual growth rates for 2010-2050 and 2050-2100, respectively). Even with more rapid growth in emerging countries over 90 years, the the traditionally developed economies continue to account for as much as ½ of the economic activity (measured at market exchange rates) through the century, but the shares or others is increasing, especially the *Other G20* (Figure 1). Of course, re-evaluating GDP at a purchasing power parity rate would give much greater weight to the emerging countries today, but if as development occurs the difference between purchasing power parity and market rates narrowed then the growth of share of emerging countries would be less. In this work, the projected growth rates are based on expectations of growth in the native currencies or at fixed market exchange rates and so a purchasing power parity adjustment is a purely after the fact calculation. Of course this is just one scenario of economic development and growth. Never the less it is a scenario of modest convergence at least of the *Other G20* and *Developed*. While growth in GDP in *Other Developing* is more rapid than in the *Developed*, all of that is due to population and labor force growth—the per capita growth in these highly aggregated regions is coincidentally identical to that in the *Developed* regions, but it is significant progress in raising real incomes despite lack of "catch-up" in per capita income.

The energy implications of this economic growth are enormous, and dominated by growth in the *Other G20* (Figure 2), and this is due largely to China and India (Figure 3). Energy use in the *Other G20*, by this projection, becomes a world by itself, exceeding global energy use as of 2010. Why this rapid growth? This projection has *Other G20* growing more rapidly, and it is also a group of countries where incomes are reaching levels where households can afford more energy using goods, and especially personal automobiles. These projections further assume that the *Developed* regions are meeting Cancun-Copenhagen greenhouse gas reduction pledges. Thus, in addition to the saturation of some energy-using activities, use is further limited by higher energy prices needed to meet emissions reduction goals. Use grows in the Other Developing regions but from a smaller base, with slower economic growth, and income levels generally remain lower so that so that household energy use growth for things such as personal automobiles remain slower.

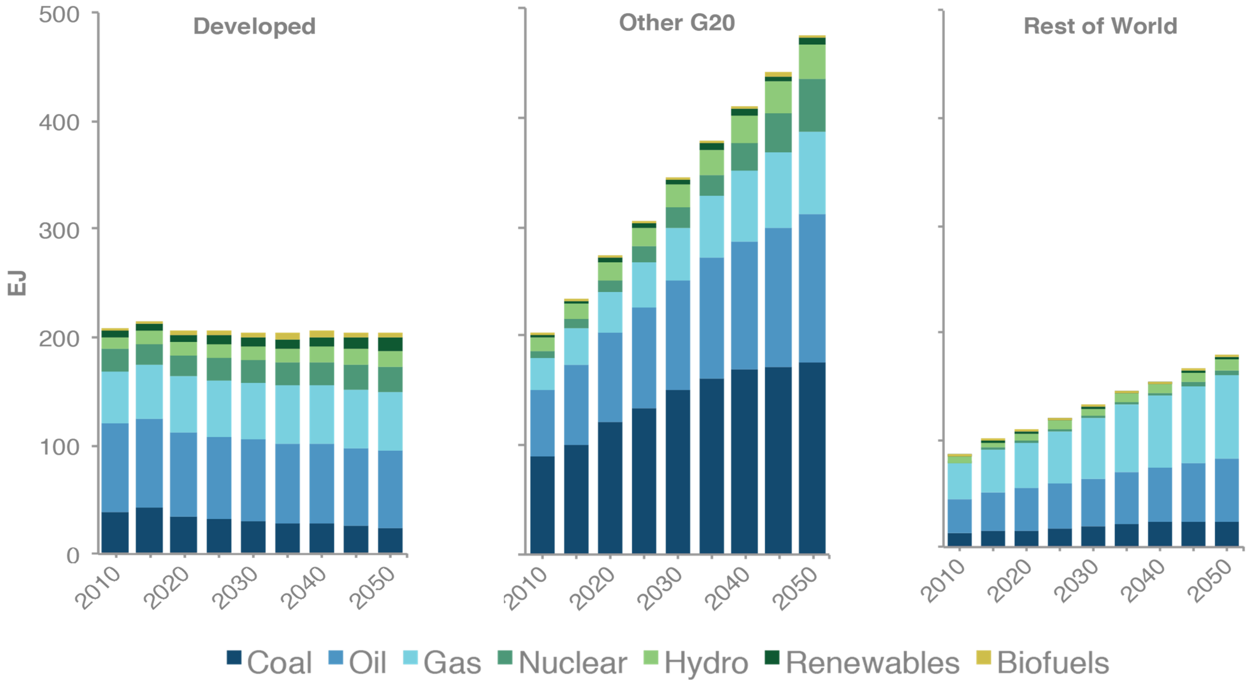

Figure 2: Energy use by fuel type: *Developed*, *Other G20*, *Other Developing*

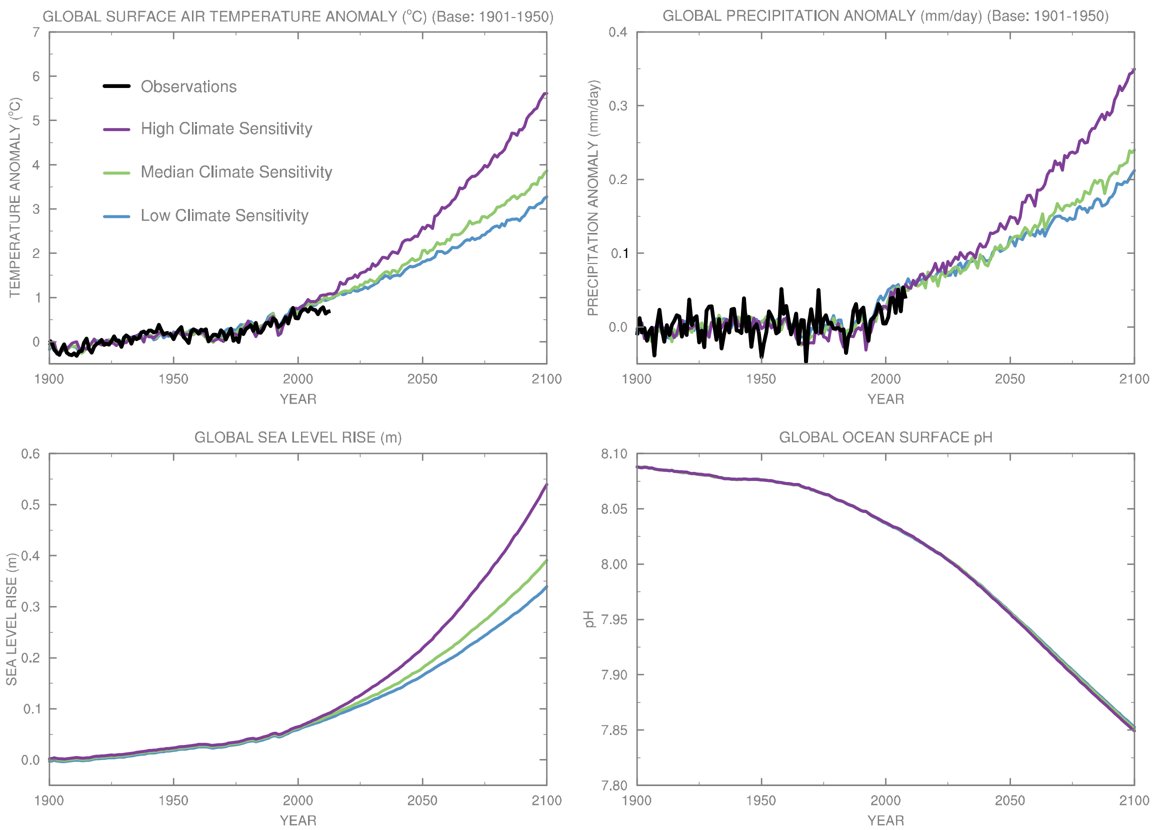

Figure 3. Indicators of global climate change: mean surface temperature, precipitation, and sea level anomalies (compared with the 1901-1950 mean) for high, median, and low earth system response to radiative forcing and ocean pH. (Note: Sea level rise includes only that due to thermal expansion, and the full effects of warming on sea level would only be observed over 100’s to 1000’s of years and so the committed sea level rise is 10’s of meters unless warming is reversed.

The modeling work supporting these projections explicitly models energy resources and depletion, and so these are consumption levels for which resources exist. With depletion, fuel prices are rising relative to other goods, somewhat restraining demand. Even with this factor slowing fossil energy use, it remains about 80% of total energy use. This has large greenhouse gas and conventional air pollution implications.

Almost needless to say, this pattern of development has substantial implications for the environment, and in particular climate and associated environmental impacts (Figure 3). Notably this is a path that would take us beyond the 2°C goal of the UN Framework Convention on Climate Change by mid-century unless we are very fortunate and the earth system response is on the lower end of existing estimates.

These global changes would pose significant challenges for emerging economies. Ocean acidification threatens fisheries, sea level rise in combination with likely stronger storms put coastal areas at significant risk, temperatures themselves are a challenge for human health, and the global average increase in precipitation, while potentially a benefit to dry areas will fall unevenly, and likely in more intense rain events, and so even where there is more, it may be associated with both worsened flooding and longer droughts.

A recent study suggests that climate would shift much production poleward, and that the combination of efforts at preserving and expanding forests for carbon sequestration, use of land for biofuels production, and higher energy prices in efforts to mitigate greenhouse gases would combine to put significant upward pressure on food prices (REILLY *et al.*, 2012). Agriculture and agriculture inputs use energy and so energy and food are already linked—carbon sequestration and biofuels development could increase the energy-food link. The recent Intergovernmental Panel on Climate Change (IPCC, 2014) also highlighted the likelihood of greater yield losses in already warmer climates, where many emerging countries find themselves. A consistent finding of agricultural studies is less severe or possibly beneficial effects of climate change in cooler climates, where warming can extend the growing season.

The energy-water link may also be important. While global precipitation is expected to increase with global temperatures, that precipitation will not necessarily fall where and when it is needed, and population and economic growth will generally lead to increasing water needs especially in emerging economies. Water is already stressed in many regions (Figure 4) and the combination of growth and climate change is expected to generally increase water stress. While water issues have been seen as large separate from energy issues, like the food and agriculture story, water and energy are increasing interconnected. An obvious connection is hydropower, but water for thermal power plant cooling is an increasing concern where low flow and rising temperatures may lower efficiency of thermal electric power plants, and in many cases severely limit operations especially where there is concern about the effects of water temperature in streams and rivers. Biofuels development may increase the need for more intense production of conventional crops, and one of the most effective ways of increasing productivity is with irrigation, and increasingly issues are associated with water and fossil energy development. Hence the combination of increasing demand for water for other purposes and changes in water resources because of climate change may create further conflicts between energy and water resources.

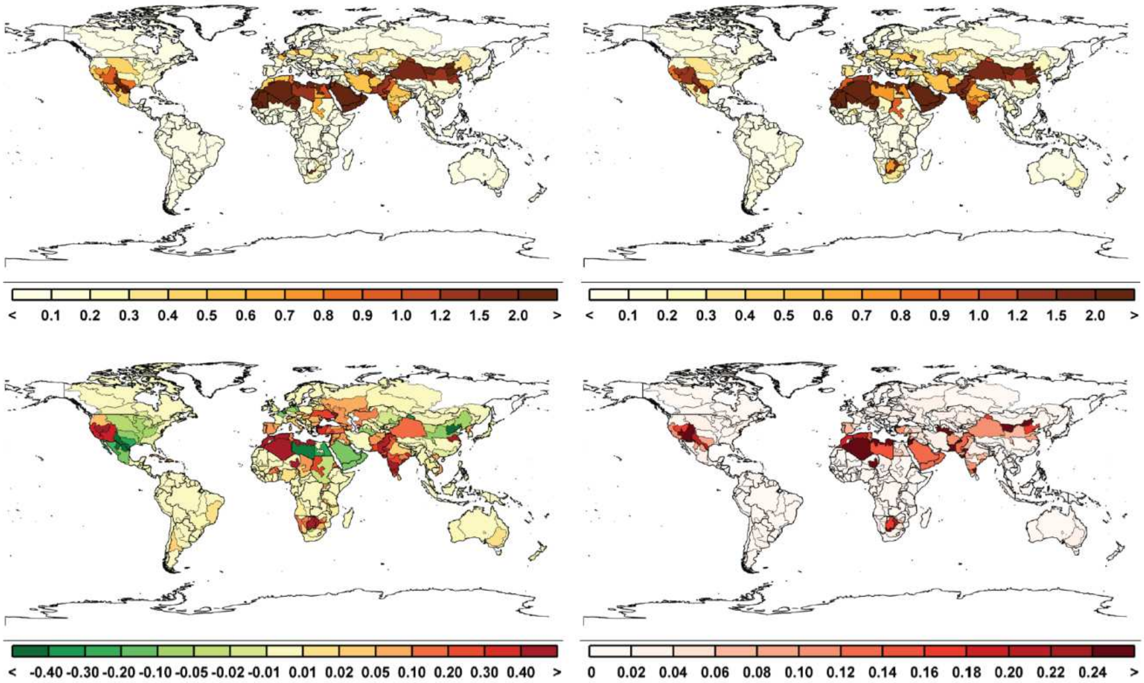

Figure 4. Water stress. Top left: Water Stress Index (WSI) in 2010. Top right: WSI in 2100. Bottom left: WSI difference, 2010–2100 (mean of different initial conditions). Bottom right: range of WSI differences in 2100 for different initial conditions. (WSI is the ratio of water needs to water supply; a ratio of 0.6 or greater is considered severe water stress, a ratio of greater than 1.0 indicates unsustainable reliance on groundwater or unmet needs.)

III. Green Growth—Sustainable Development

A recently popular concept is that of "green growth," implying that economic growth is (or could or should be) consistent with preserving or maintaining the environment. REILLY (2013) reviews the concept and offers that it is not fundamentally different than a long tradition of economics concerned with the potential for the market to deliver less than optimal performance when there are unpriced externalities. He relates the problem of green growth to pricing of externalities through taxation as in PIGOU (1932), or via internalization of externalities such as in COASE (1960) or formalized as cap and trade systems of control. Relatedly, green growth involves the efficient allocation of depletable resources over time as in HOTELLING (1931) or recognition of role of rents in allocating renewable resources (RICARDO, 1817). These are basic concepts in economics. If green growth has something new to offer it is to remind us that there is not a trade-off between environment and economic growth, or necessarily between equity and growth. Environmental damage that has severe consequences for human health, for crop growth, or for water quality and availability means that resources otherwise available for providing conventional economic services must instead be used for health services or to adapt to lower crop productivity or reduced water resources. Similarly, highly inequitable societies where childhood development is stunted from poor nutrition or where lack of access to education means children never realize their potential to contribute to the economy, are also economies whose long run growth prospects could be improved if the long run implications of poor nutrition or lack of education were properly accounted.

At the conceptual level the problem is simple, but the challenge is in implementing this program broadly involve properly accounting for economic growth and well-being, designing policy interventions that work to bring about an efficient allocation of resources, and knotty problems of optimizing over time. On the empirical issues a first step, long called for, is broader economic accounting that treats depletion of natural assets (WORLD BANK, 2011; NORDHAUS AND KOKKELENBERG, 1999; SARAFY, 1997). Accounting is the first step toward then evaluating how the economy will respond to reallocation of resources through policy instruments designed to correct unpriced or poorly priced goods. The knotty problem of optimizing over time relates to weaknesses in our decision making process when it comes to uncertainty, and in predicting (or guessing) at the evolution of technology over time. The best example of this may be utilization of fossil fuel resources. If we apply the Hotelling principle, rents on these resources (and/or their price) should rise over time, but over the long course of history they have mostly fallen in real terms. The problem departs from the pure Hotelling model in many ways: the resources are graded, there is a cost of recovery, the full amount of the resource is uncertain, and we are uncertain about the cost and our ability to recover hard to reach or less rich deposits. That prices have generally fallen over time in real terms seems like evidence that the market has consistently underestimated the amount of resources and advances in technology to recover them. Of course this is something of good news because pollution associated with use of fossil fuels is largely unpriced.

To turn this example toward a major policy decision the world currently faces, consider the problem of stabilizing climate, and accept the international goal of remaining below a 2°C increase from pre-industrial levels (or any particular stabilization goal). The recent Intergovernmental Panel on Climate Change (IPCC) has described an approximate carbon budget—how much more carbon dioxide we can emit before we exceed the 2°C target. This is essentially a Hotelling problem of optimally meting out that budget over all time (or given the approximate nature of the carbon budget calculation, at least for the rest of the century). We know the optimal price path on carbon should rise at the discount rate (although we are not sure of that rate) but we don't know how far we are from the optimal path right now—the carbon price needs to be more than zero today, but how much more? If we are optimistic about advancing non-carbon alternatives, then we know that it will be relatively low cost to switch away from fossil fuel in the future, and we can use up more of our carbon budget in the near term. Conversely, if we are pessimistic (or conservative) about future options, we would reduce more today and save more of the budget for the future. This dynamic was illustrate in US Government study where the 2020 carbon price varied from about $90 to $260/tonne, largely because of differences in technological options in the longer term (i.e. post 2050).

Then, there is much written on instrument choice, and economists are in wide agreement that a pricing mechanism is preferable over regulatory methods. Two interesting questions arise: (1) what to do with the revenue from pollution pricing—or in a cap and trade system simply given the allowances away or auction them which creates more options for using the allowance value (2) is carbon pricing sufficient. With regard to the first of these, much of what we know we owe to Larry Goulder (e.g. GOULDER, 1995) who first evaluated the potential advantages of using pollution tax revenue to offset other distortionary taxes. Assuming that the level of public funding is "appropriate" pollution tax revenue can be used to cut other distortionary taxes to some benefit to the economy in addition to whatever benefit there is from reducing the pollution in the first place. In the context of emerging economies where government spending may be inadequate for critical investments such as education or infrastructure, such revenue could be used for such purposes on the assumption that the lack of sufficient investment means the returns are higher. Where education and training is underfunded carbon tax revenue could be used to advantage, helping to prepare the populace to take up jobs in new industries needed to support the green economy. With regard to the second of these, analysis increasingly suggests that carbon pricing may not be adequate by itself and further support may be needed to advance clean technology. Again, early work is that of GOULDER and MATHAI (2000). The challenges here may be exactly how much and how to target this spending (OTTO, et al, 2008).

There are opportunities for manufacture of technology for the green economy to supply domestic and, perhaps more importantly, global demand. However, this can result in conflict as, for example, the EU and US has seen China's support for development of renewable industries as in violation of the WTO rules. Here whether emerging countries become centers of innovation in green technology, or mostly producers of the equipment, R&D and training efforts are likely needed. Experience in the agriculture suggests that if there is not R&D and training then local adoption of new technology can be limited. The technology may need to be adapted to local situations, integrated into the existing economic/technology infrastructure, and maintained over time. If domestic capability to adapt, integrate and service the new technologies is not developed then it means expensive use of foreign services. Again, these issues inevitably can cause conflict, and China is an example. Western companies operating there fear that collaboration with Chinese companies will result in copying of innovative technologies, and so are often unwilling to share details of new technology as they hope to maintain the market for themselves. These conflicting interests are probably at the heart of continued calls for "technology transfer" from North to South, along with frustration among emerging countries that it does not occur. For specific investigations of FDI and joint venture efforts see NAM (2011) and NAM AND LI (2013).

IV. Energy, Environment, and Development: The Case of China

As illustrated in previous sections, China's energy development pathway has implications not only for China but for the world as a whole. Its use of resources will have implications for global energy prices (PALTSEV AND REILLY, 2009), and its emissions of greenhouse gases and conventional pollutants will affect much or all of the world (e.g., WANG, 2009; REILLY et al., 2007). In this section I draw on an ongoing project at MIT to examine energy-environment-climate-economy links in China. A full set of papers completed under this project can be found at: http://globalchange.mit.edu/CECP/. I will briefly summarize a few key examples of important interactions that have broader lessons for energy and environment and emerging economies. Before focusing on these results, it is useful to briefly describe the general methodological approach we have applied in various studies. We utilize a classic formulation of Arrow-Debreu general equilibrium representation of the economy. Computationally we solve the model as a mixed complementarity problem, and to make the complex models we use feasible we solve the model as a recursive dynamic problem, as a succession of time periods linked together via a set of dynamic factors (population and labor growth, resource depletion, savings and capital accumulation, productivity, etc.). The key data are those in contained in a social accounting matrix. There are two key changes that allow us to consider energy-environment linkages. One is to carry along supplemental physical accounts, for example for physical flows of energy production and use which allow us to track depletion of resources against estimated physical resource availabilities. Two is the elaboration of the SAM-IO structure to include household production as shown in Figure 5 for, in this instance, evaluation of the health effects of pollution on the economy.

		INTERMEDIATE USE						*HOUSEHOLD SERVICES*		FINAL USE				OUTPUT
		1	2	…	*j*	…	*n*	*Mitigation of Pollution Health Effects*	*Labor-Leisure Choice*	Consumption	Investment	Government Purchase	Net-export	
DOMESTIC PRODUCTION	1													
	2													
	:													
	i													
	:													
	Medical Services for Health Pollution							*Medical Services*		*Health Services*				
	n													
IMPORTS	1													
	2													
	:													
	i													
	:													
	n													
LEISURE									*Leisure*	*Leisure*				
VALUE-ADDED	Labor							*Labor*	*Labor*					
	Capital													
	Indirect Taxes													
	Resources													
INPUT														

Figure 5. Social Accounting Matric, Including Non-Market Health Effects. Source: NAM et al.(2010)

While environmental impacts are often seen as "non-market" effects, the approach we utilize emphasizes a key element of traditional environmental economics. Most environmental impacts have an effect on the market economy. In the case of air pollution health effects, sickened people are not able to work or work as effectively and so there is a labor effect. They may also seek medical attention—with medical services a part of the market economy. However, the need for additional medical services draws resources away from other parts of the economy and so this has an overall detrimental effect on the provision of higher levels of consumption. We also account the value of non-work time, and can thus separately report direct impacts on the traditional market economy as well as a broader measure of welfare that includes "leisure" time. Again, to view this as purely a "non-market" effect is probably misleading, as illness of children no doubt affect the productivity of education and hence future worker productivity, and illness of non-working household members distracts from work activity and the market economy. And, in general, the distinction between the market economy (goods and services that are exchanged) and the non-market economy (activities that go on in the household but do not directly enter markets) is mostly artificial.

The first study I highlight is the interaction of domestic policy and international trade. QI et al. (2014) ask the question of whether economic restructuring will reduce China's trade-embodied CO_2 emissions. China has pursued a strongly export-led development strategy but as development has proceeded it has questioned whether that strategy is sustainable, or at least advisable, as it depends on continued growth in export markets abroad and has limited goods available for domestic consumption. A side-effect of this is that nearly one-quarter of China's domestic CO_2 emissions are related to exports, i.e. these emissions are best attributed to consumption patterns abroad, primarily its main export markets in Europe and the North America. Lesson 1: With this significant footprint of consumption in *Developed* regions on emissions in China one must look to how much of the apparent progress in reducing emissions in these regions is due to importation of embodied carbon.

QI et al. (2014) look at 3 different scenarios that shift China's growth away from one that is export-led to one relying more on domestic consumption. A first scenario, *Rebalance*, imposes sectoral GDP contributions for 2015 set out in China's Twelfth FYP. The second scenario, Demand, simulates an increase in domestic demand *in addition* to changes in sectoral GDP contributions simulated in the *Rebalance* scenario. A third scenario imposes export taxes, labeled Exp-Tax, as an alternative to the other scenarios. Key results are that these measures variously reduce China's emissions by as much as 250 mmt but on order of ½ or more of the emission reduction within China is offset by increases elsewhere in the world. Countries that depended on those exports made up for the reduction by producing the goods domestically or importing from other regions.

Table 1. CO_2 embodied in China's net exports and by region (mmt).

	Reference	Rebalance	Demand	Exp-Tax
China's net exports of emissions				
Agriculture	−2	0	−3	−2
Energy-intensive industry	312	214	158	226
Other industry	827	588	472	867
Services	40	325	290	42
Total	1177	1127	917	1133
Emissions by region				
China	5268	4986	5011	5239
U.S.	5583	5585	5582	5584
Europe	4150	4157	4155	4152
Japan	1067	1073	1072	1068
Korea	424	430	429	425
Taiwan	258	262	261	259
Rest of East Asia	474	482	482	475
Rest of world	9299	9327	9304	9306
Global	26,523	26,302	26,296	26,508

The emissions reduction gains are as great as they are because as we saw in Figure 4, China's production is among the most emissions intensive of any region. It is not hard to draw the further conclusion that if a similar approach were pursued in a region that has a relatively low emissions intensity—Japan, for example—emissions reductions there could lead to an increase in global emissions as region's with dirtier production methods made up for the reduced production there. Lesson 2: Domestic changes in emissions do not tell the whole story.

A second investigation is a look at the economic benefits of air pollution control. In this work, MATUS et al. (2012) consider the economic burden of historical levels of air pollution in China, and benefits of reducing those pollution levels. They consider a policy that meets WHO standards for particulates and ozone, and a scenario where pollution levels are

Table 2. Estimated benefits of air quality control in China: WHO standards (1) and background levels

Year	Policy 1 compared to historical				Policy 2 compared to historical			
	Δ Consumption		Δ Welfare		Δ Consumption		Δ Welfare	
	bn US$[a]	%[b]	bn US$[a]	%[b]	bn US$[a]	%[b]	bn US$[a]	%[b]
1975	11.5	17.1	16.2	10.5	12.5	18.5	17.5	11.3
1980	12.9	14.3	17.2	8.4	13.9	15.5	18.6	9.0
1985	16.4	10.9	22.1	6.5	18.0	12.0	24.2	7.1
1990	14.5	6.7	19.0	4.0	16.6	7.7	21.8	4.6
1995	22.5	5.8	32.9	3.7	26.1	6.7	37.9	4.2
2000	27.0	4.6	41.4	3.1	32.3	5.5	48.9	3.6
2005	38.0	4.1	66.4	3.0	46.6	5.0	78.6	3.6

[a] Billions of 1997 US$.
[b] % to historical consumption (or welfare) level for each year.

reduced to background levels—i.e. as if there were no industrial sources of pollution. The latter scenario is unlikely but gives an idea of the total burden of air pollution on the economy. They report results in absolute values as well as a percent of macroeconomic consumption and total welfare. The latter is a somewhat artificial calculation because it depends on how non-work time is valued. In either case the benefits include both benefits in terms of market income as well as avoided non-market damages. The logic here is that health effects for children, or effects non-working adults or non-work time of working adults has broader and longer term implications for the economy in terms of long term health, education, and child care. Somewhat interestingly, the impacts as a percent of consumption or welfare were very large in the early years. The rapid expansion of the economy leads to the effects being a smaller share of economic activity over time, even though the absolute level of damage increases. The study also goes on to demonstrate that losses in early years has implications in later years, as it, for example, reduces income and savings that might have occurred thus lowering future economic attainment as well. It should be noted that pollution levels were poorly monitored over the period of analysis and involved considerable effort to construct, or reconstruct pollution levels. So there is considerable uncertainty in these estimates that stem from uncertainty in pollution levels, as well as uncertainty in the dose-response functions that estimate health outcomes as they are affected by pollution exposure. Never-the-less, estimates of several percent of GDP are a dramatic loss—or potential benefit of pollution reduction. An important lesson: environment is not a luxury good but has significant effects on the market economy, although often invisible because we don't observe the counterfactual economy with no or less pollution. While better accounting can help us see where losses are occurring, accounting by itself will not tell us how a different level of pollution can improve economic performance.

A final example on which I will draw illustrates the potential synergy between pollution problems, in particular between control of conventional air pollutants and greenhouse gases. Here I draw on work of NAM et al. (2014). The motivation for this work is that while we face a threat of global climate change, the "global commons" nature of the problem means that individual countries have limited incentives to take on greenhouse gas mitigation themselves. However, the effects (and benefits of control) of conventional pollutants, while they can spread across large regions and even an entire hemisphere are felt strongly within the country. Thus, there is less of a problem of international coordination, and less reason to wait for others to control the problem. NAM et al. (2104) summarize their findings as cross-elasticities of emissions control—for a percentage reduction in conventional pollutants (NOx and SO_2) what percentage reduction in CO2 occurs as an ancillary benefit of the primary pollution policy. The cross-elasticity results are shown in Figure 8, where China is compared with the same exercise for the US.

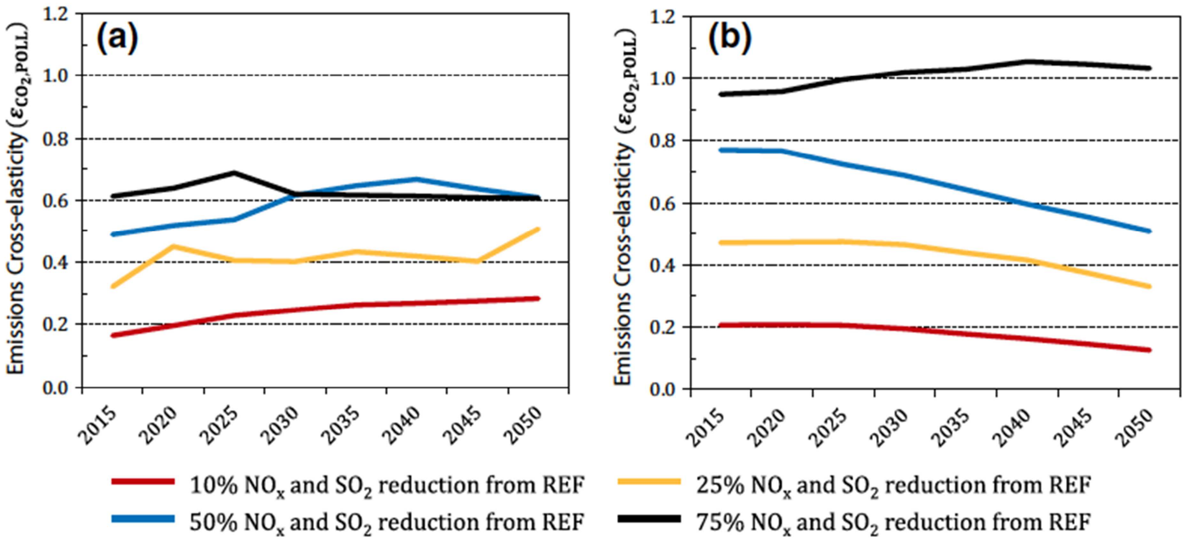

Figure 8. Cross emissions elasticity by scenario: (a) U.S., (b) China.

The basic results are that there is a strong cross-effect that is consistent over the period the authors considered. Elasticities range from about 0.2 to 1.0. At the upper end, this means that a policy directed at conventional pollutants is as effective in reducing CO_2 as it is in reducing the targeted pollutants. In general they find that the stronger the conventional pollutant policy the larger the cross-elasticity. This follows from the fact that at low levels of pollution control there are often ways to reduce the target pollutant but continue to use fossil fuels—end of pipe clean-up of the pollutant. However, with stronger emissions reductions end of pipe solutions become more expensive and so it begins to make sense to shift to completely different energy technologies that have less conventional pollutants and also less CO_2 emissions. This shift can mean from coal to natural gas or oil, or to technologies like nuclear or renewables for electricity generation, and greater use of electricity in place of fuels in the industrial and other parts of the economy. One caveat to these results: Some recent developments in China are focused on using coal to produce synthetic gas or substitute liquid fuels. These plants would be located in Western China, a distance from urban centers. Moreover, these processes could be relatively effective at reducing conventional pollutants but result in more CO_2 than direct use of natural gas or petroleum. Thus, while there is a possible synergy between pollution and CO_2 control, this synergy is dependent on the technology options.

V. Conclusions

Energy and development in emerging economies raises important concerns both within these economies and for the world as a whole. With billions of current and future people's energy needs underserved, needed economic development will likely result in increased needs for energy. The good and bad news is that there are ample resources of fossil energy, and the technology to exploit these resources has continued to improve. The bad news in this conclusion is that consumption of these fuels is likely to contribute to both local air pollution problems that have global consequences, as well as to accumulating greenhouse gases and changes in climate. While there has been a tendency to see environment as a luxury that the poor can ill afford, that is a misconception as environmental damage can affect basic human needs such as food, water, and the ability of children to develop. The relationships between energy, policy, and the economy are subtle and complex. Clearly, an important part of the task is careful empirical investigation of these relationships so that well-meaning policies do not worsen rather than improve the situation, and that efforts can take advantage of potential synergies in energy-environment solutions.

Our ongoing deep interaction with China through Tsinghua University, in what we have call our China Energy and Climate Project (CECP) (http://globalchange.mit.edu/CECP/) has proved productive both from a research perspective and we believe in shaping policy. By focusing on research methods that can investigate implications of economic growth, development, and policy measures in collaboration with in-country researchers a shared view amongst researchers can be developed. This can then lead to better understanding among governments. That appears to have been the case in our investigation of China's energy future (ZHANG ET AL. 2014) which appears to have contributed to the recently announced agreement between China and the US. For China, the research showed that measures they were prepared to undertake were feasible, practical, and allowed them to meet economic growth targets. For the US, the research made a compelling case that the effort would meaningfully reduce emissions from a business as usual scenario. Obviously many other analyses played a role, and analysis alone cannot generate outcomes countries do not see as in their interest. However, analysis can help to more accurately shed light on where country's interests lie and how to best achieve those ends.

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