PRELIMINARY VERSION

SHAPING THE GREEN GROWTH ECONOMY

A review of the public debate and the prospects for green growth

GREEN GROWTH LEADERS

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Discovering the path to a low-carbon tomorrow

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” *Can green growth arguments stand up to scrutiny from the research community?*

GREEN GROWTH: OPPORTUNITY OR DISTRACTION FOR THE CLIMATE CHALLENGE

A serious and credible response to climate change will require reductions in greenhouse gas emissions of 50-80% over the 21st century. The potential cost of those reductions, and the challenge that cost poses to economic growth, have generated intense political debate over whether and how to make the transition to a low-carbon economy. Even in the face of the imperative to act on climate change, this debate has often delayed or prevented serious action.

In response, the "green growth" argument suggests the debate over cost is misguided. Instead, it may be possible for nations to promote economic growth by reducing emissions—to have their cake and eat it, too. The European Union's road map to a low-carbon economy projects that the investment and innovation required to reduce European emissions by 80% between now and 2050 will save upwards of €175 million, generate up to 1.5 million new jobs, and improve European export competitiveness in a range of high-technology markets (European Commission 2011b, 4, 11-12). Such numbers offer the promise that action on climate change can create new economic opportunity, rather than remain simply a cost that the world must bear. And The European Union is by no means alone in making this argument. In the aftermath of the 2007-2009 financial crisis, "green growth" has attracted significant attention as a way out of today's economic doldrums.

On closer scrutiny, however, no single concept of "green growth" has emerged. In the review of the public and policy attention paid to green growth that follows, we instead find three, almost entirely separate debates with very different ambitions. The first, and most modest merely proposes that emissions reduction can be compatible with growth, *contra* those who would argue that climate action must always limit economic possibility. A second, more ambitious argument emphasizes the possibility that investments in low-carbon technology and infrastructure can become a new jobs engine in a depressed economy. Finally, the third and most ambitious argument posits that green investment can go beyond mere job creation to fuel a new "green industrial revolution" as transformative as earlier eras of economic change.

This review asks two questions: first, how have the public and policy debates over green growth evolved; and second, does academic research on economic and climate policy support the claims and assumptions made in these debates, and with what consequences for the green growth hypothesis? As we make clear, careful scrutiny of the most popular proposals for "green growth" suggests that they may well succeed at reconciling economic growth and emissions reduction. But it's by no means clear that they offer general proposals for using the transition to a low-carbon economy to generate growth directly.

We conclude the review by noting the dissonance between the green growth discussion and the scale of the emissions challenge itself. Throughout the green growth discussion, almost no mention is made of how the changes required to achieve emissions reduction might catalyze growth in the broader economy. Significant emissions reductions will require the transformation of today's high-emissions, low-efficiency energy systems. That transformation will require parallel and complementary changes to the markets, technologies, and regulatory structures that dictate how economies produce, distribute, and use energy. In its scale and scope, this transformation—of the electricity network in particular—bears some resemblance to earlier periods of network transformation, such as rail transport or information technology. As section 5 will show, those transformations, far from being a cost, fundamentally altered what was possible for the economy as a whole. Instead, they drove waves of growth by creating a platform on which the broader economy could build new innovations, business models, and modes of value creation. To replicate these earlier successes, green growth, if it is to deliver on its promises, must go beyond a short-term focus on jobs or investment. Instead, it must put more emphasis on how to structure the low-emissions energy systems transformation to enable the entire economy to discover that transformation's potential to alter and expand the possibilities for value creation and growth. Green growth, therefore, must consider how the greening of the energy sector can become the growth engine for the entire economy.

"GREEN GROWTH": DEFINITIONS AND CONCEPTS

To date, no standard definition of green growth has emerged from the public and policy debate. We identify a range of definitions, from a narrow desire to reconcile emissions reduction to economic growth, to a comprehensive plan to improve the resource efficiency and environmental sustainability of the capitalist system.[1] For the purposes of this review, we define green growth to mean "*job creation or GDP growth compatible with or driven by actions to reduce greenhouse gasses.*" This more limited definition makes no claim about the importance of the more ambitious definitions of green growth. Instead, it reflects the overwhelming interest in the climate change problem for economies facing both job creation and growth challenges in the coming years.

We find at least six different definitions of the "green" in green growth. The first four build on each other as different sets of "green" priorities with which "growth" would coexist:

1. Climate change mitigation via significant reductions in greenhouse gas emissions (e.g. International Energy Agency 2009)
2. Emissions reductions, plus ecosystem protection and the protection of human health in service of human welfare (e.g. Shafik 1994)
3. All of the above, as absolute goods rather than only in service of human welfare (e.g. Congressional Budget Office 2009)
4. 1-3, plus the mitigation of all human impacts on the natural world, including wilderness and species preservation, resource efficiency, and limits to consumption (e.g. The Danish Government et al. 2009, United Green Parties for Europe 2009)

Two further definitions expand substantially on these definitions of "green", taking a more holistic view of the relationship of economic production and environmental sustainability:

5. A general concept of "environmental carrying capacity" that seeks to reconcile economic growth to an assumption of limited ability of the environment to support human economic activity. (e.g. Daly 1991, OECD 2010, World Bank 1992).
6. A notion of the dynamic ability of the environment to respond to growth-induced shocks. (e.g. Arrow 1995).

As this overview quickly makes apparent, approaches to "green growth" cover a spectrum from narrow concerns about climate change on the one hand, to larger critiques of the environmental sustainability of modern capitalism on the other. All of these definitions of "green" have merit and many offer a more comprehensive look at environmental sustainability, but this review lacks the scope to address them all. We thus restrict our review to the question of how the move to a low-carbon economy may impact growth, and whether the investment and innovation that move will require can act as an engine for job creation or economic growth more generally.

1 Separate from a debate about which economic strategies qualify as "green", there is, of course, another debate that concerns which technologies should be considered "green." Nuclear power in particular generates substantial controversy in this debate because of its tradeoffs between zero-emissions electricity and the environmental and human health issues implicit in radioactive waste and risk of accident. This debate has become particularly acute in the aftermath of the 2011 earthquake and tsunami in Japan, and the nuclear crisis it caused. This literature review does not take a position on which technologies should qualify as "green", and notes that many of the economic strategies discussed could apply to any technology, nuclear fission included.

THE GREEN GROWTH DEBATE: POPULAR AND POLICY PERSPECTIVES

In the aftermath of the 2007-2009 financial crisis, green growth has received new attention from the popular press and policy analysts alike. That attention came not least because green growth promised to solve the growth and climate problems simultaneously. Countries concerned about the problem of unchecked carbon emissions had found a potential way around the substantial cost of emissions reductions. Those less concerned with emissions, and more with economic prosperity, could claim that investments in new energy infrastructure would create jobs and improve economic competitiveness.

But the arguments in favor of green growth differed widely in their goals and assumptions. Three categories of arguments became apparent, reflecting very different ambitions for tying emissions reduction to economic growth. The first, and most modest, argued that emissions reduction was at the least cost-neutral for an economy and as such represented little threat to economic performance. The second, targeting the widespread unemployment that followed on the financial crisis, sought to use investment in low-emissions technology and infrastructure to create jobs in the medium term. Finally, a third, more ambitious version of green growth envisions the innovation and investment required for emissions reduction as the precursor to a new industrial revolution that would bring rapid income and GDP growth.

Each of these visions of green growth makes very different assumptions about the origins of job creation and growth, and suggests very different strategies for economic policy. Here, we outline the debates over these policy prescriptions, and the key points of disagreement over their chances for success. We return to those disagreements in section 4, to evaluate whether the research literature supports the assumptions made by the advocates of different versions of "green growth". As we shall see, while these arguments has some merit, each remains highly contingent on particular circumstances, and thus of limited scope. A broadly applicable, long-term vision of green growth will need to look beyond these measures, a topic that we take up in section 5.

3.1 A modest argument: making emissions reduction compatible with growth

Designed correctly, the right policy mix may keep the cost of emissions reduction low enough to pose only negligible threats to economic growth. In the context of the climate change debate, this alone would be a major achievement. The question of cost, rather than benefit, has dominated the climate debate since its inception. Emissions reductions are seen to require substantial investments in new technology and infrastructure. These investments are usually justified on the basis of the high cost of inaction—the price of unchecked climate change. But the immediate cost of emissions reduction, if high enough, could threaten economic growth, a prospect that has proven politically unpalatable.

In that context, "green growth" can succeed if it merely minimizes the cost of a transformation to a low-carbon economy. Actually breaking even—suggesting there is no real opportunity cost to investments in emissions reduction—thus qualifies as a goal of real though modest ambition. To achieve this definition of "green growth", the popular and policy debate has emphasized the pre-eminent role of an emissions price, possibly coupled to the removal of market-distorting fossil fuel energy subsidies. It has also emphasized the immediate economic benefit of lowered exposure to fossil fuel energy price uncertainty, particularly where Middle Eastern energy suppliers are concerned. But this approach stands in contrast to the more ambitious arguments that emissions reductions can go beyond merely breaking even.

> ***Climate action and economic growth can coexist if the cost of emissions reduction can be contained.***

3.1.1 Price fundamentalism: market mechanisms for minimizing transaction costs

Economic policy arguments, looking for a market-based solution to emissions reduction, has argued that a price on emissions can drive the changes required to bring down emissions at the lowest cost. That transition to a low-emissions economy will require a host of new innovation and investment, the specific contours of which are unknown and may vary dramatically across different countries and economic systems. Given the complexity of that transition, economists have emphasized that arms-length regulation via market mechanisms will provide the most efficient, least cost method of greenhouse gas emissions reduction.[2] A policy of setting a price on carbon—whether via a tax or a cap-and-trade system—can offer greater flexibility to firms and households, ensure that emission reduction happens where the cost is lowest, and generate a clear market incentive for innovation in low-carbon technologies (U. S. CBO 2009, Nordhaus 2010, Pooley 2010).

Some estimates find that emissions prices alone can achieve emissions reduction minimal cost to GDP compared to no action at all. The Stern Review claims that the cost of emissions reduction policies may vary from a net gain of 3.7% of global GDP, to a net loss of 3.4%, depending how cost-saving mechanisms, outlined further in section 3.1.2 interact with the emissions price (Stern et al. 2006). Separately, the U.S. Congressional Budget office estimates that a national emissions pricing policy would likely reduce annual GDP growth in the United States by only 0.03% to 0.09% per annum between 2010 and 2050, in the context of an estimated 2.4% average annual growth rate (2009a, 13). These estimates do predict a temporary, but real decrease in employment during the transition to a low-carbon economy, as labor markets adjust to the decline of high-emissions sectors and the introduction of low-emissions technology. Both studies suggest that the overall cost picture improves if other efforts, such as intensified public support for basic research in low-carbon technologies or the removal of fossil fuel subsidies, occur alongside the carbon price.

Despite these relatively modest cost estimates, policy arguments against an approach reliant solely on prices come in four forms:

> ***A price on emissions will play an important role in making emissions reductions more efficient.***

> ***But critics fear that high emissions prices will undermine support for long-term emissions reduction, and hurt economic competitiveness for energy-intensive industries.***

1. That increased consumer energy prices will disproportionately affect poorer people;
2. That increased energy prices will impose high costs on industry and lead to lost competitiveness, significantly increasing the cost of emissions reduction;
3. That the process of permit allocation under cap-and-trade systems is open to abuses and corruption that will necessarily increase the program's cost;
4. That a carbon price may be politically unfeasible in certain national contexts, delaying emission reduction efforts.

Moreover, even if successfully implemented, such a program may achieve only minimal emissions reduction, while creating other problems along the way. Critics point to the European Union's Emissions Trading Scheme (ETS) as a case in point. Detractors attribute to the ETS Europe-wide increases in household and industrial energy costs, and the labor protests that followed (Mufson 2007). Recent news regarding the cyber theft of insecure carbon allowances valued at € 30 million from several EU states has further corroborated arguments of the potential for abuse and corruption (Chaffin 2011). Furthermore, opponents contend that the EU cap has not succeeded in lowering emissions (Mufson 2007). Indeed, the recession, and not the ETS, has arguably been the most effective emissions reduction tool in Europe over the last decade. These objections led Nordhaus and Shellenberger (2007) to critique a carbon cap-and-trade as politically impossible within the American political context, noting pervasive interest group and party opposition. Focus on such efforts will derail any real action; instead they propose massive public investment in renewable energy as the best means to achieve emissions reductions amidst a hostile political climate.

In response to critiques of the European model, proponents of the cap-and-trade policy argue that the EU example is in its nascent stage and requires a few trial years to smooth out price and allocations specifics and should not be viewed as an indictment of the entire policy (Duggan 2009). Proponents of cap-and-trade further argue that an emissions cap is essential to actually reducing emissions.

2 This argument is consistent with a longstanding tradition from environmental economics that treats pollution as a market failure that creates negative externalities. In those cases, the correct solution is a Pigouvian tax or an equivalent permit scheme that treats the right to pollute as a property right that can be valued in the market. (Baumol 1972, Weitzman 1974)

Pooley (2010) notes that, absent a cap and within the context of increasing demand, investment in renewables will provide another source of energy rather than a replacement to fossil-fuel sources. This may keep emissions from growing, but will not contribute to their reduction.

3.1.2 Eliminating barriers to growth: fossil fuel subsidies and corrective taxation

Elimination of fossil fuel subsidies provides another route towards low-cost emissions reduction. Removal of fossil fuel subsidies, the argument proposes, would facilitate the transition to a low-carbon economy by removing the policy-induced distortions that favored an emissions-intensive economy. Moreover, doing so would reduce the fiscal burdens on oil-importing nations. These savings could be used to further the low-carbon transition through support of low-carbon technologies, and compensation to those displaced by the move away from fossil fuel-dependent production (OECD 2010). The IEA estimates that a global removal of fossil-fuel subsidies would reduce CO_2 emission by 6.9% and reduce global energy demand by 5.8% by 2020 (International Energy Agency 2009, 5, 7).

However, opponents point out that oil-exporting countries are likely to suffer some real income losses through these policies, reducing the overall cost-reduction impacts of subsidy elimination (OECD 2010). In addition, without price support energy will become prohibitively expensive for the world's poor, particularly harming the developing world. India has already witnessed large protests over petroleum subsidy removal (Reddy 2010). The political opposition that could result in these circumstances may undermine both economic growth and support for further emissions reduction.

Proponents have suggested that revenue from carbon tax or permits can be used to address the burden of higher energy costs on low and middle-income households (Center for American Progress 2008). Improving equity has little impact on economic growth, but can make policies more politically appealing and thus sustainable over the long term.

Finally, using fossil fuel taxes or the savings from subsidy removal to fund tax reform could generate a "double dividend" of emissions reductions and improved economic efficiency. Policy analysts have argued that shifting the tax burden from these "goods" to environmental "bads" like fossil fuel consumption and carbon emissions can improve the efficiency of the tax system, increase employment and investment, and support emissions reduction (OECD 2010). Theoretically, at least, this could yield two gains—for emissions reduction and for the efficiency of the economy as a whole. Such an economic trifecta would offer the promise that policy measures like carbon pricing would, under the right circumstances, improve immediate economic welfare via job creation and capital investment. These policies formed a significant component of many European tax reform packages in the 1990s, but with mixed results. We return to the analysis of these experiences in the research literature in section 4.1.3.

> ***Energy subsidy and tax code reforms may help alleviate the impact of emissions prices on competitiveness, while still achieving emissions reductions.***

3.1.3 Energy security: reducing the uncompetitive impacts of fossil fuel importation

Finally, by reducing vulnerability to volatile and increasing international fossil fuel prices and supply disruptions, the adoption of low-emissions renewable energy can offset its higher costs and mitigate the impact of emissions reductions on growth. Energy importing economies face global prices for energy over which they have little control. Increased global demand for energy, limited supply, and political instability and conflict in many energy-producing regions, have created substantial price volatility, particularly for petroleum. In other cases, political conflict between countries has led to supply disruptions, such as the stoppage of natural gas flows to eastern Europe consequence of a dispute between Russia and the Ukraine.

Price disruptions harm economic growth and competitiveness via two mechanisms. High energy prices distort production costs and affect the competitiveness of domestic firms on international markets. Volatile energy costs impose hedging costs as firms attempt to insulate themselves. Both high and volatile prices put pressure on exchange rates as import costs increase, affecting national balance of payments and exchange rate stability. For countries dependent on imported fossil fuels, exposure to volatile energy prices has adverse impacts on competitiveness via both the cost of energy and through the exchange rate channel.

Energy supply disruptions can be even more harmful than price volatility. For countries highly dependent on imported energy, supply disruptions—whether directly or via a third-party transit country—can bring economic activity to a standstill. This proved to be the case for Eastern Europe, when natural gas supplies from Russia stopped during the winter of 2007. In that context, the potential for domestic production of renewable energy began to look quite economical compared to the shutdown of the economy for lack of energy supplies.

Therefore, an emissions reduction strategy that lessens import dependence can offset its costs via increased stability of supply and price. These cost offsets may minimize the price of the transition to a low-carbon economy and generate real, immediate benefits for firms and energy consumers (Keohane 2008; Wall Street Journal Europe 2010). The public salience of this argument became quite

> *By protecting economies against high, volatile fossil fuel prices, renewable energy can improve energy security and economic competitiveness.*

clear when South Korean President Lee Myung-bak referenced "energy vulnerability", consequence of his country's dependence on oil and gas imports, as strong driver for Korea's ambitious green growth strategy (Associated Press 2009). Danish and American political leaders have voiced similar arguments (Zichal 2011; IEA 2006). Indeed, Danish firms are widely regarded to become more globally competitive as fossil fuel prices rise, due to their relatively lower dependence on fossil fuels as energy inputs.

In sum, it may be possible to "green" present patterns of economic growth, reducing emissions at relatively minimal cost. Advocates of this view of green growth content that a sensible carbon price, coupled to savings from reduced exposure to energy price and supply risks and reduced carbon fuel subsidy costs, could drive transition costs to a minimum. But this argument remains both publically and politically contentious, and requires a range of choices—to impose taxes and reduce subsidies—that stand to create real opposition. Moreover, the argument as a whole offers little immediate benefit, even as it also suggests little actual pain.

3.2 The allure of green jobs

In the face of high unemployment following the 2008 financial crisis, a second, more ambitious argument for green growth emerged in the public debate. If investments in renewable energy or energy efficiency could create jobs, rather than just impose costs, it could create the basis of a new green employment market. In the subsequent debate, three different versions of the green jobs argument emerged:

1. That Keynesian demand stimulus at times of recession should be used to create jobs and invest in needed improvements to the energy infrastructure.
2. That green jobs should come from the sponsorship of new green industries, whose demand for labor would offset job losses in older, "brown" sectors.
3. That cost savings from energy efficiency improvements could be recycled into consumption from higher-labor-intensity industries, generating net job gains even as the relative demand for labor in the energy sector fell.

These arguments, while not mutually exclusive, take three very different views of how and how quickly green jobs could be created, and how long we should expect them to last.

3.2.1 Green Stimulus and the Keynesian logic of job creation

John Maynard Keynes fathered the idea that governments should engage in deficit spending during recessions as a means of compensating for lost demand and restoring the economy to full employment. Taken a step further, advocates of emissions reduction argue that this spending should be targeted at renewable energy and energy efficiency investments that both create jobs and lay the groundwork for a lower-carbon economy (Jones 2008). These arguments found real traction in response to the 2008-2009 global recession. Almost every OECD country, and some non-OECD countries included so-called "green" spending in their economic stimulus packages. By the end of 2009, China pledged a third of its stimulus package, a total of $218.8 billion dollars, to green spending and investment; similarly, the US has also committed 12% of its stimulus package, amounting to $117.7 billion green investment. In the EU, at least 60% of the stimulus funds went to green measures, but totaled only $23 billion due to a smaller stimulus package overall. The government of South Korea spent as much as 78.7%, or $59 billion of its stimulus package on green programs despite having a smaller overall stimulus package (Barbier 2010).

Advocates for green stimulus measures drew on a range of data in support of their position. First and foremost, they contended that the investment in low-carbon energy infrastructure would be needed in any event, and the recession offered the opportunity to use that investment to offset the lost jobs elsewhere in the economy. That argument drew support from advocates like Engel and Kammen (2009), who present data suggesting that investment in renewable energy capacity generated more jobs than an equivalent investment in traditional energy sources. Those jobs might come at modest cost, particularly if, as Jones (2008) argued, the savings from energy efficiency investments were counted against the cost of those investments. Finally, policy leaders like United Nations Secretary General Ban Ki-Moon (Ban and Gore 2008) noted that so-called "green' sectors already employed 2.3 million people, more than in the traditional

> *Public investment can create "green jobs" by investing in energy efficiency and infrastructure programs during recessions.*

energy sector, suggesting that investment should target new emerging industries rather than moribund technologies of the prior century.

3.2.2 Green industrial policy: re-industrialization and the demand for high-skilled labor

Of course, Keynesianism is necessarily short-term: as the recession recedes and economies return to full employment, the cost of Keynesian job creation increases and its rationale fades. Looking at job creation over the long term, enthusiasts for a transition to green employment argue that emissions reduction targets can provide the support required to launch a new wave of green industries that will bring with it high-quality jobs; and that reallocating savings from energy efficiency investments to other sectors can expand demand across the economy as a whole.

New green industries, the first of these arguments contends, and specifically renewable energy, can form the basis of a renaissance in industrial economies battered by deindustrialization and international competition (Jones 2008). Because many of these jobs are location-specific, they may also be less vulnerable to offshoring than other manufacturing sectors. Constructing and maintaining wind farms or solar generators, or manufacturing the new generations of very large wind turbines, requires significant on-site expertise from skilled labor. Many of the skills required, moreover, correspond to jobs in sectors that have suffered as China, Southeast Asia, and Latin America entered global production chains (Friedman 2007). Moreover, because these jobs, as Engel and Kammen (2009) argued, are more labor-intensive than the sectors they replace, the green economy has the potential to become a net employment generator.

Some signs of the employment opportunities created by the shift to renewable and low-carbon energy are already apparent. Rising demand in the United States has already attracted new factories from the Spanish wind turbine firm Gamesa, and sparked new interest in electric car manufacturer Tesla (Greenhouse 2008). Labor has been as enthusiastic and management for these changes, and has called for government support of green sectors in tandem with new economic policy to protect manufacturing (Buffa 2009).

> ***As the economy recovers, durable green jobs may come from the creation of a new generation of green industries and products.***

> ***The money saved from energy efficiency improvements may increase demand for goods and jobs elsewhere in the economy.***

3.2.3 More productivity, less energy: energy efficiency and employment

Energy efficiency promises job creation via both short-term employment of labor otherwise idle during recession; and via long-term recycling of the cost savings from energy efficiency improvements. As section 3.2.1 noted, energy efficiency programs are already an important and effective part of stimulus packages in Europe and the United States. Programs such as building retrofitting and weatherization are labor intensive and require on-site work that does not compete with cheaper overseas labor (Friedman 2007; Jones 2008). Thus efficiency programs can create net employment that would otherwise sit idle during economic downturn.

But the effects of these investments may continue to stimulate employment even as the economy recovers. Improved energy efficiency can continue to create jobs through expenditure switching, increased productivity, and deficit reduction. As efficiency lowers energy services cost, households may spend their energy savings on other goods or services. If those goods or services are more labor-intensive than energy, this expenditure switching could lead to increased employment (Roland-Holst 2008). Energy savings would also entail a net productivity gain from firms who could produce the same value with fewer inputs.

Finally, proponents of the growth-generating effects of energy efficiency suggest energy efficiency investments could become self-sustaining by reinvesting a portion of the savings in the next round of improvements. Such iterated investment could create self-sustaining employment opportunities independent of government investment. The ambitious European resource efficiency flagship initiative predicts that its Ecodesign Directive building efficiency measures will save 340 TWh of electricity, worth €51 billion euro if one uses an average European electricity rate of €0.15 per kilowatt-hour (European Commission 2011a, 7; Europe's Energy Portal 2011), and Van Jones has made similar arguments for the US (2008). If sustainable, ongoing investments on that scale could provide durable job growth that persisted beyond the end of the economic downturn.

3.2.4 A green jobs myth Potential vulnerabilities in the green jobs argument

Having painted such a promising picture of the prospects for green job creation, it was no surprise that these arguments generated skepticism in equal measure. Some went so far as to call the very idea of green jobs a "myth." Critics point to the uncertain effectiveness of Keynesian stimulus, the jobs and productivity to be lost in fossil fuel industries, the threat of green mercantilism as forces that would counter, and perhaps eliminate, any employment gains. Moreover, they note that there's no reason to think that the new demand generated by reallocated savings from energy efficiency wouldn't itself drive up energy demand and minimize any emissions reductions. Thus, critics charge, the green jobs argument and its link to energy efficiency rest on uncertain grounds, making aggressive policy hard to justify.

Seventy years after Keynes made his original arguments for demand stimulus in the General Theory, his critics remain influential. Moore suggests that federal stimulus is ineffective in creating employment; public sector measures are far more wasteful and costly in creating jobs than private sector actions (2011). Others suggest that a green stimulus will not address the structural problems responsible for the current recession, and as such policy should focus on long-term investments in physical and human capital rather than ancillary targets like emissions reduction (Sachs 2010).

Skeptics also doubt whether jobs in green industries can either replace or exceed those lost in declining brown industries. The same regulation of emissions and fossil fuels that supports the ascent of renewable energy or energy efficiency sectors also, by design, makes energy-intensive or fossil fuel-based energy sectors less viable. The transition from one set of sectors to another inevitably imposes adjustment costs on labor and capital, and may result in net job loss (Kolbert 2009). Indeed, past experience with technological innovation suggests that green energy could, *contra* Engel and Kammen (2009), prove less labor intensive than today's energy system, leading to overall job losses in the energy sector (Sharan 2010).

What of the argument that green jobs, by being location specific, are less vulnerable to overseas competition than other manufacturing sectors? Recent years have provided numerous examples of renewable energy companies moving production to China, suggesting that green jobs in high-productivity manufacturing remain vulnerable to outsourcing (Glaeser 2011). Ironically, the lack of environmental regulation and resulting lower production costs may provide China the opportunity to become the export leader in renewable energy generation equipment like wind turbines or solar cells (Dreyfuss 2010).

> ***"Some doubt whether Keynesian spending, even for energy infrastructure, can ever recoup its costs.***

> ***"Jobs in high-wage, high-productivity "green" sectors are no less vulnerable to overseas competition than the rest of the economy.***

These arguments, however, often fail to differentiate between green jobs that are site-specific, such as local construction of energy infrastructure, and those manufacturing jobs that can be easily moved abroad. With both the EU and the United States estimating the investment required for new energy infrastructure in the trillions of euros or dollars, significant job creation opportunities could nevertheless persist in the face of intense competition from rapidly developing economies in the wind turbine and solar cell markets. But that merely suggests that Glaeser (2011) remains correct to conclude that that green jobs will follow traditional patterns of global trade with employment opportunities in developed countries created from entrepreneurship, education, high-tech innovation, and services, rather than from large scale manufacturing. In that respect, green industries are no different from the brown ones they replace.

Finally, even if energy efficiency measures prove more successful than other policy instruments in creating employment, they may not generate much in the way of emissions reduction. As noted above, any savings from reduced energy consumption will go elsewhere. Roland-Holst (2008) argues that those savings might go to more labor-intensive sectors, generating employment growth. But any growth in economic output entails increased use of energy. Given a sufficiently large rebound effect, the emissions savings from reduced consumption of energy per unit output could be overwhelmed by increased output. One may argue that in developed economies this rebound will be relatively small, since most consumers are already consuming the energy services they desire. This argument may not hold in developing countries, where energy remains a significant constraint on economic activities; more affordable energy services may imply greatly increased household energy consumption as well as production of energy-intensive goods. This view argues energy efficiency may prove a powerful driver of growth, but that it is not linked to emission reductions (Jenkins, Nordhaus, and Shellenberger 2011). If true, it would be difficult to justify that growth as "green".

> *Spending money saved via energy efficiency in the rest of the economy may increase energy demand and eat up some of the efficiency gains.*

3.3 Emissions reductions as a driver of GDP growth

The final, and most ambitious, green growth argument, proposes that emissions reduction measures can drive GDP growth. While proponents discuss some similar mechanisms as those arguing for green job growth, the arguments differ in their understanding of how green investment and innovation will affect productivity. The argument for green employment, as we have seen, contends that some positive employment effect derives from the higher labor-intensity of the renewable sector compared to fossil-fuel industries. This increased labor intensity can have a neutral or negative effect on overall productivity and output, even as it broadens the employment base. In contrast, proponents of green GDP growth believe that emission reductions can drive growth in aggregate output by either promoting comparative advantage in green sectors or increasing productivity through innovation But the emphasis on export-led growth in many of these arguments makes them vulnerable to two critiques: first, that export-led growth as a model has limited applicability; and second, that it encourages a zero-sum view of the green growth economy, promoting a new green mercantilism that could make international competition more damaging than beneficial.

3.3.1 Export promotion: winners and losers

Global adoption of renewable energy—whether for climate or other reasons—creates a huge new market for energy technology. As this market grows, capturing it for increased exports from domestic firms becomes an attractive growth strategy. National governments can help domestic firms acquire global market dominance through expansion of domestic markets for the same goods, support for innovation and R&D, promotion of a favorable business environment, and other policies that help lower production cost. Demark, Korea, and China provide examples of nations making a bid to become export leaders of green technology as a growth strategy. The Danish strategy seeks to maintain Denmark's internationally competitive position in the wind industry as a key growth objective (Rasmussen 2008). The Koreans focus on manufacturing green technologies such as solar and hydrogen fuel cells for export, leveraging previous high-tech manufacturing skills in semiconductor and shipbuilding (UNESCAP, n.d.). The Chinese, as well, have invested heavily into wind and solar production in a bid to serve domestic markets hungry for energy and become global production leaders (Walters 2011; Bradsher 2010). Finally, the European Union as a whole has explicitly targeted global competitiveness in new energy technology as one rationale for its aggressive goals for renewable energy technology development and deployment.

> *Driving growth via green industrial development has worked. But relying on export markets for growth potential makes this model hard to generalize.*

In some cases, the pursuit of export competitiveness has had real success. World markets account for 50% of the output of the Danish wind energy industry, which in turn accounts for 20% of the employment in the Danish energy sector and nearly 10% of all Danish exports. (DWIA 2009) Siemens in Germany, Gamesa in Spain, and Vestas in Denmark have all become major international players in renewable energy with significant employment and investment footprints at home. International competitiveness may also keep domestic investment at home: the lack of domestic capacity in the United States allowed China to capture as much as 90% of the California solar market's economic stimulus investments after 2007. More stable domestic investment in renewable energy might have supported the domestic capacity to keep the stimulus dollars in the United States itself.

This argument, however, reveals an underlying vulnerability in the export-led growth argument. Aggressive promotion of domestic green energy industry in the hope that it will repay the investment through exports raises concerns of a "new green mercantilism." For example, Chinese renewable energy policies include not only the normal tax breaks and subsidies, but also preferential treatment of Chinese firms, local content requirements, aggressive intellectual property transfer requirements, and other more controversial measures. These policies have come in for heavy criticism from China's international trade partners (Bradsher 2010). These policies, the argument contends, provide Chinese firms an unfair advantage in acquiring market dominance and are a violation of international trade agreements. The United Steelworkers union recently filed W.T.O. complaint against China, alleging that these practices constitute a violation of the W.T.O. rules on state aid and free trade (Daily, Steitz, and Walet 2011; Walters 2011). The Chinese counter that many countries are currently involved in subsidizing the development of renewable energy (Daily, Steitz, and Walet 2011). Export-promotion subsidies and protections such as those employed by the Chinese deny other countries export opportunities and may lead to heightened conflict over free trade among

> ***Both first movers like Denmark, and fast followers like China and South Korea, have used investment in renewable energy to generate internationally competitive "green" energy sectors.***

nations. Of course, the hope is that the rise of green sectors would give way to intra-industry trade that benefitted a wide range of sectors, rather than mere competition for control of a handful of sectors.

Finally, export-led growth does not seem like a viable strategy everywhere. For a small economy like Denmark, the renewable energy sector can constitute a significant portion of the economy and contribute to real economic growth. For a low-cost manufacturing powerhouse like China, capturing second-generation production at scale can bring needed capital at a scale proportional to its size. But for a very large economy like the United States, it's unlikely that exports of green energy alone will make much difference in the overall growth of the economy. Thus export-led growth may provide one model of green growth, but not one with broad applicability or one that capitalizes on anything novel about green technologies themselves.

3.3.2 Inventing success: technology breakthroughs and productivity growth

Regardless of whether one subscribes to any green growth argument, serious reductions in greenhouse gas emissions will require substantial innovation to provide the alternative energy resources required. Those arguing that serious emissions reductions must not imperil growth put enormous importance on the role of innovation in reducing the overall cost of emissions reduction. Likewise, if emissions reduction goals are to produce export competitiveness in a range of new firms and sectors, innovation will play a large role in securing comparative advantage. Finally, the most optimistic advocates for green growth suggest that innovations can reduce emission while spurring GDP growth through productivity improvements, creating a new range of goods and services, and transforming how economies consume and dispose of products (OECD 2010).

Past economic success with policy-led innovation have become models for public investment in green technology innovation. Nordhaus and Shellenberger (2010) point out that publicly supported research and development in information and computer technologies laid the foundations of the subsequent boom in internet and communications boom that generated substantial private investment and high levels of income and employment growth. Public support for innovation is seen to play a particularly important role in early-phase technologies, helping to bring down production costs. For renewable energy in particular, where the cost of the actual energy source is near-zero, lower capital costs could lead to energy sources substantially cheaper than today's fossil fuels. Jones (2008) argues that this outcome represents the next potential industrial revolution. However, much of this literature continues to disagree on the appropriate model for public sponsorship of low-carbon research and development. Indeed, as Huberty and Zysman (2010a) argued, it may well be that none of the prior models—even those as different as the Manhattan Project and DARPA were—provide sound guidance on how to structure public investment.

Private investors, and in particular venture capitalists, have shown increasing enthusiasm for green growth innovation . John Doerr, of Silicon Valley venture capital fame, argues that if green energy could capture even a narrow portion of the $5 trillion global energy market it would create a dramatic I.P.O increase on the scale of Internet boom (Russ 2007; Doerr 2007). He echoes a sentiment seen throughout Silicon Valley that green technology will prove the next important global industry with innovation essential to ensuring global competitiveness. VC firms perceive opportunities to earn windfall profits for those able to supply the most cutting-edge clean technologies as the demand for alternative energy increases

> ***Intensified competition for control of "green" markets risks a new mercantilism.***

> ***Innovation-led emissions reductions may create new industries and business models that provide significant growth potential.***

> ***Past successes with innovation policy may provide few clues for the design of "green innovation" initiatives.***

> ***Greentech venture capital has seen massive investment, but may face real problems achieving profitability.***

(Green 2009). These arguments tie in with export led-growth arguments, though here the exports are intellectual rather than physical property.

Those critical of green tech venture capital, however, point out that the long time spans before green tech is predicted to reach commercial viability are incompatible with conventional VC models (LaMonica 2009). The usual venture capital investment prefers to support commercialization of relatively new technologies, leading to firms that can be offloaded into the IPO or merger and acquisition markets relatively quickly. The high failure rate of venture investments tends to give preference to many small investments rather than a few very large ones. But the energy sector has been characterized by very large fixed capital investments in slowly changing technologies that pay back over decades.

These characteristics have led venture capitalists away from support of new innovation, and towards support for commercialization of late-stage technologies. But as Kenney (2010) argues, even these investments pose serious problems for the venture industry. Achieving the necessary returns on investment for the venture capital model to work relies, in part, on rapidly growing markets in which revenues scale faster than costs. But energy markets, particularly in the developed world, face slowly growing demand and large fixed capital costs that scale with the size of deployment, in the face of fixed revenue flows.

Furthermore, the size of these markets will depend quite heavily on the ambitions and sustainability of government policy, rather than any underlying cost or productivity advantages for green technology itself. This poses a third critique of green technology venture capital—that, unlike the internet boom, the green tech market would depend almost entirely on market creation through government regulation and subsidy, rather than the inherent value of the technology itself (Russ 2007).

But it may be that those regulations are growth-generating in and of themselves—the so-called Porter Hypothesis. Emissions regulation, this argument contends, provides a clear signal to firms and establishes a market for green technology innovation. This innovation will make firms more efficient, and increase productivity and export competitiveness. That forced adaptation, far from being a drag on the economy, may actually spurs growth (Pooley 2010). The innovation that drives that growth will relieve the economic cost of emission regulation even as it generates both emissions reduction and new economic opportunity. Pooley (2010) cites Norway, Sweden, and Denmark, all countries with carbon taxes and cap-and-trade programs, as evidence for this argument. These three countries typically rank among the most competitive economies in the world, and lead global markets for wind energy, carbon sequestration and biomass electricity generation. On the ground, then, green investment appears to generate growth in at least a few countries. Whether those outcomes can be reproduced elsewhere remains to be seen.

DO THE ARGUMENTS STAND UP? EVIDENCE FROM THE RESEARCH LITERATURE.

We have seen that each of these arguments—whether that emissions reductions pose no challenge to growth, or that they may create jobs, or even that they may drive GDP growth itself—have drawn significant criticism. Politicians and policy advocates have strong incentives to promote arguments rationalizing emissions reductions. Likewise, their opponents have equally strong incentives to undermine those arguments. Where and how the substantive disagreements over the opportunity for a "green economy" balance out remains unclear from the policy debate alone.

We turn to the research literature to test each of the major claims these arguments make. We find reasons for cautious optimism for green growth. The view that emissions reduction poses no threat to growth has the strongest analytic foundations. If policy combines an emissions price with support for market reforms and basic research and development, the cost of significant emissions reductions appears to pose little threat to overall economic growth.

In contrast, the potential for emissions reduction to drive employment or GDP growth may exist. But empirical evidence has relied heavily on very unique national or economic circumstances. For instance, Keynesian stimulus investments in energy infrastructure can generate employment, but only during times of recession. Likewise, innovation in support of export-led growth has worked in several economies, notably Denmark. But the question of whether all countries can become leaders in green export industries large enough to drive economy-wide growth remains open. Moreover, the emphasis on export-led growth may risk a new green mercantilism more damaging than the growth it might create.

> ***Green growth arguments should be treated with cautious optimism.***

> ***None of the current prescriptions for green growth guarantee success.***

These contingencies make generalizing green growth models difficult. Whether this points to limits for green growth remains an open question. It may well be, as section 5 will suggest, that today's focus on specific technologies, markets, or products as drivers of growth must give way to a consideration of how a low-emissions energy system can best generate systemically new opportunities for economic production across the entire economy.

4.1 A free pass: evaluating cost-mitigation arguments

The research literature shows substantial agreement that emissions pricing, combined with complementary policies to remove fossil fuel subsidies, recycle emissions revenue for tax code reform, and support research and development, can minimize the cost of emissions reduction and mitigate its threat to growth in the broader economy. However, the potential political unsustainability of emissions pricing has led several notable studies to recommend against depending on emissions pricing as the primary policy tool for long-term emissions reduction.

4.1.1 Pricing emissions: past successes and future potential

The popular debate over the wisdom of an emissions price is contentious. In contrast, research supports a general consensus that price-based policies remain the cheapest way to achieve emission targets. Compared to command-and-control regulations, market-based policies allow emission reduction to happen where the cost is lowest, while encouraging innovation instead of locking in a single technology. Both theoretical analysis and empirical studies have shown market-based mechanisms

> ***Significant research and policy experience backs the use of emissions prices to achieve emissions reductions at low cost.***

to be cost-effective in reducing pollutants. Fischer and Newell's theoretical model concludes that carbon tax and tradable emission permits are the cheapest policies to achieve emission reduction goals in the context of American power plants; in comparison, subsidies for renewable energy cost 2.47 times more than a carbon tax to achieve the same emission reduction goal (2007, 158). Stavins' comprehensive review of past market-based environmental policies around the world also concludes that market-based mechanisms enjoy proven success in reducing pollution at low overall cost (2003).

These studies are backed by recent policy experience. In particular, the SO_2 cap-and-trade program is portrayed as a model success story for market-based emissions reduction policy. Between 1990 and 2004, the program reduced annual SO_2 emissions—the main factor in acid rain—from power plants by 40% (U.S. EPA 2005, 4). Alongside these emissions reductions, the production cost of electricity in 2000 increased only 0.6% compared to pre-program levels, while the retail price of electricity actually fell more than 10% between 1994 and 2000 (Hanemann 2009, 82). The impact on the overall economy was imperceptible. Indeed, the overall benefit appears to have vastly overwhelmed the cost. According to the EPA's cost-benefit analysis, in 2010 the annual cost of the SO_2 program was only $122 billion, while annual benefits in the form of reduced impacts on human health and improved recreational sites and ecosystems amounted to $122 billion. (2004, 2). In this case, at least, price-based emissions control policy really has delivered on the promise of growth-compatible environmental regulation.

Nevertheless, there remain good reasons to think that the SO_2 experience has limited applicability to greenhouse gas emissions. Hanemann (2009) notes two fundamental differences with significant implications for cost. First, while SO_2 emissions originated from a limited number of highly centralized power plants, greenhouse gas emissions arise from sources as diverse as power plants, automobiles, airplanes, and agriculture. Market designs that worked well with a small number of participants may fail when faced with millions. Second, American power plant operators could turn to readily available and cheap solutions for SO_2 emissions reduction, such as SO_2 scrubbers and low-sulfur coal. In contrast, most low-emissions solutions for greenhouse gasses do not yet exist, or exist only at substantial cost (Hanemann 2009, 96).

> ***But the conditions that helped emissions prices work well in the past are not present in the climate challenge.***

Finally, as Noll (2010) points out, the conditions under which prices are normally understood to promote innovation may not pertain for the energy industry. In particular, the monopolistic nature of electricity transmission and distribution, and the windfall profits that accrue to oil producers, both generate economic returns that are decoupled from competition pressures. In either case, technology plays little role in allocating returns to market participants. If this is the case, then there's little reason to believe that a high carbon price (even if it could be sustained politically) will necessarily generate substantial innovation in critical parts of the energy value chain.

These factors stand to increase the cost of policy adoption. A more diverse market for innovation may raise the cost of compliance, especially for retail consumers. Emissions prices would of course create demand for low-emissions technologies, which firms and inventors would respond to. But the costs of this innovation contrast with the SO_2 program, which only had to encourage adoption of existing technologies. Furthermore, energy markets appear not to satisfy the optimum preconditions for price-driven innovation. Thus past experiences do not guarantee success for a greenhouse gas cap-and-trade program; other complementary policies are still needed to make a carbon price more effective and more efficient.

4.1.2 Optimizing the energy market: the benefits, costs, and limitations to fossil fuel subsidy removal

Removing distortionary subsidies for fossil fuels can, consistent with the arguments discussed in section 3.1.2, complement a carbon price and reduce the cost of emissions reduction. Research estimates suggest that doing so would save billions of dollars annually around the globe and reduce carbon emissions by as much as 5%. Politically, however, effective subsidy removal will require careful attention to their effects on lower-income households in particular.

Today, most governments provide some kind of subsidy—explicit or implicit—for fossil fuel energy, though the extent of support can be difficult to determine. Definitions of what constitutes a subsidy range from the difference between domestic and international energy prices; to more specific tax breaks or direct subsidies to fossil fuel industries; to expansive definitions that count the cost of navies that secure the high seas for oil shipping.

Using only the difference between global and domestic prices as a subsidy measure, Larsen and Shah (1992, 5)

> ***If countries can manage the impact on the poor, removing fossil fuel subsidies can reduce emissions and save money.***

estimate that the world as a whole spent $230 billion dollars on fossil fuel subsidies in 1991, the bulk of which were paid out in the former USSR, China and other middle-income and developing economies (1992, 5). But by this definition alone, the United States, for instance, does not subsidize fossil fuels, a conclusion contradicted by explicit tax code provisions. In contrast, Koplow and Dernbach's review (2001) of studies on American fossil fuel subsidies, which takes a broader view and includes subsidies or tax write-offs for activities such as oil exploration, finds a large range of different estimates. According to the EIA, American fiscal and tax provisions for fossil fuels totaled $2.5 to $2.9 billion in 1998-1999. Going beyond subsidies for consumption or exploration, a Spanish study argues that the fossil fuel subsidies should include the investments made for roads and highways, and the security cost of maintaining safe shipping routes for the international petroleum market. Under that much more expansive (and quite controversial) definition of subsidy, oil subsidies alone are estimated at $574 to $1,736 billion in 1998 (ICTA 2001, 366).

Though there is disagreement over the extent of fossil fuel subsidies, scholars agree removing subsidies will increase overall economic welfare and reduce emissions. Larsen and Shah estimate that the removal of all fossil fuel subsidies—even under their narrow definition—would reduce global emissions by 5% and improve net economic welfare, even accounting for the losses that would impose on fossil fuel exporters (1992, 21). Koplow and Dernbach (2001) and Moor (2001) come to similar conclusions.

That said, net improvements in welfare may not mean equitably distributed improvements. Removal of subsidies to fossil fuel usage will increase the cost of some energy services, which may disproportionately impact lower-income households. Moor (2001, 172) argues that this effect should be limited because the lowest income populations in developing economies don't consume many commercial energy resources to begin with. Moreover, his estimates suggest that even higher-income groups that feel the impacts more acutely will suffer at most a 3% loss of income.

However, low-income households in developed economies may suffer more from subsidy removal since they spend a relatively large share of their income on energy goods. The United States Congressional Budget Office (CBO) has analyzed the effect of energy price increases resulting from a cap-and-trade program for greenhouse gasses. While not strictly equivalent to removal of energy subsidies, such a program would still increase the cost of energy services to the entire population, with potentially skewed distributional effects. The CBO finds that households with income in the lowest quintile suffer the greatest loss of purchasing power; however, a revenue-neutral program that uses the revenue of the cap-and-trade program to support low-income households can create a net gain in purchasing power for these households (2009a, 24-25). This raises an important point: while the removal of subsidies on fossil fuels can increase net economic welfare and reduce greenhouse gas emissions, nothing about subsidy removal policy itself solves its potential distributional problems. Doing so requires a separate choice on how to use the welfare enhancements.

4.1.3 In search of a double dividend: experience in environmental tax reform

Using emissions tax revenues to fund reductions in taxes on labor or capital can both reduce emissions and generate better incentives to hire and invest. But "green growth" from this kind of tax reform appears more likely to encourage job creation than overall GDP growth. Furthermore, achieving both sides of the "double dividend" depends on starting from a tax code that imposes significant burdens on labor or capital to begin with. In less distortionary tax systems, emissions taxes can still achieve emissions reductions but will deliver fewer economic benefits.

From section 3.1.2, we saw that emissions prices could, theoretically, improve economic performance while cutting emissions. This so-called "double dividend" suggested that replacing taxes on labor or investment with taxes on emissions—switching from taxing "goods" to taxing "bads"—could therefore generate both growth and lower emissions.

The research literature does not dispute the theoretical argument. Emissions taxes correct the distortion inherent in negative environmental externalities, and as such should not create deadweight losses for the economy. In contrast, much more common taxes on labor and capital may distort incentives to work, hire, or

> ***Countries with very inefficient tax codes can improve markets for labor and investment and reduce emissions by recycling emissions tax revenues into tax code reform.***

> ***But the "double dividend" appears more promising for jobs than for economic growth.***

invest. Using emissions tax revenues to offset reductions in taxes on labor or capital could therefore reduce the total deadweight loss of the taxation system even as it also reduces emissions. This so-called "double dividend" can make the environment better off while improving the efficiency and competitiveness of the economy as a whole.

How large an effect this would have remains the subject of debate (Goulder 1995). The most aggressive form of the double-dividend theory claims that revenue recycling can reduce the cost of a carbon tax to zero or negative in a typical economy. In order for the carbon tax to have zero or negative cost in general situations, it must yield an increase in non-environmental welfare. Most studies reviewed by Goulder show that this will occur only when the taxation system already highly inefficient. Manresa and Sancho's model of the Spanish CO_2 tax shows that recyclng the tax revenue can reduce emissions, make the tax system more efficient, and increase employment. But this "triple-dividend", as they call it, only arises because the Spanish tax system is highly inefficient and places excess tax burden on labor (2005).

Hoerner and Bosquet's analysis of the experience of environmental tax reform in eight European countries also shows that recycling tax revenues can increase employment (2001). Net impacts on GDP appear to be smaller: across 44 studies, the overall change in GDP growth rates before and after tax reform ranged between -0.5% and 0.5%. (2001, 2). Thus environmental tax reform may support emissions reductions and can, in some cases, generate overall employment growth. But it appears to have a relatively small impact on economic growth itself; and its effects are proportional to the severity of distortion in the original tax system. Thus hopes that environmental tax reform can generate net benefits from emissions taxation appear limited to specific cases; the best outcome possible in most cases appears to generate emissions reductions at little to no cost.

4.1.4 Inventing lower costs: the role for technology breakthroughs

Research finds that rapid reduction in the cost of low-carbon energy costs via innovation is possible, based on historic experience with energy technology. But a price alone may not be sufficient to support innovation, particularly where demand for energy or energy services is relatively price-inelastic. Other measures, such as direct support for basic energy research and development, will be required to generate the innovation needed for significant emissions reduction at low cost.

Technological innovation will set the framework for the costs of a transition to a low-carbon economy. If innovation can quickly reduce the cost of low-carbon technologies, then the cost of emission reduction can be small. How best to generate this innovation has received attention in three areas in particular:

1. What kind of innovation—for new technologies or new processes, for instance—is required?
2. How does that innovation take place?
3. And given (1) and (2), will an emissions price suffice as an incentive for the innovative activity demanded for a low-carbon energy systems transformation?

In total, the need for both process and product innovation, and the potential for substantial innovation via experience as well as through research, recommend against dependence on an emissions price alone.

A transition to a new green energy system will require more than just new technologies. It will also require a great deal of knowledge in domains such as wind farm operation, renewable resource discovery and optimization, and power grid management with intermittent energy inputs. Along with improvements to manufacturing processes to drive down the cost of new technologies, these kinds of innovations suggest huge gains from Learning By Doing (LBD) in addition to more traditional research and development.

The LBD innovation process is a core assumption in the argument that states should support renewable energy investment now in order to drive down costs in the future. The LBD model assumes the cost of technology decreases with cumulative output. With significant investment during a technology's infancy, its price can decrease rapidly. If true, that would reinforce the assumption, made by both the cost-minimization and GDP growth schools, that renewable energy can quickly become competitive against conventional energy.

Despite its popularity, assumptions behind the LBD model have been questioned. I.S. Wing points out that the LBD model suffers from a technological "free-lunch" syndrome that simply assumes more efficient production to be a byproduct of output, requiring no deliberate, costly improvement to original production processes (2006). A more modest critique points out that the LBD argu-

> ***The low-carbon economy needs innovation across a wide range of both products and processes.***

> ***Merely starting the transformation to a low-carbon energy system will generate valuable innovation and experience.***

> ***Given appropriate support, "green" innovation need not detract from other innovation that supports economic growth.***

ment assumes that low-carbon technology has a much higher learning rate than conventional energy technology, leading to the conclusion that renewable energy can quickly become competitive against conventional energy. However, there is little evidence suggesting renewable energy learn faster than conventional energy technology.

Whatever these theoretical arguments, practical experience in renewable energy lends support to the LBD model. Matthias Heymann (1998) presents evidence that the Danish wind industry has developed successfully based on a bottom-up approach that emphasized incremental innovation based on knowledge gained through building and deploying successively more advanced turbines. In contrast, a top-down engineering approach like that adopted in Germany or the United States had much less success at either building viable wind turbines or developing a competitive wind industry (Heyman 1998, 654-659). Grubler, Nakicenovic, and Victor's study on technological change also provides many examples of cost reduction as a result of increased output in nascent technologies. In the U.S, photovoltaic cells, wind turbines, and gas turbines all saw their cost per kilowatt capacity drop significantly as total capacity expanded (Grubler, Makicenovic and Victor 1999, 254).

Whether a carbon price represents, as Nordhaus (2010) claims, a sufficient condition to drive low-emissions innovations remains controversial. Hanemann (2009) points out that a high carbon price will not be politically sustainable, since it erodes real income and standard living; therefore, complementary policies are needed to accelerate the innovative process in order to reduce the price of carbon needed to achieve emission goals. Popp (2009) also finds that the preponderance of the literature on climate policies and innovation also supports the view that R&D subsidies should be used as reduce the magnitude of the carbon price required for innovation.

> ***But that doesn't mean that these initial investments will pay for themselves—innovation still requires investment.***

These models all suggest, however, that investments in climate innovation will not come at the cost of other innovations that also produce economic growth. But in Wing's knowledge stock model of innovation, some opportunity cost is incurred in diverting resources for discovery of low-emissions technologies. This effect is particularly pronounced under the assumption that the human and physical capital required for innovation comes from a fixed stock of a rival good. In that case, all innovative activity comes from a common pool of resources, and expansions to the innovation activity in one sector necessarily detract from such activity elsewhere (Wing 2006, 560). At the very least, this model would argue that a carbon price alone, by not necessarily expanding the resources devoted to R&D, may not be sufficient to link innovation to growth. Even then however, it may prove difficult to avoid crowding out other research and development investments.

4.1.5 Conclusion

The research literature supports public arguments that emissions prices can provide cost-effective means of reducing greenhouse gas emissions, particularly if complemented by changes to fuel subsidies, support for R&D, and broader reforms of inefficient tax codes. In total, the consensus that a properly designed suite of such policies, taken together, represent a relatively modest cost to the economy and thus a relatively minimal threat to growth.

4.2 Job creation in the green-collar economy: separating myth from reality

Investment in energy projects can provide effective Keynesian stimulus for short-term job creation, and serve as a stepping-stone to longer-term job gains from energy efficiency. But formal analysis of job creation via energy investments suggests these policies are often more growth-oriented than green. Green stimulus can certainly create jobs in times of recession, and promote new industries and improve energy efficiency in the long-term. But whether the emissions reductions generated by these policies are sufficient to offset the increased energy use and emissions that follow as a natural consequence of expanded economic activity, remains unclear.

4.2.1 Green stimulus: a short-term green labor market

As discussed in section 3.2.1, the 2008-2009 financial crisis saw the adoption of Keynesian demand stimulus measures in both developed and developing countries. Anywhere from 10-70% or more of stimulus spending was targeted at greenhouse gas emissions reductions or energy efficiency programs. Advocates for Keynesian policy claim that this spending represents a valid corrective to the fall in aggregate demand characteristic of recessions. Consistent with Keynes' General Theory, they argue that short-term stimulus spending can maintain employment and keep the economy from settling into a low-demand, high-unemployment equilibrium (Ghosh 2006, xxv). Moreover, a dollar of spending may promote more than a dollar of overall economic activity, as the effects of that spending cascade through the economy. The validity of Keynesian green spending as a job creator thus rests on two arguments: first, that governments can effectively offset a fall in private-sector demand; and second, that the dollars they spend in doing so multiply through the economy, generating consumption and investment beyond the domain of stimulus investments alone.

The scale of the Keynesian multiplier—the relationship between a dollar of spending and the scale of additional consumption or investment it promotes—remains hotly contested. The Congressional Budget Office used a range of multipliers from 1.0 to 2.5 to estimate the effect of the American Reinvestment and Recovery Act (Congressional Budget Office 2009, 4). Official estimates from the United States Council of Economic Advisors suggested that a dollar of federal spending generated 1.6 dollars of overall economic activity (Romer and Bernstein 2009). A comprehensive review of the size of the Keynesian multiplier found that it is probably positive but smaller than these estimates, and could turn negative under the right circumstances (Hemming et al 2002).

Skeptics of Keynesian stimulus as a jobs creation mechanism find the notion of a positive multiplier implausible. They argue that any increase in government spending must per force crowd out some private sector spending, via two mechanisms. First, government spending absorbs capacity—capital and labor—that might otherwise be used more efficiently by the private sector. Second, when financed by deficits, government spending will lead taxpayers to restrict spending further now in expectation of higher taxes—to pay for those deficits—in the future. This would offset any increase in demand from expanded government investment.

> *And significant Keynesian investment risks misallocation of funds and distortion of the economy.*

These arguments ultimately conclude that a dollar of government spending produces at most a dollar of economic activity, and at worst destroys net economic activity and employment. A series of papers in on the 2008-2009 stimulus packages in particular found Keynesian multipliers equal to or less than one—in other words, government stimulus distorted the economy to the point that it reduced economic efficiency and impeded job creation (Mullligan 2010; Cogan et al 2009). Cwik and Wieland (2009) find similar results for proposed stimulus measures in the euro-area economies. In the perspective of these analyses, government spending—green or otherwise—is more likely to reproduce the 1970s, when attempts to stimulate demand gave way to wage inflation and depressed economies that eventually required extreme measures by the likes of Paul Volcker to correct.

In response, advocates for Keynesian measures object primarily to the assertion of perfect Ricardian equivalence—the idea that taxpayers necessarily save a dollar today for every dollar of government deficit spending, in anticipation of the taxes that must eventually pay for the spending. If true, that would mitigate any net impact of government spending. But those skeptical of the perfect equivalence argument note that the real danger isn't that of government action, but of stabilization at a bad equilibrium in which low demand leads to low investment, which in turn leads to low employment and thus low demand. In that world, the choice isn't between private versus public-sector investment (as the Ricardian equivalence arguments assert) but between public

> *Keynesianism—even "green Keynesianism" remains a short-term strategy that cannot sustain green job creation.*

> *But demand stimulus can provide an important corrective to economies stuck at a low-output equilibrium—and improve the energy infrastructure at the same time.*

> ***Initial studies suggest that the 2008-2009 green stimulus measures did deliver both green jobs and emissions-reducing investment.***

investment and no investment at all (Krugman 2009). In such a world, it is argued that government investment to spur economic activity necessarily raises overall levels of output as a means to displace the economy out of this bad equilibrium. That, they argue, remains the lesson of the great financial crises of the 1980s and 1990s—Latin America, Japan, and Southeast Asia.

In contrast to the significant attention given to the general Keynesian hypothesis, less attention has been paid to whether green Keynesian stimulus delivered on its job creation goals. Barbier (2010) estimates that the world as a whole spent $522 billion, out of $3.3 trillion in total stimulus, on emissions reduction measures. Most of that money went to energy efficiency. He finds that US programs did deliver on their goal of creating 500,000 net jobs by 2012. The OECD (2010, 27) finds that similar measures in South Korea added 960,000 new jobs. Houser (2009, 2-5) finds that green stimulus performed as well or better than traditional stimulus, creating 20% more jobs than traditional infrastructure spending and also producing emission reduction and energy savings (2009, 2-5). But as we have seen, whether these jobs offset the long-term effect of the budget deficits that financed them remains hotly debated among economists.

We emphasize that the dispute over the effects of green stimulus on job creation and economic activity do not undermine the other rationale for government investment in emissions reduction during a recession. Given the assumption that such investments will be required anyway, investment during a recession may prove a cost-effective way of shifting future investments to the present to take advantage of cheaper labor and capital (Bowen et al. 2009, 14; Houser et al. 2009, 1-2). Thus government investment in support of green jobs at a time of recession represents an opportunity to lock in low-carbon production and consumption patterns for the future.

However the Keynesian debate settles, it does not affect the fundamentally limited time horizons of Keynesian job creation. Fiscal stimulus is by necessity short-term. Sustaining large deficits for "green" job creation into periods of economic recovery becomes more expensive, distorts labor markets, and risks wage inflation. Thus no matter the size of the stimulus, or its overall effect on job creation, "green growth" cannot rely on Keynesian policies for long-term success.

4.2.2 Emissions reduction, new sectors, and employment: between job creation and carbon leakage

Beyond short-term Keynesian policy tools, green growth advocates have argued that investments in emissions reduction will spawn new sectors and firms. The new jobs associated with these "green" industries will, in their view, offset the jobs lost in high-emissions sectors, leading to net new job creation. While academic studies of the net employment effect of green investments generally support the argument that new green industries will create new job opportunities, those effects appear highly contingent on local conditions, informing against a one-size-fits-all policy prescription for green job creation.

Spain has generated a great deal of academic interest given its emphasis on green energy as an economic development strategy. Studies of the region around Navarre, where wind turbine maker Gamesa has a significant presence, generally show positive employment effect of renewable industries. Faulin et al. (2005) find that achieving a renewable electricity consumption rate of 12% in the region will have net positive employment effects. Moreno and Lopez (2006) find similar effects of renewable energy mandates in the Spanish region of Asturia. In this case in particular, the employment affects appear to originate from reallocating energy demand from Asturia's fossil fuel sector, which has low labor intensity compared with the manufacture, installation, operation, and maintenance of renewable energy capacity.

These results also appear to apply to outside Spain. In the United States, Barkenbus et al. (2007) find that biomass energy investments can complement Tennessee's pre-existing expertise in agriculture and create net new jobs. Lehr et al. (2007, 117) predict that German renewable sectors could provide 400,000 new jobs by 2030. Most of the positive employment effect, however, comes from Germany's high export competitiveness, and depends on the assumption that global markets will continue to be receptive to German exports (2007, 117). This suggests the importance of export-led growth to green growth arguments, a potential vulnerability we discuss in section 3.3.1.

Overall, then, the literature shows that investing in renewable energy markets at can generate net employment gains. But that outcome appear highly location-contingent—as in the relative labor intensity of Spanish

> ***Local jobs and economic growth can benefit from expansion of local renewable energy markets under the right circumstances.***

> *But the overall impact of renewable energy growth depends heavily on how industry handles higher energy costs—especially in energy-intensive sectors.*

> *Recycling savings from energy efficiency improvements into the rest of the economy may cut overall energy efficiency gains by 10-70%.*

industry, the agricultural capacity of Tennessee, or the export competitiveness of German manufacturers. This result should inform against the assumption that green energy investments always and everywhere create employment. Moreover, we would emphasize that many of these employment creation numbers rely on expanding employment through lower productivity, in renewable energy industries that require more labor per unit output than the fossil fuel industries they replace.

Finally, these results hinge on expectations of how the markets would balance the cost of renewable energy resources. For the German case, Hillebrand et al. (2005, 3493) argue, *contra* Lehr et al. (2007) that the higher cost of renewable energy mandated by the EU's renewable energy standard will have negative net employment effects over the long term. Long-term leakage of jobs and investment in high-energy-intensity sectors will eventually overwhelm job creation in new renewable energy sectors, leading to net job loss. These fears are particularly acute in the absence of a global emissions deal, which could allow some countries to use relatively lower energy costs from unchecked emissions to attract production from elsewhere. Such concerns have figured prominently in the design of, for instance, the European Emissions Trading Scheme, which provides a range of exemptions for so-called "carbon leakage" sectors.

4.2.3 Energy efficiency: green jobs, or merely jobs?

Reallocating savings from energy efficiency investments towards other areas of economic activity can create new demand and the jobs that come with it. But that increased economic activity itself requires energy, diminishing the overall energy savings and emissions reduction of the energy efficiency investments themselves. Hence the very process that creates these jobs also undermines their "greenness." Investments in energy efficiency may make economic sense, and certainly generate employment. These jobs are particularly attractive because, as jobs in services like construction, they are relatively immune to international competition compared with manufacturing. This has led to widespread support for investments in job creation via energy efficiency policy.

But the "greenness" of the jobs created remains subject to some dispute. In particular, the savings from energy efficiency are always recycled into other forms of economic demand. Depending on the profile of that demand, the reductions in energy use and emissions from the investments themselves could be entirely offset by increased energy demand and emissions elsewhere. Thus energy efficiency can create jobs, but the downstream effects of having done so mitigate the "greenness" of these jobs and their overall effect on emissions reduction.

Empirical studies of the employment effects of energy efficiency investments support the job creation argument. An analysis of the US building efficiency program using input-output model concludes that the program will create nearly half a million jobs, increase wage by $7.8 billion dollars, and save $207million worth of energy capital goods between 2005 and 2030 (Scott et al. 2008, 2283). The state California provides another example of energy efficiency's economic benefits. David Roland-Holst's 2008 study shows that in California, between 1972 and 2006, a well-documented total household energy savings of $56 billion has been redirected towards other more labor-intensive goods and services, creating 1.5 million jobs with a total payroll of $45 billion over this thirty-four years period (4). Another econometric analysis of Californian economy also shows that between 1977 and 1993, decreasing industrial and commercial energy intensity caused per capita GDP to increase by 2.74% (Bernstein et al. 2000, 57).

This consensus over jobs does not extend to the conclusion that energy efficiency investments lead to emissions reduction. If energy efficiency improvements expand demand for energy-containing goods, some or all of the emissions gains may be offset by growth in overall energy demand. The presence and magnitude of these effects appears to vary by development level. Schipper and Grubb's empirical study of energy use in IEA countries between 1970 and 1990 reveal no significant rebound effects either at the micro / household or macro / economy level (2000, 386). Jenkins et al. (2011, 14-16) provide a comprehensive review of both micro- and macroeconomic attempts to estimate the magnitude of this effect. Microeconomic studies of the rebound effect in developed economies estimate it as positive but small—perhaps 10-30% of the savings gained by the energy efficiency investments themselves. But this result is contradicted by the few macroeconomic studies of energy efficiency effects, which suggest overall rebound effects on the or-

> ***Ironically, better energy efficiency may encourage more energy use and higher emissions, particularly in developing economies.***

der of 60%. Nevertheless, this range of estimates would suggest that at least some energy savings persist; and only a few studies find that 100% of energy gains are lost to increased economic activity (Jenkens et al. 2011, 28-33).

However, both Jenkins et al. (2011) and Schipper and Grubb (2000) warn that their findings apply largely to the developed economies. For developing economies that lack energy services, increased efficiency can incentivize the expansion of energy demand by reducing the cost of better lighting, heating, or other technology services. Herring (2006) provides evidence from the UK during its late period of industrialization. There, electricity consumption for street lighting increased 30-fold over the 20th century, even as lighting efficiency improved 20-fold. Jin (2007) finds more modest rebound effects, on the order of 30-40%, for residential energy use in South Korea after the 1970 energy crises. Dimitropolous (2007) finds relatively few studies of developing economies, and a very wide range of estimates for the rebound effect in those countries, ranging from 44% on the low end to 77% or higher.

In sum, energy efficiency investments do appear to generate net positive employment effects. However, the overall "greenness" of those jobs—their contribution to emissions reductions—appears highly contingent on the dynamic effects of increased energy efficiency. Most estimates find that somewhere between 10-50% of the efficiency gains are lost to higher consumption of energy overall, with effects being somewhat higher in developing economies.

4.2.4 Conclusion

Thus both near-term and long-term proposals to link emissions reduction investment to job creation can create jobs, but their potential impacts on emissions themselves appear limited. All three mechanisms outlined—green Keynesian stimulus during the recession, investments in and mandates for green industry products, or energy efficiency improvements—can provide net positive job creation under the right circumstances. But of these, only expanded renewable energy production for the purposes of replacing fossil fuel energy resources unambiguously reduces emissions. Furthermore, the particular contours of policy inform against blanket prescriptions for these investments or mandates. The connection between the form of green investment and job creation appears highly contingent on pre-existing conditions in national economies, and not on the green investment itself. Thus all three mechanisms face limitations as effective, generally applicable green growth strategies.

4.3 Growing green: do emissions mitigation measures drive GDP growth?

The most ambitious body of green growth literature contends that reduction can drive GDP growth. These arguments center on using export markets to increase output above domestic demand for renewable energy or low-emissions goods; and on driving low-emissions innovation to increase productivity and real income. Each of these approaches has its empirical success cases. But research on both proposals suggests that either strategy remains highly dependent on local conditions, and calls into question their applicability as global approaches to achieving real GDP growth via investments in green energy and emissions reduction.

4.3.1 Export-led green growth: an uncertain national strategy

As section 3.3.1 noted, the global success of renewable energy firms in Denmark, Germany, and elsewhere has made export-led green growth a popular goal. Advocates for green growth argue that promotion of domestic markets and firms will translate into international comparative advantage that supports job and GDP growth at home. But empirical studies have had difficulty establishing a causal link between export growth and economic growth. At best, these appear correlated, as in the experience of East Asian development; at worst, the experience with import substitution strategies in Latin American after the 1950s suggests that misguided policy can deny nations the benefits from trade and erode economic performance.

Japan, Singapore, South Korea, Taiwan, and now China usually lead the list of countries that have used export markets to successfully drive domestic development. In an attempt to ascertain whether these countries are representative of the broader experience of export-led growth, Lewer and Van den Berg (2003) reviewed 53 empirical studies, examining countries from all regions of the world over time. They conclude that export growth and economic growth are positively correlated: for every one percentage point increase in export growth, they find

> ***Green-tech export-led growth could replicate earlier successes in driving growth across a range of countries and industries.***

a statistically significant 0.2 percentage point increase in economic growth (Lewer and Van den Berg 2003, 363).

But correlation does not, of course, imply causality. Giles and William's review (2001) of 150 empirical research papers shows that even those papers that attempt to estimate causality have difficulty establishing the direction of a causal link in the export-growth relationship. In other words, even if exports and economic growth are causally related, it remains unclear whether exports drive growth or vice-versa. Thus claims that exports drive growth always and everywhere should be treated cautiously.

Furthermore, the work of Hidalgo et al. (2007) and Hausmann and Hidalgo (2010) shows that comparative advantage in particular kinds of goods must, in general, grow out of similar capacities—skills, capital, knowledge, and institutions—in related sectors. Thus even viable green export strategies face certain limits. Denmark or Germany, already expert at high-precision machine goods, found the move into wind turbines, and the generation of jobs and growth in that sector, relatively easy; countries without these traditions may not.

Finally, an emphasis on developing comparative advantage in particular sectors may create countervailing economic distortions that offset growth effects. The import-substitution period in Latin America denied economies there gains from trade in a variety of goods, even as it tried to build export industries without strong foundations in the broader economy. The same problem applies to green energy goods. Concerns over Chinese competitiveness in solar cells, for instance, should be offset by the tremendous reductions in per-unit costs for solar cells that Chinese factories have been able to accomplish. If the zeal for export-led growth lead to a new green mercantilism, it may increase the cost of emissions reduction, with impacts to the economic efficiency and job creation potential of the broader economy. It might also threaten the stability of the international trade regime, if competition for a share of this new sector undermines support for trade in green goods as a whole.

Thus relying on exports of renewable energy or low-emissions products to drive GDP and jobs growth remains a green growth strategy with limited applicability. Those nations who gained from first-mover advantage—Denmark in particular—did so on the basis of pre-existing national competencies. Second-stage countries now face intense global competition from developing and developed countries alike, and may lack the foundations for moving into those products. Finally, over-emphasis on exports as a growth strategy may undermine both growth and emissions reduction by distorting domestic investment, denying countries the benefits of trade in green energy industries, and raising the cost of emissions reduction and renewable energy goods.

> ***Generalizing the green export success of countries like Denmark or Germany will prove difficult.***

> ***But competition for export markets in strategic energy sectors risks a new "green mercantilism".***

4.3.2 Innovation-based growth: theory and criticism

Few studies support the notion—referred to as the Porter Hypothesis—that stringent regulation pays for itself by inducing private sector innovation. Rather, complementary policy is required to ensure that regulation alone doesn't impose significant burdens on firms and consumers.

As we saw in section 4.1.4, the potential exists for significant technological progress in renewable energy. But most policy analysis has focused on how to achieve that innovation at minimal cost to the efficiency of the economy as a whole. No one disputes that the green economy can provide new opportunities for innovation and business models. Rather, concerns over the cost of achieving these innovations relative to other opportunities for the economy give rise to fears that emissions reductions and economic growth necessarily represent tradeoffs.

In contrast to this argument, Pooley (2010) and others have argued that carbon regulations themselves make firms more competitive by making them more resource efficient and forcing innovation. If true, this would imply that environmental regulations could drive growth through productivity-enhancing innovations at very low cost. Proponents often point to Swedish or Danish wind and bioenergy companies that have become more successful internationally despite stringent domestic regulations.

This argument, known as the Porter hypothesis in academic literature (Porter and Van der Linde 1995), has been strongly criticized by economists. Palmer and Oats (1995, 120) object to Porter's assumption that firms can discover cleaner, more efficient production processes without incurring any added costs. In the United States, firms report their pollution abatement cost and expenditure (PACE) as well as cost-savings from the regulation-induced innovation that Porter describes; net PACE in United States still exceeded $100 billion in 1992 (Palmer and Oats 1995, 128). Wagner's review (2003) of empirical studies of the Porter hypothesis find that costs and benefits vary significantly across firms and industries, suggesting that this result may not be widely applicable.

Theoretical analysis shows some support for the Porter hypothesis. Assuming efficient regulation, widespread demand for environmentally differentiated goods, and readily available but unused technology options are present, there can be a favorable relationship between environmental regulation and competitiveness (Wagner 2003, 31). But as Hanemann (2009) has noted, this is not yet the case for greenhouse gas emissions reduction. In particular, we do not have a stable of unused low-carbon technologies waiting in the wings. That implies that restrictions on emissions alone will be insufficient to drive innovation and growth. Instead, we may face an extended period of investment in new technologies, and in the development of consumer demand, before the Porter Hypothesis conditions are realized. If so, that would imply substantially higher transition costs—and correspondingly less favorable conditions for emissions-reduction-led growth.

Finally, Noll (2010) points out that energy technologies require a series of complementary innovations—such as innovations in electric cars as well as a charging infrastructure. The need for a network of innovations in order for a given innovation to take off generates significant coordination costs, which Noll describes as a "chicken-and-egg" problem: who goes first, at what scale, can become a source of debilitating uncertainty for innovators and investors. Neither a carbon price nor the Porter Hypothesis provide answers as to how price-based or regulation-based innovation will overcome these issues. Indeed, the problem suggests falling back on the state as the primary source for coordination. But that simply returns us to the original argument for price-based emissions regulations: that the state has limited information and is likely to do a bad job "picking winners."

> ***The "Porter Hypothesis"—that emissions restrictions alone can drive significant innovation at low cost—has little empirical support.***

4.3.3 Conclusion

Empirical and theoretical studies of the link between emissions reduction and improved GDP growth are thus decidedly mixed. In some countries, under some circumstances, support for domestic renewable or low-carbon energy adoption has led to internationally competitive firms that generate real income and employment gains at home. The same may also be true of the link between innovation-driven productivity improvement and emissions regulation. But both outcomes, conceived in terms of the narrow link between developments in the energy sector and growth for the economy as a whole, appear highly contingent on time and place. Furthermore, in a global economy, they do not appear able to support a broad-based outcome for green growth. And in their worst form, they may encourage a view of the green technology sector as a zero-sum game, and green growth as a mercantilist battlefield.

BEYOND EMISSIONS AND ENERGY: ENERGY SYSTEMS TRANSFORMATION AND THE CREATION OF ECONOMIC OPPORTUNITY

Stepping back from the topic of green growth, it's striking how limited the debate depicted above actually is. The proposals discussed so far emphasize growth in the energy sector—but the total value of that sector in most advanced industrial economies is a mere 2-5% of GDP. The rate of demand growth for energy of any form remains limited to a few percent a year at most, and energy efficiency improvements might reduce even that. For all but small countries like Denmark, then, the energy sector alone appears to be a poor candidate for generating dynamic growth for income and employment in the economy as a whole.

Furthermore, this emphasis on energy in isolation runs contrary to the core problem of emissions reduction itself. Treating emissions reduction as a mere problem of reducing energy demand or increasing the supply of low-carbon energy ignores the underlying economic and technological challenges posed by low-carbon energy itself. Intermittency, distributed generation, and demand management all pose basic challenges to the energy system as a whole, not just one component of it.

This process is better characterized as an energy systems transformation (Zysman and Huberty 2010a, 2010b). That transformation will span not just the technological contours of the energy system, but the design of its markets and the characteristics of the regulations and business processes that govern these markets. The economic activity for such a transformation will go beyond just the creation of competitive renewable energy firms, or innovation to provide lower-cost, lower-carbon energy alternatives. Rather, it will embrace patterns of economic production for the economy as a whole.

That transformation poses profound challenges to growth-oriented climate policy. In particular, and unlike earlier energy systems transformations, the "green" electrons we hope to adopt offer few immediate or obvious advantages compared to the "brown" ones economies currently enjoy in abundance. Indeed, much of the investment required for this energy systems transformation is needed to remedy the problems of intermittency and diffuse resources that make large-scale adoption of renewables so challenging. In other words, we will spend a vast amount to make sure that tomorrow's energy supply looks about the same to the consumer as today's does.

But it may also generate enormous opportunities to translate climate change mitigation into growth. Past systems transformations—the adoption of the railways, the electrification of the energy supply, or the rise of information technology—have created enormous economic growth even as they required massive investment. That economic growth has come, not merely in the rail or energy or IT sectors, but because of the opportunities created by innovation in those sectors for the economy as a whole. Indeed, in each case the growth in a given

> ***Durable, sustainable "green growth" must look for growth beyond just the energy sector.***

> ***Can the low emissions energy systems transformation create new opportunities in the broader economy?***

> ***Earlier technological transformations in large systems—ICT or rail—created growth by generating new opportunities for economic production.***

sector was far outstripped by the growth in the broader economy. That growth came about because the innovations themselves changed what was possible for economic production, and those changes drove massive and repeated investment in new business models, products, and modes of production. As Perez has described for the first and second industrial revolutions, those changes then became the foundation of long-term growth (Perez 1985, 1993).

How best to structure policy in pursuit of this kind of transformation poses a choice fraught with risk. Studies of highly networked systems point to the enormous inertia that most networked systems display. By definition, networked systems like energy generate huge returns to scale. Conversely, the value of a single system with large numbers of users forestalls attempts to shift the system to a new developmental trajectory (Katz and Shapiro 1985, 1986, 1994). This is certainly true of today's energy system, which is locked into fossil fuels through both the design and capabilities of the infrastructure that ties together production, distribution, and use; and the structure of the markets and regulations that operate this infrastructure (Unruh 2000).

Escaping this lock-in poses real challenges. Even if an emissions price alone appears insufficient to shift the system as a whole, Noll (2010) rather persuasively argues that escaping systemic inertia by simply picking the winning technologies for a new system risks locking in suboptimal, expensive, or nonfunctional technologies. As Smil (2010) notes in the case of China, those technologies can lock tomorrow's energy system into a given pattern of operation just as surely as the fossil fuel investments of the last century did.

In contrast, Zysman and Huberty (2010) argue for an approach that treats the network itself as the innovation platform. The inertia inherent in the network makes the network itself a barrier to innovation—both in the energy sector and in the broader economy. As with other systems transformations, an open power grid, based on stable legal and technical standards, can enable the kind of private sector activity necessary to discover what opportunities new modes of energy production, distribution, and use can generate for the economy as a whole.

Of course, energy is not IT or the railroads. Both these earlier transformations benefitted from starting from a clean slate. Neither transcontinental transportation nor the internet faced predecessor systems that had to keep operating even as the transition to a new system took place. And for ICT in particular, the relatively modest cost of innovation atop the platform, combined with the immediate advantages ICT innovations provided to the private sector, drove rapid and iterated waves of innovation and investment that produced tremendous economic growth. Not so for the energy industry, where billion-dollar investments depreciated over decades remain common.

But if growth is to come, it must come through the possibility that a new energy system can create for the economy as a whole—not just the new products or investments in a replacement for today's systems. That, as we've seen, poses serious challenges for policy, investment, and innovation in networked economies. But if it could be accomplished, it would not be the first energy systems transformation to change the potential for economic growth. Consider, for instance, the role of coal in the British industrial revolution. Nef (1932) argued that coal itself was the major factor in making Britain an early leader in the industrial revolution. But more recent studies, notably Clark and Jacks (2007), show that the rate of productivity growth in coal mining in fact lagged behind that of the British economy as a whole. Indeed, textiles and transport led the way before coal became vitally important in the latter 19th century. But it is the network effects that are so interesting. As Sieferle (2001) showed, the adoption of coal over wood freed up land for other industrial and agricultural uses, and relieved the energy budgets of very energy-intensive industries like iron and glassmaking. Thus even if the contributions of coal to overall English productivity growth were themselves small, the adoption of a coal-based energy system had significant implications for production in the broader economy. Even if, as Clark and Jacks argue, England could have satisfied its energy needs from wood until the mid-19th century, doing so would have forestalled doing other things with the resources dedicated to a wood energy system. This early experience with energy systems transformation suggests that the key to green growth in the future lies not so much in using energy itself to drive growth, but in discovering how the changes required to decarbonize today's energy system alter the possibilities for the economy's ability to generate and sustain prosperity and employment on the whole.

> ***Major differences in starting points will challenge attempts to replicate the successes of earlier systems transformations.***

MOVING THE GREEN GROWTH DEBATE FORWARD: SYSTEMS, SOLUTIONS, AND POLICY CHOICE FOR LOW-EMISSIONS PROSPERITY

The decarbonization of modern industrial economies will take the better part of the next century. Sustaining a commitment to emissions reduction policies over that kind of timeframe will require an approach that generates its own momentum. Relying on the goodwill, altruism, or environmental friendliness of voters to sustain a commitment to sometimes costly and disruptive changes, all in pursuit of diffuse and gradual benefits, remains an unlikely recipe for success.

Green growth turns this problem on its head. It promises that the investments required for emissions reduction can come at minimal cost, and potentially expand both wealth and employment. But as this review has demonstrated, the horizons of the current green growth debate remain somewhat limited. Emissions reductions appear possible at moderate cost. The jobs they generate may be real and even durable, but in many cases may just offset those lost to the declining "brown" sectors. Finally, the possibilities for real economic growth so far identified rely heavily on exports, rather than on improvements to productivity or other more traditional sources of growth. Altogether, this paints a picture of green growth that may be real and achievable, but hardly generalizable or inevitable.

Transcending these limitations will require going beyond a view of green growth as something driven predominately by the energy sector. Earlier systems transformations drove growth only in part through the investment in the transforming sector itself. Rather, whether by rail transport or instant communication or limitless energy, they changed what was possible for the economy as a whole. In doing so, they became platforms for new innovations, products, and business models that themselves provided the foundations for rapid and sustained growth.

Achieving this vision of green growth may therefore require more emphasis on discovery, and less on the specifics of energy itself. Structuring the energy networks of tomorrow, and the markets that govern how energy is produced, distributed, and used, so as to enable discovery and innovation, may provide the best opportunity for green growth. But that remains a difficult and uncertain policy challenge.

> ***The real green growth challenge requires structuring the low-carbon energy systems transformation to allow the entire economy to discover the growth potential created by new ways of producing, distributing, and using energy.***

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