Climate and economic storms of our grandchildren

John A. “Skip” Laitner

Abstract: The evidence continues to mount. As our industrial economy continues to dump large amounts of carbon into the atmosphere, we are affecting the atmospheric chemistry of the global climate. This has led prominent physicist and climate scientist James Hansen to reach the “startling conclusion” that the continued exploitation of fossil fuels threatens not only the planet, but also the survival of humanity itself. At the same time, however, the evidence also suggests that the lagging rate of energy productivity is among the critical reasons for both a slumping economy and an imperiled climate. Hansen further suggests the backbone of a strategy to ensure a “global phaseout” of all fossil fuels is to encourage “a rising price on carbon.” This paper suggests we can achieve the same result in a less costly manner through cost-effective energy efficiency programs and standards. This action will require a smaller carbon charge even as we strengthen the robustness of the larger economy.

Keywords: Climate change . Carbon charge . Economic activity . Energy efficiency

Introduction

Since 1750 and through the year 2012, the global consumption of fossil fuels and cement production within the industrial economy has released approximately 380 billion metric tons of carbon into the air (Boden et al. 2012).[1] If the typical automobile now weighs about 4, 000 lb (about 1.8 mT), this means we have dumped the weight equivalent of about 211 billion junked cars into the global atmosphere. Half of these global emissions (or junked cars) have occurred since the mid 1980s. With even a rudimentary understanding of atmospheric chemistry, it very easy to believe that pumping this magnitude of carbon into the atmosphere would likely have significant implications for climate change and our planet.[2]

After many long years in the detailed study of how the Earth is responding to the perturbing forces of climate change, physicist and climate scientist James Hansen reached the “startling conclusion” that the “continued exploitation of all fossil fuels on Earth threatens not only the other millions of species on the planet but also the survival of humanity itself” (Hansen 2011, ix). The American Geophysical Union released a revised statement on climate change that confirmed

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[1] The original data is provided through 2009 with supplement data used by the author to extend the dataset to 2012. Also note that, especially in the first two sections of the narrative, this paper uses carbon rather than carbon dioxide (CO_2) as an emission metric. For those who want to convert from carbon to CO_2, use the ratio of their atomic weights. The atomic weight of carbon is 12 atomic mass units. The weight of CO_2 is 44 because it also includes two oxygen atoms which weigh 16 atomic mass

Hansen's judgment, declaring that “extensive independent observations confirm the reality of global warming” (AGU 2013). Given that reality, what is to be done?

Hansen argues in his updated book (2011), Storms of My Grandchildren, that an immediate solution to global warming is needed. This requires, he suggests, “a strategic approach that leaves most of the fossil fuels in the ground” (p. 172). The workable backbone of this strategic approach is “a rising price on carbon” as an effective way to ensure a “global phaseout” of all fossil fuels (p. 205). The effect of such a charge would be to increase the cost of any energy resource that contains carbon. This includes coal, oil, and natural gas but not resources as nuclear energy, or wind and other solar or renewable energy supplies. He then advocates a “fee-and-dividend” in which a uniform fee is collected at the first point of sale of all fossil fuels. The dividend then becomes the means to return revenues back to consumers, depending on how much carbonrelated energy they consume. This ostensibly revenue-neutral policy would provide a price signal to consumers to affect their behavior in ways that encourage their move away from energy consumption—thereby reducing carbon emissions from fossil fuel-based energy resources—while returning the collected revenues through a monthly dividend.[2]

The question explored in this paper—acknowledging and agreeing completely with the critical insights that Hansen provides about climate change—is whether the “carbon-charge” remedy he proposes is the economically smart way to move ahead. The reason for posing this additional question is that the emerging evidence also points to a troubled economy, and the reason which drives the very worrisome trends in climate also constrains the robustness of both the US and the global economy.

It turns out that the US economy is not especially energyefficient. Of the total high-quality energy consumed to support economic activity in 2010, only 14 % was converted into useful work (Laitner 2013). In other words, the American economy wasted 86 % of all the energy used that year in the production of goods and services. One can easily imagine that waste of this magnitude creates an array of costs that weakens the nation's economic and social well-being. More to the point, when we properly measure the conversion efficiency, we can observe that the rate of improvement has flattened out in the last couple decades. In short, the lagging rate of efficiency improvement is among the critical reasons for both a slumping economy and an imperiled climate. Hence, any meaningful energy policy requires that we solve for both a threatened climate and a less robust economy—if we are to avoid both the climate and the economic storms of our grandchildren. This paper assesses that larger context over the next three sections that follow.

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[2] In economic parlance, the world is essentially divided into producers and consumers. Thus, any entity, agent, firm, or household that buys a particular good or service is, in that moment, a consumer. Consumer

The paper is organized as follows. Section 2 opens the extended discussion of the economic context that is largely missing in most of the climate assessments. Section 3 reviews the role of price and non-pricing programs and policies that might change producer and consumer behavior in ways that still achieve cost-effective but large-scale reductions in carbon emissions. Section 3 also reviews a previous study by the author which provides a concrete assessment of how the integration of conservation behaviors and greater introduction of technology deployment programs complement the carbon price signal—but do so in ways that reduces the needed carbon charge while also boosting economic well-being. Section 4 then closes with a review of the key findings which point to a set of policy recommendations that might logically follow this broader assessment.

Climate change within the energy and economic context

The national energy accounts for the US are a well-maintained and quality dataset that is tracked and collected by the Energy Information Administration (EIA).[3] But the current database provides in two different ways a highly limited record of energy at work within US. First, it treats energy consumption as a flow of commodities that are merely sold on the market rather than highlighting energy as work. Second, it includes energy consumed as feedstocks which are used to create consumer products such as tires and pharmaceuticals, but it omits a significant part of the energy flows necessary to enable work within the economy. These distinctions are important ones as they provide new insights into the critical link between energy and economic activity. The distinction also has critical implications for climate policy since conservation behaviors and more aggressive efficiency investments can lower carbon emissions by more than half by 2050, even as the economy may become more robust and resilient (Laitner et al. 2012). But to fully understand that opportunity, we need to expand our understanding of energy as it shapes the physical work environment. Clarifying the role of energy as work

Merely tracking energy as tons of coal, gallons of gasoline, kilowatt hours of electricity, or cubic feet of natural gas— essentially treating energy as purchased or tradable commodities—does not help us understand their value as work. Here, work is defined as the capacity to transform matter into the desired goods and services necessary to maintain our economic and social well-being. In a further clarification, what economists, business and policy leaders, and most other people call energy is actually reference to a high-quality form of energy that physicists, chemists, and engineers call exergy. Total energy equals exergy plus anergy, where anergy is the useless form of energy which is present within our environment. While the total amount of energy (exergy

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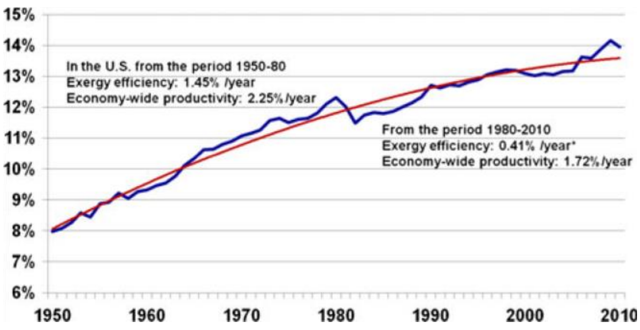
[3] See, for example, the Annual Energy Review 2011 (Energy Information Administration 2012).

plus anergy) is constant, consistent with the laws of thermodynamics, exergy can be degraded into useful anergy.[4] As it turns out, when the full accounting of energy as the potential for work (or exergy) is compared to the EIA dataset that tracks energy as commodities, the EIA data may account for roughly 80 % of the work actually performed by exergy.[6] More critically, it is the rate of converting exergy into work that constrains or enables the robustness of economic activity. Hence, the appropriate metric for evaluating economic performance is exergy efficiency. We can explore the implications of exergy efficiency in Fig. 1 that follows.

Fig. 1 Conversion efficiency—total exergy to useful work.



Source: Laitner (2013)

Exergy efficiency and economic activity

As starting point, the US economy had an exergy efficiency of only 2.5 % efficient in 1900 (Ayres and Warr 2009). Despite a positive 2.4 % annual rate of improvement, by 1950 the exergy efficiency of the US economy grew to only 8 %. As shown in Fig. 1 (adapted from Laitner 2013), the 8 % exergy efficiency in 1950 grew four percentage points to 12 % by 1980. Economy-wide productivity increased by a healthy average of 2.25 % per year during that same 30-year period. Over the next 30 years through 2010, however, the conversion efficiency grew just two additional percentage points even as economy-wide productivity slumped to 1.72 % annually. When spread over a 30-year period, even a few tenths of a percentage point can have a very big impact on the productivity and the size of the economy.

In 2010, for example, the actual size of the nation's gross domestic project (GDP) was an estimated $13,240 billion (measured in constant 2005 dollars).[7] Had the US economy maintained a productivity improvement of 2.25 rather than a 1.72 % over the period of 1980 to 2010, the nation's GDP would have been more than $2 trillion larger than actually recorded. More to the point, it appears the annual productivity of the economy may be weakening even further. Without investment policies that improve energy or exergy efficiency, GDP growth as shown in Fig. 2

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[4] As Kümmel (2011) notes, the conversion of exergy into anergy is the entropy process. [6] For a more complete discussion of these distinctions, see Laitner (2013) and especially Ayres and Warr (2009) and Kümmel (2011).

below may hover closer to 2 % per year rather than the 2.6 % that might be otherwise projected, or even the 3.0 % many hope for. [1].

We can step back at this point and review the combination of historical trends and future projections of the nation's GDP. This gives us an opening look at the inadequacy of economic assessments which omit the conversion of exergy (highquality energy) as means to provide work, or as economists might refer to it, the conversion of exergy as a factor of production. If we examine the longer historical context, we might see, in this regard, a more worrisome picture emerge. Again, Fig. 2 below highlight the trend in annual GDP growth rates for the US economy. The chart first provides an historical perspective over the same 30-year historical periods shown in Fig. 1—in effect, for the years 1950 through 1980 and then again through 2010. To this, we add the projected growth rates made available by Moody's Analytics (2012) and take them another 30 years into the future—out to the year 2040.[8] The solid blue line shows both the historical and the forecasted growth rates while the dashed red line is a stylized mapping of the slumping rate of growth.

The period of 1950 to 1980 in Fig. 2 is generally seen as a vigorous—though an already declining—expansion of the US economy with an annual growth rate that averaged 3.6% in those three decades.[9] The period of 1980 to 2010 in Fig. 2 saw a continued weakening of economic activity. Even if we disregard the obvious impacts of the recession in December 2007 through June 2009, the average annual growth rate fell to 2.7 %. Perhaps of greater concern is the prospect for a continued weakening of the economy over the next 30 years— generally through the year 2040. As shown in Fig. 2, the economic growth rate may hover around 2 % annually. This likely will not be a sufficient level of activity to provide adequate jobs and income for those who need or want them. Nor will it be sufficient to support current educational becomes what might we imagine to be among the general causes of the fading progress?

The usual explanations range from too-easy monetary policies to the failure of regulation. In the case of the recession 2008–2009, for example, economists and pundits from both the conservative and liberal perspectives commented heavily on key elements they believed to be the cause of the downturn. All of the discussion tended to focus on elements of finance— that is, “a frenzy of irresponsible borrowing on the part of banks and consumers alike”—to “regulation that failed to keep up with the system.” Yet there was no consensus as to a “sufficient condition” or key factors that would have caused the crisis in the absence of any others (Weisberg 2010). Nor have there been any programs, ongoing research, and development initiatives, or existing social service programs, or even new climate change policies and higher levels of investment to improve our nation's infrastructure. The question to be asked, then, becomes what might we imagine to be among the general causes of the fading progress?

Figure 2. US historical and projected average annual GDP growth rates 1950-2040

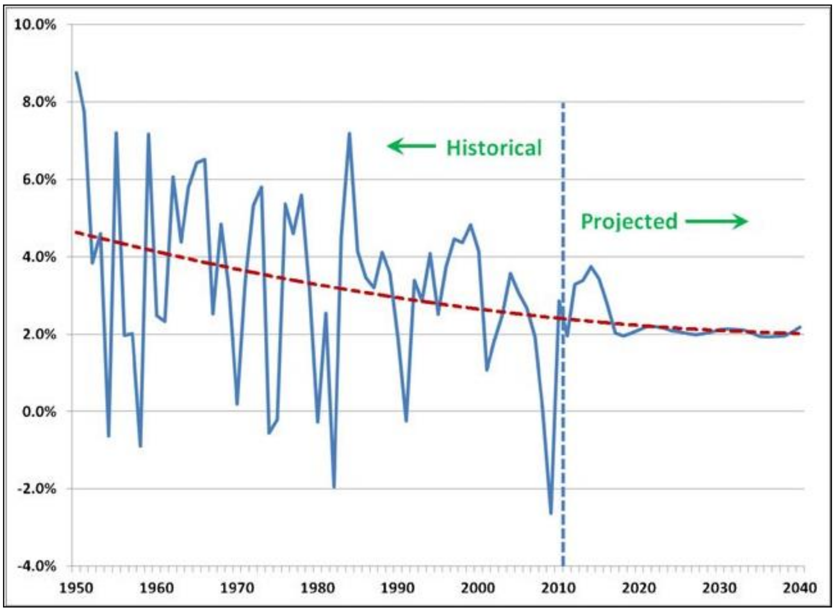

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Table 1 Varying energy intensity to shape both GDP and carbon emissions

Metric	Unit	(A) 1980	(B) 2012 ref case	(C) 2012 Policy One	(D) 2012 Policy Two
1. Gross domestic product	Billion 2005$	5,834	13,593 (2.7 %)	17,464 (3.5 %)	15,444 (3.1 %)
2. Energy intensity	kBtu/$GDP	13.4	7.0 (-2.0 %)	5.1 (−3.0 %)	5.1 (−3.0 %)
3. Carbon intensity	MMTCe/Quad	61.2	55.4 (-0.3 %)	44.4 (−1.0 %)	33.3 (−1.9 %)
4. Energy use	Quads	78.1	95.1 (0.6 %)	88.3 (0.4 %)	78.1 (0.0 %)
5. Carbon emissions	MMTCe	4,776	5,268 (0.3 %)	3,921 (−0.6 %)	2,601 (−1.9 %)

All of the values listed in parentheses for the three different 2012 outcomes are annual average percent changes compared to the initial data for that same own as shown in the 1980 column. Source: Author calculations based on Laitner (2013), AEC (1991), and Energy Innovations (1997)

Does a bigger economy mean more emissions?

We can ask a further question at this point. Would not a higher level of economic activity imply a greater use of energy and, therefore, a greater level of carbon emissions? We can devise a thought experiment to place the climate issue in the larger context of a more productive economy. Two things are helpful in setting it up. The first is an improved understanding of what we might call the economic recipe; that is, how the so-called factors of production—what economists refer to as capital, labor, and energy (more properly, exergy)—enable economic activity. While the current momentum and market structure tend to constrain any big or immediate changes, there is nothing in either physics or economics that says we cannot imagine or create a different recipe for the nation's economy. That is to say, we can vary the annual blend of new investments in our nation's equipment, buildings, structures and infrastructures (capital), our work activity (labor), and our choice in high-quality energy resources which enable work within the economy and the social environment (exergy).

The second useful element in setting up this particular thought experiment is data and prior analytical or economic model efforts that can inform the thought process. Fortunately, there are a large number of previous studies which have evaluated a range of energy efficiency improvements and their impacts on carbon emissions. Two significant studies include America's Energy Choices (AEC 1991) and the Energy Innovations (1997) reports. These two highly detailed assessments, sponsored by a consortium of nonprofit organizations and research groups, suggested that—with the right mix of policies and investments—it was economically possible to reduce the nation's total primary energy consumption by one half by the year 2030 compared to standard forecasts available at that time. Harvey (2010) provides an encyclopedic detail that further reinforces such prospects. In effect, these past assessments of long-term energy efficiency improvements envisioned the substitution of innovation and more productive capital as smart replacements for the inefficient use of energy. And Laitner (2013) provides an exercise which highlights the work potential of greater exergy efficiency as a means to boost to GDP. Table 1 summarizes the key elements of this thought experiment as it compares three different but entirely possible outcomes for the year 2012 for the US economy.[5]

In setting up the thought experiment, we can draw from three sets of data over the years, from 1980 (shown in Table 1 column A) with different outcomes in year 2012 (in columns B, C, and D). The first is GDP expressed in billions of 2005 dollars (data row 1). The second is energy use in quadrillion Btus or Quads (data row 4). The last (in data row 5) is energy-related carbon

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[5] The inadequate collection of data tracking energy as work, or exergy, forces us to turn to the more conventional EIA accounting at this point, even as we keep in mind that the complete accounting and conversion of exergy into useful work is the central idea behind this analysis. Also, greater rates of standard energy efficiency, by definition, will necessarily move us toward the kind of outcomes associated with greater rates of exergy efficiency.

emissions in metrics of metric tons equivalent (MMTCe). From these data, we can then construct both energy and carbon intensities. Energy intensity (data row 2) is expressed as thousands of Btus per dollar of economic activity or GDP (again expressed in real 2005 dollars). Carbon intensity (in data row 3) is a function of energy usage and so is expressed as million metric ton equivalent per quadrillion Btu. The year 1980 (column A) provides the historical starting point of our analysis. The year 2012 gives us the endpoint for three different outcomes (in columns B, C, and D) in our thought experiment.

Preliminary actual data for the year 2012, highlighted in column B labeled as 2012 ref case, indicates a 1980 economy (data row 1) that grew from $5,834 to 13,593 billion (column B). This reflects an economic expansion index of 2.3 times the level of GDP in 1980 (column B, data row 1), a 2.7 % annual rate of growth. At the same time, energy consumption, as conventionally measured (data row 4) by the more limited EIA dataset (Energy Information Administration 2012) grew from 78.1 quads in 1980 to 95.1 quads (an index of 1.2), while carbon emissions (data row 5) grew from 4,776 MMTCe to 5, 268 MMTCe (an index of 1.1). The good news is that both energy use and the resulting carbon emissions grew much more slowly than economic activity because of a significantly reduced energy intensity, with 13.4 kBtu/$GDP in 1980 dropping to nearly one half that value, or 7.0 kBtu/$GDP by 2012. This reflects a 2.0 % annual rate of decline. Because the economy grew more rapidly than the rate of improvement in energy and carbon intensities, total energy use and carbon emissions also increased—albeit at a much smaller rate. This helps frame the question, might we have done better; and if so, how would that shape both economic activity and energy and carbon emissions?

We can now pull in the key analytics from both the AEC (1991) and Energy Innovations (1997) studies to set up an array of outcomes that examine how the year 2012 might have looked from a variety of policy perspectives.[6] What is immediately interesting in Table 1 is that GDP can be enhanced even as both energy consumption and carbon emissions are substantially reduced.[7] In column C labeled 2012 Policy One, for instance, we make one change by reducing the nation's conventional energy to 5.1 kBtu/$GDP by 2012 (shaded in light blue as shown in the second data row of that table). So instead of a 2.0 % annual decline in the nation's energy intensity shown in the reference case, based on AEC (1991) and Energy Innovations (1997), we can extend that rate

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[6] Without providing an exhaustive literature review here, we can cite a variety of other studies suggesting large-scale investments that can positively impact the US economy. Among many others, see for example, AEF (2009), APS (2008), Carlsmith et al. (1990), Cleetus et al. (2009), Hanson et al. (2003), InterAcademy Council (2007), Interlaboratory Working Group (2000), Laitner (2009a, b), Lovins, Amory, and the Rocky Mountain Institute (2011), McKinsey (2009), and Von Weizäcker (2009). Perhaps not immediately obvious but these and other studies suggest that the marginal returns associated with greater levels of resource efficiency than for conventional energy supply.

[7] Also worth pointing out is the increasing discussion of GDP as a weak measure of social and economic well-being, a criticism with which I agree. See, for example, Daly and Cobb (1989), Kubiszewski et al. (2013), and Stiglitz et al. (2009). At the same time, however, this paper focuses on increasing energy or exergy efficiency as means to boost overall economic well-being while reducing both energy consumption and energy-related carbon emissions.

of decline to 3.0 % annually. The positive impact on GDP is significant, moving from an initial value of $13,593 billion in 2012 to $17,464 billion in the 2012 Policy One option.[13] At the same time, we can pull in more carbon-free energy resources to power the balance of needed useful work within the economy. In effect, we might increase the rate of decline in annual carbon intensity by 1.0 % (column C) rather than the reference case pace of 0.3 % (column B). The combined result reveals not only a stronger economy but significantly less energy used in 2012 (88.3 quads in column C) compared to the 1980 consumption level of 95.3quads. Even more important for this analysis is a very large reduction in carbon emissions so that the 2012 Policy One value of 3,921 MMTCe (column C) is actually less than the 1980 emission level of 4, 776 MMTCe.

We can continue the thought experiment by asking yet another question. Would it have been possible to forego some economic expansion and still have been better off economically—even as (1) conventional energy requirements remained at 1980 levels, and (2) carbon emissions were reduced even further below 1980 levels? These results are summarized in column D of Table 1, labeled 2012 Policy Two. If we assume that the energy intensity in data row 2 remains the same in column D as in column C, then we must reduce GDP to $15,444 billion (column D, data row 1, shaded in light blue for emphasis) to ensure the same energy level as reported in 1980. Note, however, that although we might give up some GDP in the 2012 Policy One (column C) scenario to reduce energy consumption, economic activity is still about 14 % above the actual historical value of $13,593 billion that was recorded for 2012 (column B). By reinvesting some of that foregone GDP into more expensive carbon-neutral energy resource, the carbon intensity of energy consumed might decline to 75 % of the 2012 Policy One scenario, declining to 33.3 MMTCe per quad (column D, data row 3, also shaded in light blue for emphasis). This just 60 % of the 2012 reference case (column B) which means that total energyrelated carbon emissions would have been one half of the 2012 the historical value and just 54 % of the 1980 starting value in this analysis (column A). In short, we have a still stronger economy even as energy use remains the same at in 1980 and carbon emissions are significantly lowered compared to 1980 values.

With the initial results of this thought experiment in mind, we have established several key insights that might inform the development of an immediate set of energy policies that positively impact both climate change and our now-lagging economy. First, the future economy does not necessarily require more energy than is being used today, or even yesterday. In fact, as documented in the American Council for an Energy-Efficient Economy (ACEEE) study on the Long -Term Energy

Efficiency Potential (Laitner et al. 2012), it is entirely possible to cut future energy consumption by half or more. Those findings, combined with the thought experiment reviewed here, suggest that, yes, we can achieve the multiple goals of a more resilient and stronger economy even as we dramatically reduce carbon emissions. And this can be done consistent with Hansen's judgment (2011) that we require a strategy which “leaves most of the fossil fuels in the ground.” The question now becomes one of whether a price-driven approach is the optimal way to proceed.

Price or non-pricing policies?

There is little serious doubt that climate change is real. Nor there is any real doubt that environmental price signals, fees, taxes, and incentive-based mechanisms in general can be a very effective means to affect the actions of consumers and firms. Price mechanisms also provide stim- many social differences and frictions, and the many positive and negative externalities,[8]the evidence suggests that many important choices of our society cannot adequately be coordinated by the price system alone (Laitner et al. 2000).

Consistent with Hanemann (2010), however, while it is essential that there be some form of a price signal to inform consumers and producers on the impact of pollution emissions, the evidence also suggests that stringent but flexible performance standards are equally necessary. Hanson et al. (2004) were perhaps the first to concretely compare the economic impacts of both price and non-price programs and policies. Among other things, they found total emission reductions are generally greater in an energy policy scenario that integrated both perspectives, especially in the later years of the scenario. Looking at the year 2050, for example, what they termed a moderate climate policy that include both price and non-price mechanisms showed carbon reductions of just over 40 % for a carbon price of $93/metric ton of carbon (MtC).[15] Using only the price signal to drive emissions reductions, they found that the same carbon price of $93/MtC would reduce emissions by only 16 %. Even a doubling of the carbon charge to $186/MtC reduced carbon emissions by only 27 % (Hanson et al. 2004). In effect, policies and programs greatly amplified the price signal. Conversely, policies and programs reduced the size of the price signal needed to achieve a given result.

The array of non-pricing programs

What might be the array of complementary programs that amplify the benefits of the price signal? Rogers et al. (2013) summarize the wide variety of programs to encourage improved energy efficiency within the US. These include programs operated by the federal government as well as states, utilities, municipalities, and even nonprofit organizations. Some of these programs are decades old, though many are more recent. The programs range from those which offer

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[8] Externalities are the incidental—often not inconsequential—effects that the transactions or activities of one party have on another party, or the impact from a decision to produce and consume by one group of actors may have on others outside that market decision. The tendency is to think of negative environmental impacts that might follow from a deci-

different financial incentives to those providing training and technical assistance to energy consumers. They also include the research and development of new technologies as well as performance standards and products testing. Efficiency standards, in particular, have played a major role in saving both energy and water in ways that significantly reduce utility bills.

A report by Mauer et al. (2013), they analyzed how the choices available to consumers have changed over time as efficiency standards have also changed. They then compare the performance, features, and prices of ten categories of consumer products available before and after each standard were implemented.[9] They found that as products have become more efficient, product performance generally stayed the same or improved, and manufacturers offered new features to consumers. Prices declined or stayed the same for five of the nine products for which price data were available, and for the other four products, observed price increases were outweighed by electricity bill savings. These and other ACEEE studies of the many energy efficiency appliance standards suggest that consumer choice, cost, and performance benefits tend to outweigh the costs.

Beyond these immediately obvious consumer products, opportunities exist for efficiency improvements in electricity generation, large-scale improvements in transportation, and through behavioral feedback mechanisms. A new study by Chittum and Farley (2013) explored the possibilities of expanding a family of technologies called combined heat and power (CHP). Currently, many industrial or large commercial applications may purchase electricity from one utility and then buy natural gas separately. The separate heat and power technologies might approach a 50 % system efficiency. CHP technologies, on the other hand, are systems that produce electricity and which also convert wasted thermal energy into either additional electricity or mechanical power and process heat. The current generation of these high-performance systems can operate at a combined efficiency of more than 80 %. CHP systems now provide about 12 % of our nation's electricity. Chittum and Farley (2013) suggest a program potential that might increase to more than 30 %.

According to ACEEE, the recent federal car and light truck fuel economy and greenhouse gas emissions standards for model years 2017 to 2025 will mean an 80 % increase in fuel economy for the average model year 2025.[10] Savings from reduced fuel consumption will pay back the higher vehicle costs in less than 4 years. The higher fuel economy standard will generate energy savings nationally of 3.1 million barrels of oil per day in 2030 (Langer 2012). The implication is

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[9] The ten categories of products included refrigerators, clothes washers, dishwashers, residential and commercial heat pumps and air conditioners, toilets, general service light bulbs, incandescent reflector lamps, fluorescent lamp ballasts, and refrigerator vending machines.

[10] This will effectively increase the 2011 Corporate Average Fuel Economy requirement for new cars from 27.6 miles per gallon to just over 50 miles per gallon.

that this one energy efficiency standard will save about 40 % of our oil production in 2030. Looking at a longer term, Laitner (2012) found that a combination of car, truck, train, and other systems improvements could reduce the nation's transportation energy needs by as much as 50 to 60 % by 2050. While higher prices would certainly help mover the economy toward greater fuel economy, it is the variety of programs and standards that drive these kinds of savings. Although the majority of programs focus on technology installations and investments, there are also a growing number of programs that encourage both conservation and efficiency improvements through behavioral and feedback mechanisms (Ehrhardt-Martinez, Karen and John A. “Skip” Laitner 2010; Laitner 2012).

Comparing emission prices and complementary energy efficiency programs

While the previous discussion provides an admittedly cursory overview, it seems clear that the potential energy efficiency savings are very large, and that some combination of technology deployment programs can go a very long way to save energy and cost-effectively reduce carbon emissions. Still, an extension of the earlier analysis by Hanson et al. (2004) might help frame a better set of policy questions for decision makers. Recent federal legislation offers a basis for that analysis. In June 2009, the US House of Representatives passed the Waxman–Markey climate and energy bill—also known as the American Clean Energy and Security Act, or more formally as House Resolution or H.R. 2454. [2].

While the Waxman–Markey bill did not move beyond the House Chamber, the legislation included important program provisions designed to build energy efficiency increases into some of the nation's investments in factories, buildings, homes, schools, and hospitals. Unfortunately, the economic benefits of those provisions promoting energy-efficiency investments, and the extent to which they could be strengthened to generate even more energy savings, were largely ignored or grossly underestimated by studies produced or funded by opponents of cap and trade legislation (Laitner 2009b). Analysts with the ACEEE evaluated the variety of costs and potential energy savings associated with that legislation. This provided the needed information to evaluate the cost and economic benefits of the bill using the DEEPER modeling system (Laitner 2009b).[11]

The DEEPER model was benchmarked to what was then the most current version of the Annual Energy Outlook published by Energy Information Administration (2009) with projections out to the year 2030. The time horizon was subsequently extended to 2050 using a variety of other data sources. The baseline scenario—assuming that no federal climate legislation were signed into law—suggested that the nation's energy consumption would increase by 8 % by 2030 and 28 %

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[11] DEEPER is the Dynamic Energy Efficiency Policy Evaluation Routine, a 15-sector quasi-dynamic input–output model that has been widely used for various state and national energy and climate policy assessments.

by 2050, and greenhouse gas emissions would grow 8 % by 2030 and 21 % by 2050. The assessment then evaluated three different policy scenarios, all designed to achieve a total 76 % reduction in total greenhouse gas emissions using a combination of cap and trade (thereby increasing the associated carbon prices over time) and a wide variety of technology deployment programs and performance standards.

Scenario 1 was climate legislation as it was actually passed by the House of Representatives. By 2030, this scenario would produce an average net energy spending reduction of $354 per household and an increase of nearly 425,000 jobs. By 2050, the job increase would grow to nearly 1.2 million. In addition to the basic technology deployment programs written into the bill, the analysis found that the carbon price (measured here as the cost in 2007 dollars per metric ton of carbon dioxide emission equivalent) would rise from about \$47/ tCO_2e in 2030 to \$239/tCO_2e in 2050.

Scenario 2 was the “improved” version of H.R. 2454 with a 50 % increase in energy efficiency programs. In this case, consumer energy costs would drop 23 % by 2030 and 21 % by 2050, nearly double the savings from the House-passed bill, and nearly three quarters of a million extra jobs would be created by 2030 with more than 2 million additional jobs created by 2050 (or nearly double the number of extra jobs that would be created by the House-passed legislation). In this scenario, carbon price would rise from about \$41/tCO_2e in 2030 to \$185/tCO_2e in 2050.[12]

Scenario 3 was then “further improved” with double the energy savings of the House-passed bill. Consumer energy costs, according to the analysis, would decline 27 % by 2030 and 32 % by 2050, nearly triple the savings from the Housepassed bill, and more than one million additional jobs would be created by 2030 with more than 2.5 million extra jobs created by 2050 (or more than double the additional jobs created by the House bill as it then was written). The scenario 3 carbon price would rise from about \$35/tCO_2e in 2030 to \$128/tCO_2e in 2050.

From this high-level overview of the three primary scenarios in the analysis of H.R. 2454, we can draw two can be done in ways that strengthen economic activity. This is true whether we are examining the possibility of lower total energy costs or net gains in employment. The second insight is that including a greater array of cost-effective programs can actually decrease the size of the carbon price necessary to reduce total emissions by 76 % of the baseline forecast for 2050. We can extend this analysis in perhaps a more useful way as we explore a series of sensitivity assessments to explore more closely the carbon price/energy program connection. The subsection that follows tackles that perspective.

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[12] –Markey bill because of

Hansen and others are critical of the Waxman its complexities, among other things. At almost 1,000 pages, that is a fair comment. As we shall see, however, it has so many cost-saving provisions that it turns out cheaper and better for the economy on the whole. Ideally, it could be streamlined while maintaining the larger objectives.

Table 2 Highlighting the impact of key scenario assumptions in 2050

	Case #1 Big tech—big price	Case #2 Big tech—little policy	Case #3 H.R. 2454 basic EE	Case #4 H.R. 2454 enhanced EE	Case #5 H.R. 2454 optimal EE	Case #6 H.R. 2454 optimal EE big behavior
Emissions price ($/tCO2e 2007$)	$1,839	$753	$239	$185	$128	$57
End-use energy savings	29 %	36 %	43 %	46 %	52 %	61 %
Energy price increase	316 %	144 %	52 %	38 %	24 %	10 %
Energy expenditure increase	195 %	56 %	−13 %	−26 %	−41 %	−57 %

A DEEPER review of energy efficiency impacts on carbon prices

Table 2 that follows provides a backdrop that might help us more fully appreciate the positive benefits that cost-effective energy efficiency programs might have on the carbon price necessary to achieve the steep greenhouse gas emissions reductions envisioned the Waxman–Markey legislation. In Table 2, we examine six different cases as the impact four variables. The first is the impact on the carbon charge while the next three are percent changes in energy savings, energy prices, and total energy expenditures. All percentages are from the 2050 reference case. The six cases that we review, as explained further, begin with a price only policy to drive down emissions—again by 76 % from the 2050 reference case. From there, we introduce different policy and programs assumption to ease the transition to a more robust and energyefficient economy.

With that backdrop, we might now observe in Table 2 two significant patterns starting with case #1—what is referred to as the "Big Tech–Big Price" scenario. In this example, we assume consumers will respond only to the highest of energy prices, and that there are no further efficiency programs beyond those now authorized; the modeling exercise would then suggest very high prices for CO_2 permits would be needed to bring overall greenhouse gas emissions down to the target levels. As a result, very little of the reductions occur from efficiency gains but, instead, are the result of very large and very expensive low- or no-carbon energy supply technologies (e.g., large nuclear plants or fossil fuel units with carbon capture systems). In fact, it is unlikely that this kind of scenario would actually occur since the very high prices would likely spur many new innovations and a changing pattern of consumer response. But this scenario also shows that, yes, any model can be designed to show highly negative impacts.

At the same time, as we move to case #2 with some additional energy efficiency programs now being incorporated into the climate policy, the emissions prices come down steeply although they are still at a very high level. Moving into the H.R. 2454 energy efficiency programs (case #3, #4, and #5), and showing a changed consumer response as concern about the climate problem becomes more widespread and as the programs make consumers and businesses more aware of cost-effective opportunities to save on their energy bills, the emissions prices continue to drop. Finally, in case #6, we can see that an optimal set of efficiency programs—delivering about twice the benefits as the current H.R. 2454 legislation now support—the emissions prices declines to a low of $57 dollars per metric of CO_2 equivalent. In effect, there are two big drivers in creating a highly net positive outcome from legislation like H.R. 2454.

The very first insight is that if cost-effective energy efficiency programs are delivered at a sufficient scale and over a sufficient period of time, that will reduce the need for a large price signal to drive the same magnitude of change compared to our first case. Second, a pronounced shift in consumer behavior can deliver a much larger willingness to adopt smart technologies—also without as large of a price signal.[13] With that backdrop, it becomes very clear that if climate policies can be designed to encourage greater investment in more productive technologies, then the economy as a whole can benefit. What is the bottom line from this part of the analysis? A smart approach to shaping future climate policy is one that encourages greater levels of conservation-oriented behaviors and energy efficiency investments while, at the same time, providing consumers and businesses with sufficient information and motivation to enable the integration of conservation and efficiency improvements more seamlessly into their homes, schools, and workplaces.

Critical policy steps for a more robust economy

The ideas advanced in this report challenge the much of the conventional accounting of energy consumption and climate change policies. Despite the enormous promise of existing technologies, and the even more productive ones yet to come, most of the economic assessments of climate change policies to date have tended to overlook the role of both conversation behaviors and productive investment in helping achieve the twin goals of a healthy economy and a healthy climate. As this study suggests, a productivity-enabled outcome would likely lower the kinds of price signals required to substantially reduced carbon missions over time. At the same time, the deployment of greater efficiency improvements are likely to lower overall energy costs for consumers even as they provide more job opportunities, not fewer.

The unwritten assumption in most modeling exercises is that controlling greenhouse gas emissions is all about cost containment rather than a smart redirection of investments toward the more productive use of people, resources, and technologies. This analysis and accompanying set of thought experiments is markedly different in that respect. It draws from both a consumer

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[13] In this case, for example, the assumption is that the implicit discount rate for consumers falls from 30 to 20 % over times. The changing preference—in effect suggesting that while consumers today might want a technology that, on average, pays for itself with energy bill savings over a 3.3-year period (or 1/0.30), but tomorrow (or sometime in the future and in response to growing concerns about the climate or worries about rising energy prices) may be happy with a technology that have a 5-year payback (or 1/0.20).

behavior and a productive investment-based perspective rather than a cost-constrained analysis, and it assumes imperfect markets and information flows that might be better informed through complementary policies that are embedded and expanded within the H.R. 2454 policy framework. It asks the question, how can we increase the robustness of the US economy while positively impacting the global climate even as we lower overall energy costs? The evidence suggests that new behaviors and smart technology investments can protect the climate and maintain a robust economy—if we choose to develop those associated opportunities. And if those choices are actively pursued, then we are more likely to avoid the climate and the economic storms of our grandchildren.

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