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EMPIRICALLY CONSTRAINED CLIMATE SENSITIVITY AND THE SOCIAL COST OF CARBON

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Integrated Assessment Models (IAMs) require parameterization of both economic and climatic processes. The latter includes Equilibrium Climate Sensitivity (ECS), or the temperature response to doubling CO_2 levels, and Ocean Heat Uptake (OHU) efficiency. ECS distributions in IAMs have been drawn from climate model runs that lack an empirical basis, and in Monte Carlo experiments may not be constrained to consistent OHU values. Empirical ECS estimates are now available, but have not yet been applied in IAMs. We incorporate a new estimate of the ECS distribution conditioned on observed OHU efficiency into two widely used IAMs. The resulting Social Cost of Carbon (SCC) estimates are much lower than those from models based on simulated ECS parameters. In the DICE model, the average SCC falls by approximately 40–50% depending on the discount rate, while in the FUND model the average SCC falls by over 80%. The span of estimates across discount rates also shrinks substantially.

Keywords: Social cost of carbon; climate sensitivity; ocean heat uptake; carbon taxes; integrated assessment models.

1. Introduction

Integrated Assessment Models (IAMs) emerged in the 1990s and have become central to the analysis of global climate policy, especially for estimating the Social Cost of Carbon (SCC)[1] or the marginal damages of an additional unit of carbon dioxide (CO_2) emissions. A particularly influential application has been through the US InterAgency Working Group (IWG, 2010, 2013) which estimated SCC rates for use in US climate and energy regulations. IAMs operate at a high level of abstraction and require extensive

[1]Various reviews of IAMs exist, each highlighting or criticizing different aspects, such as Parson and Fisher-Vanden (1997), Stanton *et al.* (2009) and Pindyck (2013).

parameterization of both climatic and economic processes. Among the economic parameters, the most influential are the discount rate and the coefficients of the damages function (Marten, 2011). A key climate parameter is Equilibrium Climate Sensitivity (ECS), which represents the long term temperature change from doubling atmospheric CO_2, after allowing sufficient time for the deep ocean to respond to surface warming. It is either included explicitly or implicitly in the IAM functions determining temperature responses to CO_2 accumulation.

Optimal SCC estimates depend strongly on the damage function, which in turn is strongly influenced by ECS (e.g., Webster *et al.*, 2008; Ackerman *et al.*, 2010; Wouter Botzen and vanden Bergh, 2012). ECS uncertainty has multiple dimensions, beginning with the wide range of point estimates within the major IAMs (van Vuuren it *et al.*, 2011). The interaction between ECS and ocean heat uptake (OHU) efficiency is an important but largely overlooked source of uncertainty because it affects the time-to-equilibrium which affects SCC estimates via the role of discounting (Roe and Bauman, 2013). A number of authors have studied how quickly ECS uncertainty may be reduced over time via Bayesian learning as new information become available (Kelly and Kolstad, 1999; Leach, 2007). Interestingly, Webster *et al.* (2008) find that learning is slowest in the low ECS case while Urban it *et al.* (2014) find it slowest in the high ECS case, with the difference being due to the role of OHU efficiency.[2]

IWG (2010, 2013) represented ECS uncertainty by modifying three standard IAMs[3] to include a Probability Density Function (PDF) parameterized to fit a range of estimates from climate modeling simulations, which then gave rise to a distribution of marginal damages. The choice of ECS distribution can strongly influence the average SCC if it has a large upper tail, which pulls up both the median and mean values. The IWG used a PDF from Roe and Baker (2007, herein RB07) which does have a long upper tail. RB07 was an exploration of why uncertainties over ECS have not been reduced despite decades of effort, with the explanation centering on the amplified effect of uncertainties in the value of the climate feedback parameter f on final temperatures, due to its position in the denominator of the equation for ECS. To illustrate the point they fitted a curve to a small selection of ECS estimates published between 2003 and 2007, yielding an ECS curve that had a long upper tail even though there was no unbounded source of uncertainty in the underlying model.

The reliance by IWG on RB07 is questionable for two reasons. First, as Roe and Bauman (2013) pointed out, the distribution in RB07 was not directly applicable in the context of IAM simulations because the wideness of the tails is a function of the time span to equilibrium, which depends heavily on the assumed OHU efficiency, and the

[2]The representation of uncertainty itself can introduce uncertainty. Crost and Traeger (2013) argue that averaging Monte Carlo runs of deterministic models rather than using a Stochastic Dynamic Programming (SDP) framework yields inaccurate and potentially incoherent results. But Traeger (2014) finds that applying SDP in the DICE framework causes problems of dimensionality which necessitate introducing new simplifications elsewhere, including in the representation of OHU efficiency.

[3]The three IAMs are called DICE (Nordhaus, 1993), FUND (Tol, 1997) and PAGE (Hope, 2006).

time span associated with the fat upper tail is not relevant to SCC calculations. In the real world, CO_2 doubling is not instantaneous, the transition to a new equilibrium state is exceedingly slow, and the oceans absorb huge amounts of heat along the way depending on OHU efficiency. In simplified climate models, time-to-equilibrium increases with the square of ECS, so an upward adjustment of the ECS parameter outside the range consistent with the assumed OHU efficiency parameter can yield distorted present value damage estimates. In particular, the higher the ECS, the slower the adjustment process, making the fat upper tail of realized warming physically impossible for even 1000 years into the future (Roe and Bauman, 2013, p. 653). An ECS distribution applicable to the real world must therefore be conditioned on a realistic OHU efficiency estimate.

Second, RB07 predated a large literature on empirical ECS estimation. As was common at the time, they fitted a distribution to a small number of simulated ECS distributions derived from climate models. It is only relatively recently that sufficiently long and detailed observational data sets have been produced to allow direct estimation of ECS using empirical energy balance models. A large number of studies have appeared since 2010 estimating ECS on long term climatic data (Otto *et al.*, 2013; Ring *et al.*, 2012; Aldrin *et al.*, 2012; Lewis, 2013; Lewis and Curry, 2015; Schwartz, 2012; Skeie *et al.*, 2014; Lewis, 2016). This literature has consistently yielded median ECS values near or even below the low end of the range taken from climate model studies. General Circulation Models (GCMs) historically yielded sensitivities in the range of 2.0–4.5°C, and (based largely on GCMs) RB07 yields a central 90% range of 1.72–7.14°C with a median of 3.0°C and a mean of 3.5°C (see comparison table in IWG, 2010, p. 13). But the median of recent empirical estimates has generally been between 1.5°C and 2.0°C, with 95% uncertainty bounds below the RB07 average.

This inconsistency has attracted growing attention in the climatology literature (Kummer and Dessler, 2014; Marvel *et al.*, 2015). It is also discussed in the documentation for Nordhaus' DICE model[4] where it is cited as a reason for a slight downward revision in the ECS parameter. However, that change was based on early evidence published prior to 2008, whereas all the studies discussed herein were published after 2010.

For the most part, however, the inconsistency between empirical and model-simulated ECS estimates has been ignored in the climate economics literature. But, as we will show herein, it has potentially massive policy implications. We replicate the IWG's SCC estimates using the EPA's modified versions of two IAMs (FUND and DICE),[5] then we re-do the calculations using an observational ECS distribution from a recent study (Lewis and Curry, 2015, herein LC15) that controls for observed OHU efficiency, thereby yielding an empirically constrained climate sensitivity distribution. The resulting SCC values drop dramatically compared to those reported in the IWG (2010, 2013). Using DICE with the model-based RB07 ECS distribution at a 3% discount rate yields a mean SCC for the year 2020 of $37.79, in line with the

[4] See http//aida.wss.yale.edu/~nordhaus/homepage/documents/DICE_Manual_100413r1.pdf, pp. 17–18.
[5] We did not use a third model, PAGE, because its code is unavailable for independent usage.

IWG estimates that currently guide US policymaking. Substituting the empirical ECS distribution from LC15 yields a mean 2020 SCC of \$19.66, a drop of 48%. The same exercise using FUND yields a mean SCC estimate of \$19.33 based on RB07 and \$3.33 based on the LC15 parameters — an 83% decline. Furthermore, the probability of a negative SCC (implying CO_2 emissions are a positive externality) jumps dramatically using an empirical ECS distribution. Using the FUND model, which allows for productivity gains in agricultural and forestry from higher temperatures and elevated CO_2, under the RB07 parameterization at a 3% discount rate there is only about a 10% chance of a negative SCC through 2050, but using the LC15 distribution, the probability of a negative SCC jumps to about 40%. Remarkably, in the FUND model, replacing simulated climate sensitivity values with an empirical distribution calls into question whether CO_2 is even a negative externality. The lower SCC values also cluster more closely together across different discount rates, diminishing the importance of this parameter.

We chose the LC15 distribution of ECS because of its explicit treatment of OHU efficiency. A higher value of OHU efficiency implies more heat has been sequestered in the oceans over the past century and hence a greater divergence between the historical surface climate record and the total amount of warming that will ultimately occur (Roe and Bauman, 2013). Consequently, estimates of ECS for use in real-world policy simulations need to take into account information on OHU efficiency as well as CO_2 forcing and temperature records. This is the approach taken in LC15. They used the 1750–2011 forcing and OHU estimates from the then-most recent IPCC report (IPCC, 2013), yielding a median ECS of 1.64°C and a 5–95% uncertainty range of 1.05–4.05°C. This is in line with empirical estimates from Otto *et al.* (2013), Ring *et al.* (2012), Aldrin *et al.* (2012) and Lewis (2013), but is in clear contrast to the IWG parameterization using RB07. The central value in LC15 falls below the 5% lower bound of the ECS distribution used in IWG (2010, 2013). Not surprisingly, this implies that the corresponding SCC estimates form a lower and tighter distribution.[6]

2. SCC Calculations Using Empirical Parameters

We obtained the code for DICE and FUND[7] as used for the IWG (2010, 2013) studies from the US Environmental Protection Agency. We first replicated the SCC estimates that would have been used in IWG (2013) from both the DICE and FUND models

[6]The distinction is not strictly between empirical and model-simulated estimates. The RB07 distribution is derived from a simple feedback model fitted to model-derived ECS distributions and so is reasonably labeled 'simulated'. But the LC15 estimate relies on observational as well as some model-generated data, since forcing series are not directly observable and must be simulated. For simplicity however we refer to it as an empirical estimate since it is based on and constrained by observations as much as is feasible.

[7]Model authors' source code is available at http//www.econ.yale.edu/∼nordhaus/homepage/(DICE) and http:www.fund-model.org/(FUND). We are grateful to the EPA for providing us with the MATLAB code they used which contains the modifications for the IWG analysis.

Table 1. Replication of IWG (2013) SCC estimates for DICE and FUND models for 2020, under three discount rate assumptions. Replications done herein denoted "Repl".

	2.5%		3.0%		5.0%	
	IWG	Repl	IWG	Repl	IWG	Repl
DICE	$57	$57	$38	$38	$12	$12
FUND	$33	$33	$19	$19	$3	$3

based on the RB07 ECS distribution. The damage paths are contingent on the emissions scenarios so five scenarios are used and the results are averaged.[8] As we did not include the PAGE model in our work (due to the unavailability of the code) we cannot directly compare our results with the IWG tables since they are averaged over all three models. Table A5 in IWG (2013) lists separate results for FUND and DICE for 2020 and we were able to check our results against those. Table 1 shows the DICE and FUND SCC estimates for 2020 compared with our replications ("Repl") for three discount rates, demonstrating that we have statistically reproduced the IWG results.

2.1. *DICE model*

Table 2 shows the mean SCC estimates for four discount rates, applying the RB07 and LC15 ECS distribution to the DICE model. The final row shows the percentage change for the 2020 estimates (all years exhibit about the same percentage changes). Under the widely used RB07 distribution, the SCC ranges from $4.02 to $87.70 depending on the

Table 2. Mean SCC estimates by year under four discount rates from the DICE model, for both the simulated (RB07) and empirical (LC15) ECS distributions. Last row shows the percent change as of 2020.

Discount rates	Mean SCC–DICE model							
	Using simulated ECS				Using empirical ECS			
	2.50%	3.00%	5.00%	7.00%	2.50%	3.00%	5.00%	7.00%
2010	$46.58	$30.04	$8.81	$4.02	$23.62	$15.62	$5.03	$2.48
2020	$56.92	$37.79	$12.10	$5.87	$28.92	$19.66	$6.86	$3.57
2030	$66.53	$45.15	$15.33	$7.70	$33.95	$23.56	$8.67	$4.65
2040	$76.96	$53.26	$19.02	$9.85	$39.47	$27.88	$10.74	$5.91
2050	$87.70	$61.72	$23.06	$12.25	$45.34	$32.51	$13.03	$7.32
% Chg at 2020					−49.2%	−48.0%	−43.3%	−39.2%

[8]The scenarios are called Image, Merge Optimistic, Message, MiniCAM and 5th Scenario. Four of the five are business-as-usual scenarios ending in CO_2 concentrations between 612 and 889 parts per million. The fifth is based either on an assumption of aggressive policy measures or more optimistic assumptions about technological change that yield an ending concentration of 550 parts per million. See http://sites.nationalacademies.org/cs/groups/dbassesite/documents/webpage/dbasse_169500.pdf p. 8.

Table 3. Average standard deviation of SCC estimates by year under four discount rates from the DICE model, for both the simulated (RB07) and empirical (LC15) ECS distributions. Last row shows the percent change as of 2020.

Discount rates	Average standard deviation–DICE model							
	Using simulated ECS				Using empirical ECS			
	2.50%	3.00%	5.00%	7.00%	2.50%	3.00%	5.00%	7.00%
2010	\$25.91	\$15.01	\$3.30	\$1.19	\$19.18	\$11.54	\$2.78	\$1.12
2020	\$31.51	\$18.91	\$4.62	\$1.81	\$23.48	\$14.56	\$3.84	\$1.67
2030	\$37.01	\$22.90	\$6.03	\$2.50	\$27.63	\$17.52	\$4.90	\$2.23
2040	\$42.83	\$27.44	\$7.77	\$3.40	\$32.32	\$20.81	\$6.11	\$2.92
2050	\$46.31	\$30.12	\$9.33	\$4.25	\$36.83	\$23.98	\$7.46	\$3.64
% Chg at 2020					−25.5%	−23.0%	−16.9%	−7.8%

discount rate and the future year. Under the LC15 parameter distributions the SCC ranges from \$2.48 to \$45.34. For the year 2020 the largest proportional drop — nearly 50% — is observed in the low discount rate case. The high discount rate case yields a drop of just under 40%.

These reductions are primarily due to the LC15 distribution containing a smaller upper tail and therefore greater probability mass at lower temperatures. Table 3 shows the average standard deviations of the two sets of estimates. The largest reduction, slightly over 25%, again occurs at the lowest discount rate, compared to only 7% at the highest discount rate. The LC15 distribution provides uniformly more certainty for the SCC for all years and all discount rates. These results are in line with previous research performing similar computations by applying the Otto *et al.* (2013) ECS distribution in the DICE model (Dayaratna and Kreutzer, 2013).

2.2. *Fund model*

Tables 4 and 5 present the same results as Tables 2 and 3, but for the FUND model. A number of differences are notable. The mean SCC estimates are lower under both parameterizations, and under the empirical LC15 coefficients they are, on average, mostly negative at 5% or higher discount rates out past 2030. A negative value implies that carbon dioxide emissions are a positive externality, so that an optimal policy would require subsidizing emissions. Also, in contrast to the DICE model, use of the LC15 coefficients increases the average standard deviation, indicating higher uncertainty compared to the RB07 case.[9] The increased uncertainty includes a much larger lower tail, implying a larger probability of a negative SCC. DICE is constrained to a transformed quadratic global damage function such that damages cannot be negative

[9]ECS is the only stochastic parameter in DICE so the reduction in variance between RB07 and LC15 leads automatically to a corresponding reduction in the SCC variance. By contrast, dozens of parameters in FUND are stochastic so reduction in the mean and variance of ECS interacts in a more complex way with the rest of the model. The net effect, as shown is to increase the spread of SCC estimates.

Table 4. Mean SCC estimates by year under four discount rates from the FUND model, for both the simulated (RB07) and empirical (LC15) ECS distributions. Last row shows the percent change as of 2020.

Discount rates	Mean SCC–FUND model							
	Using simulated ECS				Using empirical ECS			
	2.50%	3.00%	5.00%	7.00%	2.50%	3.00%	5.00%	7.00%
2010	\$29.69	\$16.98	\$1.87	−\$0.53	\$5.25	\$2.78	−\$0.65	−\$1.12
2020	\$32.90	\$19.33	\$2.54	−\$0.37	\$5.86	\$3.33	−\$0.47	−\$1.10
2030	\$36.16	\$21.78	\$3.31	−\$0.13	\$6.45	\$3.90	−\$0.19	−\$1.01
2040	\$39.53	\$24.36	\$4.21	\$0.19	\$7.02	\$4.49	−\$0.18	−\$0.82
2050	\$42.98	\$27.06	\$5.25	\$0.63	\$7.53	\$5.09	\$0.64	−\$0.53
% Chg at 2020					−82.2%	−82.8%	−118.5%	−197.3%[a]

[a]Change from −\$0.37 to −\$1.10 is, arithmetically, a positive number, but is shown here as negative to indicate that it is a change to a larger negative magnitude.

Table 5. Average standard deviation of SCC estimates by year under four discount rates from the FUND model, for both the simulated (RB07) and empirical (LC15) ECS distributions. Last row shows the percent change as of 2020.

Discount rates	Average standard deviation – FUND model							
	Using simulated ECS				Using empirical ECS			
	2.50%	3.00%	5.00%	7.00%	2.50%	3.00%	5.00%	7.00%
2010	\$64.24	\$31.45	\$5.19	\$2.24	\$67.60	\$42.54	\$8.07	\$2.52
2020	\$70.66	\$35.68	\$6.28	\$2.79	\$80.17	\$52.61	\$11.27	\$3.51
2030	\$77.28	\$40.24	\$7.48	\$3.40	\$93.86	\$64.26	\$15.69	\$5.02
2040	\$84.05	\$45.14	\$8.78	\$4.05	\$108.03	\$77.23	\$21.75	\$7.37
2050	\$90.75	\$50.31	\$10.22	\$4.76	\$121.20	\$90.55	\$29.76	\$11.04
% Chg at 2020					+13.5%	+47.4%	+71.2%	+25.8%

regardless of temperature change. FUND allows the gains for regions that benefit from moderate warming to potentially outweigh the costs in other regions so some scenarios can yield negative net costs at the global level. Table 6 shows that, under the RB07 parameterization, at a 2.5% discount rate the probability of carbon dioxide emissions being a positive externality is only 7.1% in 2050. But using the LC15 parameters this probability jumps to over 35%.

Figure 1 shows normalized histograms of SCC calculations for the Merge Optimistic scenario at 2.5% discounting as of 2030. The height of each bar represents the probability of choosing an observation within a particular bin interval, and the sum of the heights across all of the bars is equal to 1. The bin width for RB07 is 5, the bin width of LC15 is 3. Comparing the top and bottom panels we see that model simulation of ECS introduces uncertainty not found in observations by creating an extended upper tail.

Table 6. Probability of a negative SCC under four discount rates in the FUND model.

Discount rates	Probability of negative SCC – FUND model							
	Using simulated ECS				Using empirical ECS			
	2.50%	3.00%	5.00%	7.00%	2.50%	3.00%	5.00%	7.00%
2010	0.087	0.121	0.372	0.642	0.416	0.450	0.601	0.730
2020	0.084	0.115	0.344	0.601	0.402	0.432	0.570	0.690
2030	0.080	0.108	0.312	0.555	0.388	0.414	0.536	0.646
2040	0.075	0.101	0.282	0.507	0.371	0.394	0.496	0.597
2050	0.071	0.093	0.251	0.455	0.354	0.372	0.456	0.542

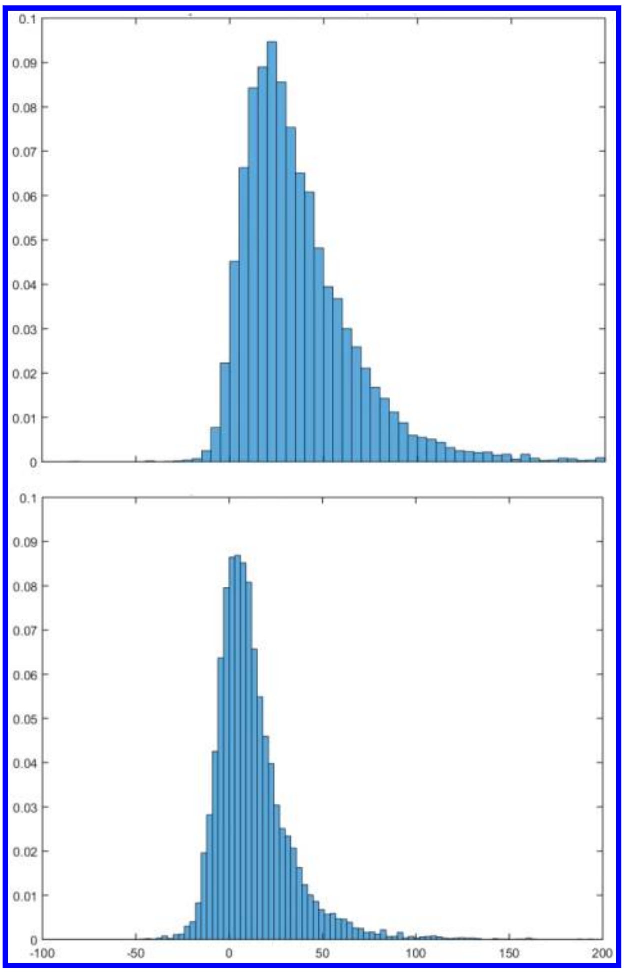

Figure 1. Frequency histograms of SCC computations in FUND under different ECS distributional assumptions. Top panel: Using MERGE 'Optimistic' scenario with 2.5% discount rate, as of 2030, SCC rate on horizontal axis and number of times observed on vertical axis, ECS follows Roe–Baker (2007) distribution. Bottom panel: same but ECS follows Lewis–Curry (2015) distribution.

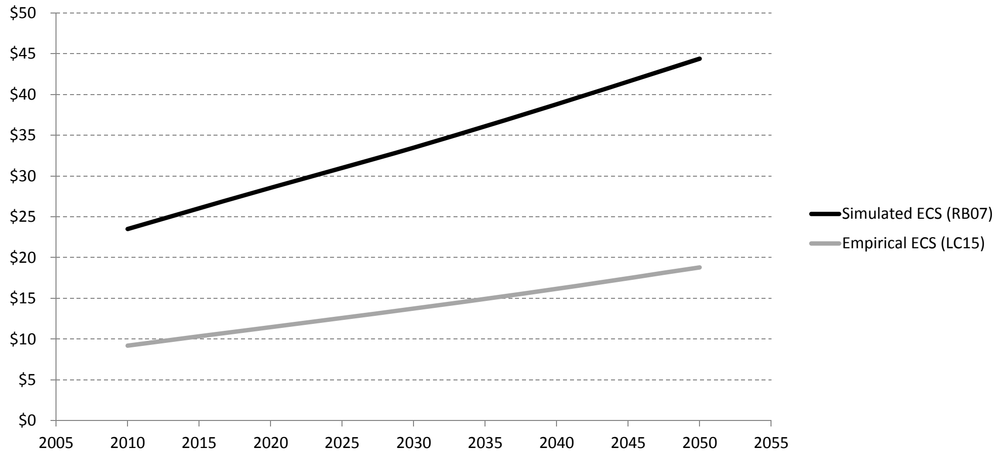

Figure 2. SCC Estimates, 2010–2050, average of DICE and FUND models applying a 3% discount rate. Top (black) line using simulated ECS parameter distribution. Bottom (gray) line using empirical ECS parameter distribution.

These results are in line with previous simulations using other ECS distributions that have smaller upper tails than RB07, namely Otto *et al.* (2013) and Lewis (2013); see Dayaratna and Kreutzer (2013). Figure 2 summarizes the calculations by comparing the mean of DICE- and FUND-computed SCC values from 2010 to 2050 at a 3% discount rate using the simulated (black, upper line) and the empirical (gray, lower line) ECS values. As of 2050 the empirically constrained value ($18.80) is still below the 2010 value ($23.51) based on simulated ECS.

3. Discussion and Conclusion

IAMs play an important role in climate policy analysis. They rely on a number of influential parameter choices, such as ECS. Model-based ECS distributions are misleading for use in SCC calculations because they are not conditioned on OHU efficiency rates relevant to IAM timelines and because they are skewed upwards relative to the current empirical evidence. The model-observational discrepancy in ECS estimation is not attributable simply to a specific empirical methodology, as similar results have been found by Otto *et al.* (2013), Ring *et al.* (2012), Aldrin *et al.* (2012) and others using a variety of methods. Nor is it an artifact of selecting a specific estimation period, as LC15 showed their results were robust to numerous variations on the choice of base and final periods (LC15, Table 4).

We incorporated the Lewis and Curry (2015) ECS distribution, which is conditioned on updated forcings and OHU data, into the DICE and FUND models. This reduces the estimated SCC in both, regardless of discount rates. Using a 3% discount rate and the RB07 ECS distribution, DICE yields an average SCC ranging from about $30 to $60 between now and 2050, but this falls to the $15 to $33 range using the

LC15 ECS estimate. The corresponding average SCC in FUND falls from the $17 to $27 range to the $3 to $5 range. Moreover, FUND which takes more explicit account of potential regional benefits from CO_2 fertilization and increased agricultural productivity yields a substantial (about 40%) probability of a negative SCC through the first half of the 21st century, putting into question whether CO_2 emissions are even a social cost.

A further way in which use of empirically constrained parameters reduces uncertainty is the shrinking of the SCC range across discount rates. In the DICE model under the RB07 parameterization, the mean SCC estimates span over $45 as of 2010 depending on choice of discount rate, with the span rising to over $85 as of 2050. This span shrinks to the $23 to $64 range under the LC15 parameterization. Using the FUND model, the uncertainty range associated with the choice of discount rate is from about $30 to $43 under the RB07 parameterization, falling to $5 to $8 range under the LC15 parameterization. Thus, use of well-constrained empirical parameters makes a substantial contribution also to reducing uncertainty associated with the choice of discount rate.

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References

Ackerman, F, AA Stanton and R Bueno (2010). Fat tails, exponents, extreme uncertainty: Simulating catastrophe in DICE. *Ecological Economics*, 69, 1657–1665.

Aldrin, M, M Holden, P Guttorp, RB Skeie, G Myhre and TK Berntsen (2012). Bayesian estimation of climate sensitivity based on a simple climate model fitted to observations of hemispheric temperatures and global ocean heat content. *Environmetrics*, 23, 253–271.

Crost, B and CP Traeger (2013). Optimal Climate Policy: Uncertainty versus Monte Carlo. *Economics Letters*, 120, 552–558.

Dayaratna, K and D Kreutzer (2013). Loaded DICE: An EPA model not ready for the big game. Heritage Foundation Center for Data Analysis Backgrounder No. 2860, Washington DC, 21 November. Available at http://report.heritage.org/bg2860.

Dayaratna, K and D Kreutzer (2014). Unfounded FUND: Another EPA model not ready for the big game. Heritage Foundation Center for Data Analysis Backgrounder No. 2897, Washington DC, 29 April. Available at http://report.heritage.org/bg2897.

Hope, C (2006). The marginal impact of CO2 from PAGE2002: An integrated assessment model incorporating the IPCC's five reasons for concern. *The Integrated Assessment Journal*, 6(1), 19–56.

Intergovernmental Panel on Climate Change (IPCC) (2013). *Climate Change 2013: The Physical Science Basis. Working Group I Contribution to the Fourth Assessment Report of the IPCC*. Cambridge: Cambridge University Press.

▶Kelly, DL and CD Kolstad (1999). Bayesian learning, growth, and pollution. *Journal of Economic Dynamics and Control*, 23(4), 491–518.

▶Kiehl, JT (2007). Twentieth century climate model response and climate sensitivity. *Geophysical Research Letters*, 34, L22710, doi: 10.1029/2007GL031383.

Kummer, JR and AE Dessler (2014). The impact of forcing efficacy on the equilibrium climate sensitivity. *Geophysical Research Letters*, doi: 10.1002/2014GL060046.

▶Leach, AJ (2007). The climate change learning curve. *Journal of Economic Dynamics and Control*, 31(5), 1728–1752.

Lewis, N and JA Curry (2015). The implications for climate sensitivity of AR5 forcing and heat uptake estimates. *Climate Dynamics*, doi: 10.1007/s00382-014-2342-y.

▶Lewis, N (2013). An objective Bayesian, improved approach for applying optimal fingerprint techniques to estimate climate sensitivity. *Journal of Climate*, 26, 7414–7429.

▶Lewis, N (2016). Implications of recent multimodel attribution studies for climate sensitivity. *Climate Dynamics*, 46(5), 1387–1396.

Marten, AL (2011). Transient temperature response modeling in IAMs: The effects of over simplification on the SCC. *Economics E-Journal*, 5(2011-18). Available at http://dx.doi.org/10.5018/economics-ejournal.ja.2011-18.

Marvel, K, GA Schmidt, RL Miller and LS Nazarenko (2015). Implications for climate sensitivity from the response to individual forcings. *Nature Climate Change*, doi: 10.1038/NCLIMATE2888.

Marvel, K, GA Schmidt, RL Miller and LS Nazarenko (2016). Online correction to: Implications for climate sensitivity from the response to individual forcings. *Nature Climate Change*. Available at http://www.nature.com/nclimate/journal/vaop/ncurrent/full/nclimate2888.html#correction1. Accessed on 14 March 2016.

Nordhaus, W (1993). Optimal greenhouse-gas reductions and tax policy in the "DICE" model. *American Economic Review*, 83(2), 313–317.

Nordhaus, W and P Sztorc (2013). DICE 2013R: Introduction and User's Manual. Yale University. Available at http://aida.wss.yale.edu/∼nordhaus/homepage/documents/DICE_Manual_100413r1.pdf.

▶Otto, A, FEL Otto, MR Allen, O Boucher, J Church, G Hegerl, PM Forster, NP Gillett, J Gregory, GC Johnson, R Knutti, U Lohmann, N Lewis, J Marotzke, B Stevens, G Myhre and D Shindell (2013). Energy budget constraints on climate response. *Nature Geoscience*, 6, 415–416.

▶Parson, EA and K Fisher-Vanden (1997). Integrated assessment models of global climate change. *Annual Review of Energy and the Environment*, 22, 589—628.

▶Pindyck, RS (2013). Climate change policy: What do the models tell us? *Journal of Economic Literature*, 51(3), 860–872. Available at http://dx.doi.org/10.1257/jel.51.3.860.

▶Ring, MJ, D Lindner, EF Cross and ME Schlesinger (2012). Causes of the global warming observed since the 19th century. *Atmospheric and Climate Sciences*, 2, 401–415.

▶Roe, GH and MB Baker (2007). Why is climate sensitivity so unpredictable? *Science*, 318 (5850), 629–632.

▶Roe, GH and Y Bauman (2013). Climate sensitivity: Should the climate tail wag the policy dog? *Climatic Change*, 117, 647–662, doi: 10.1007/s10584-012-0582-6.

▶Schwartz, SE (2012). Determination of Earth's transient and equilibrium climate sensitivities from observations over the twentieth century: Strong dependence on assumed forcing. *Surveys in Geophysics*, 33(3–4), 745–777.

▶Skeie, RB, T Berntsen, M Aldrin, M Holden and G Myhre (2014). A lower and more constrained estimate of climate sensitivity using updated observations and detailed radiative forcing time series. *Earth System Dynamics*, 5, 139–175, doi: 10.5194/esd-5-139-2014.

Stanton, E, F Ackerman and S Kartha (2009). Inside the integrated assessment models: Four issues in climate economics. *Climate and Development*, 1(2), 166–184.

Tol, RSJ (1997). On the optimal control of carbon dioxide emissions: An application of FUND. *Environmental Modeling and Assessment*, 2, 151–163.

Traeger, CP (2014). A 4-stated DICE: Quantitatively addressing uncertainty effects in climate change. *Environmental and Resource Economics*, 59, 1–37.

Urban, NM, PB Holden, NR Edwards, RL Sriver and K Keller (2014). Historical and future learning about climate sensitivity. *Geophysical Research Letters*, 41, 2543–2552, doi: 10.1002/2014GL059484.

US Interagency Working Group on Social Cost of Carbon (IWG) (2013). Technical Support Document: Technical update of the social cost of carbon for regulatory impact analysis Under Executive Order 12866. United States Government.

US Interagency Working Group on Social Cost of Carbon (IWG) (2010). Social Cost of Carbon for Regulatory Impact Analysis under Executive Order 12866. United States Government. Available at http://www.whitehouse.gov/sites/default/files/omb/inforeg/for-agencies/Social-Cost-of-Carbon-for-RIA.pdf.

van Vuuren, D, J Lowe, E Stehfest, L Gohar, A Hof, C Hope, R Warren, M Meinshausen and G Plattner (2011). How well do integrated assessment models simulate climate change?*Climatic Change*, 104(2), 255–285.

Webster, M, L Jakobovits and J Norton (2008). Learning about climate change and implications for near-term policy. *Climatic Change*, 89, 67–85, doi: 10.1007/s10584-008-9406-0.

Wouter Botzen, WJ and JCJM van den Bergh (2012). How sensitive is Nordhaus to Weitzman? Climate policy in DICE with an alternative damage function. *Economics Letters*, 117, 372–374.

CO2, The Economy, and The Climate

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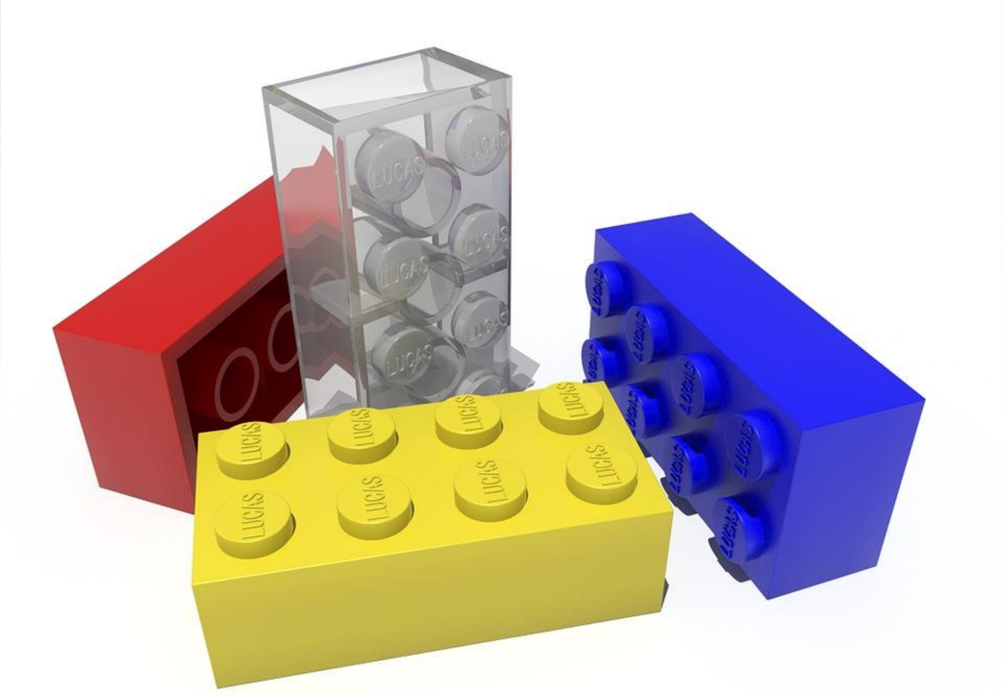
Pennsylvania CO2 and Climate | Pennsylvania House Environmental Resources & Energy Committee
Harrisburg, PA | October 28, 2019

Energy:
The Fundamental Building Block of Civilization



What have we heard over the years?

- The climate is changing
- CO_2 and other GHGs contribute significantly
- Action must be taken

What solutions were proposed?

- Cap & Trade
- Clean Power Plan
- Paris Agreement
- Green New Deal
- State level initatives

What are these policies predicated on?

The Social Cost of Carbon …

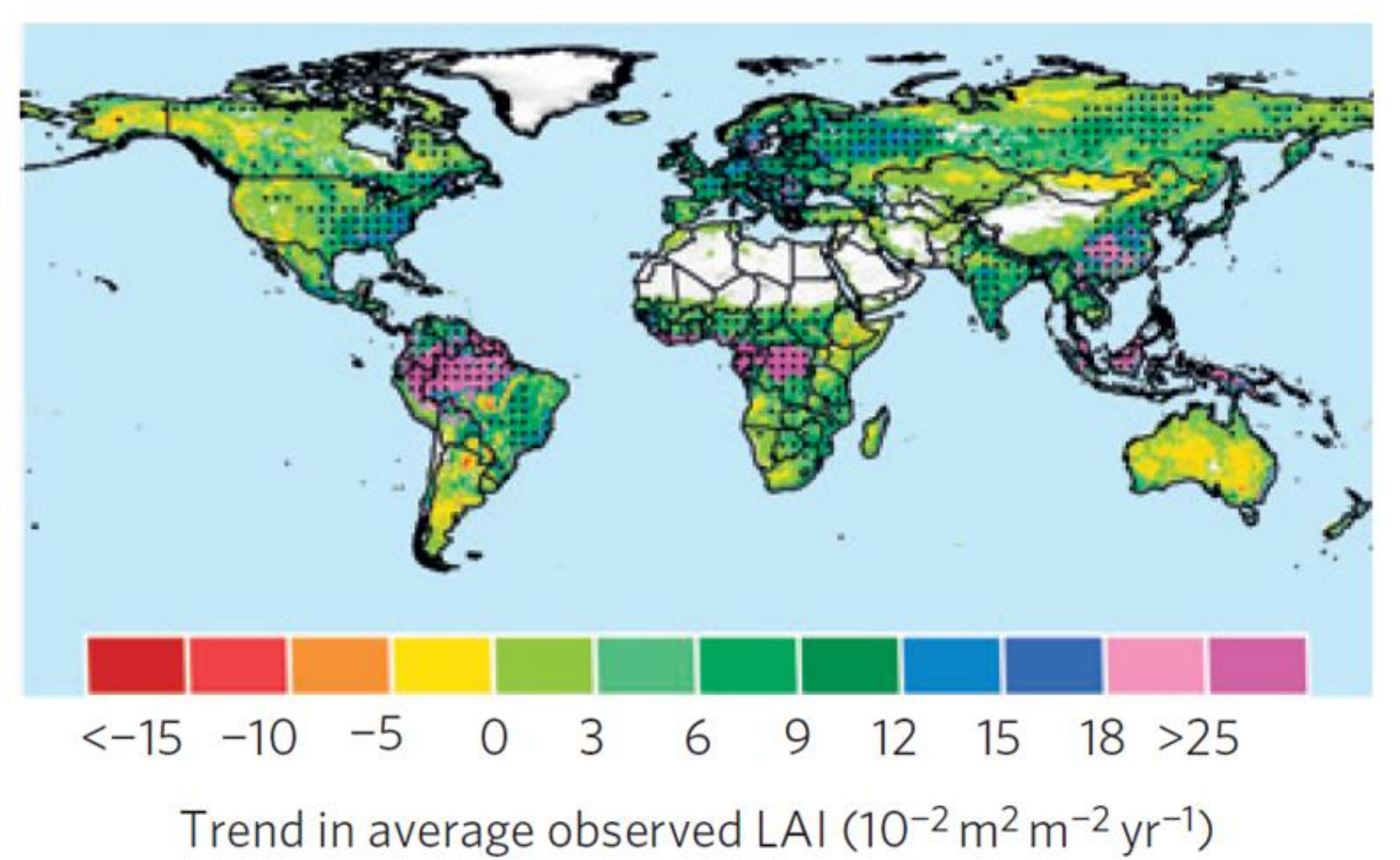
What is the SCC?

- Class of models proposed as basis for regulatory policy by the Obama Administration
- Defined as “the economic damages per metric ton of carbon dioxide emissions”

So how does one actually estimate the SCC?

- General question – What is the long-term economic impact of carbon dioxide emissions across a particular time horizon?
- Three statistical models (IAMs)
  - – DICE model
  - – FUND model
  - – PAGE model

The greening of the planet 1982-2009



Zhu et al (2016)

As with any statistical model …

These models are based on assumptions …

What does altering the assumptions made by the Obama administration do?

- Ran two of the three models …
- SCC can drop by 40-200%
- Can even be negative at times, under very reasonable assumptions
  - Policy implication

So what exactly is the SCC?

Green New Deal

What does the Green New Deal entail?

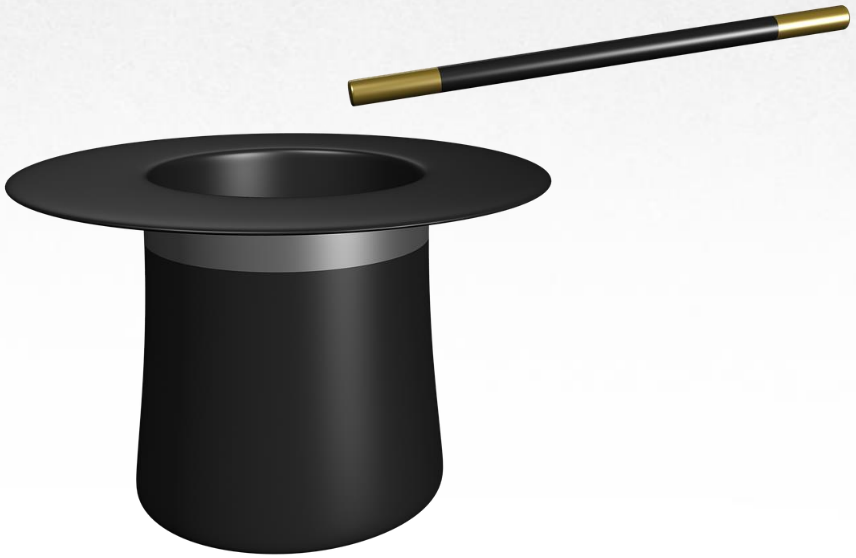
- Derive 100 percent of America's electricity from "clean, renewable, and zero-emission" energy sources
- Eliminate GHGs from pretty much every sector
- Spend massively on clean and renewable-energy manufacturing;
- Maximize energy efficiency

How can we model the economic impact of the Green New Deal?

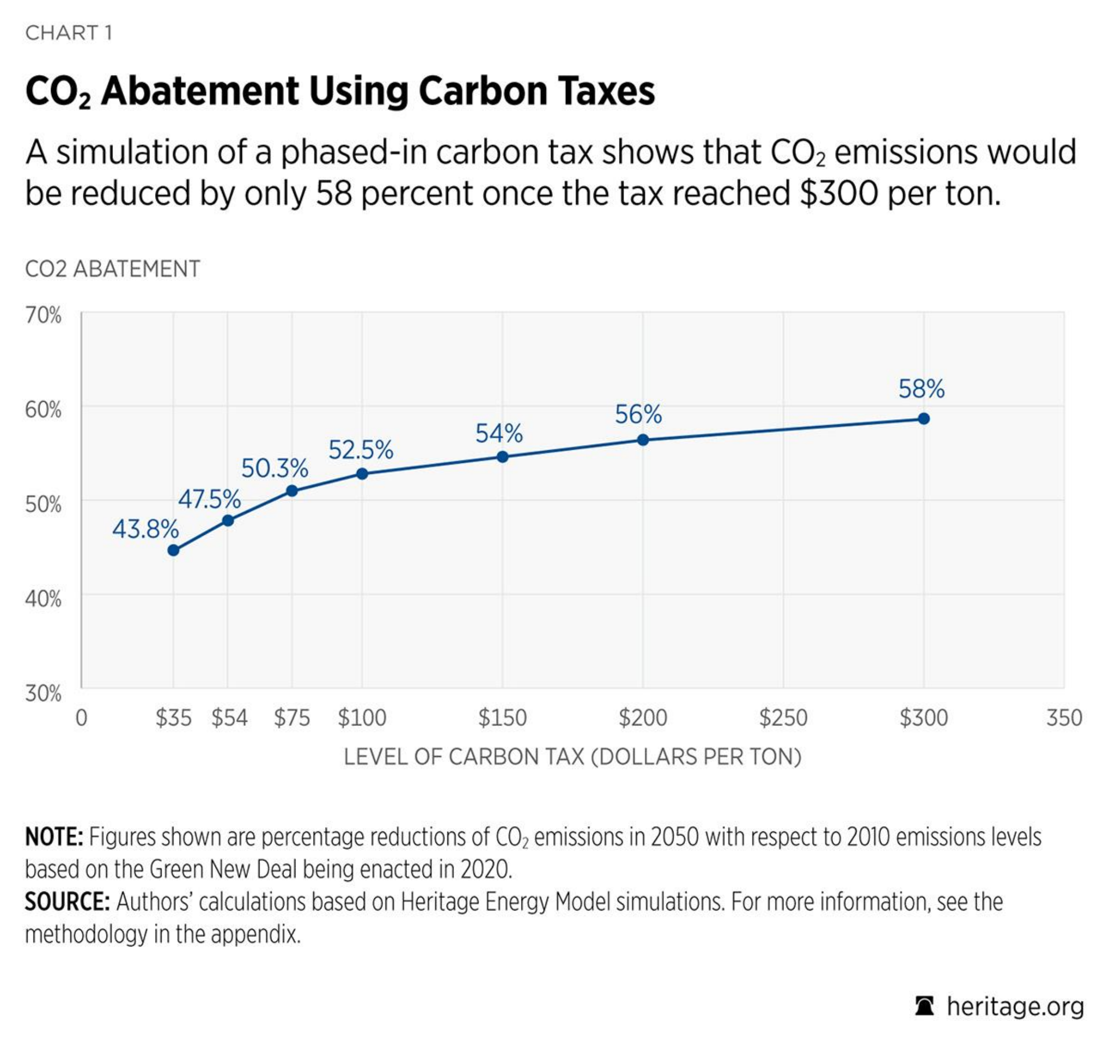
Modeling the economic impact of the GND

- Used the Heritage Energy Model
  - Focused exclusively on the energy component
  - Carbon tax
  - Regulations on manufacturing
  - Mandates on renewables

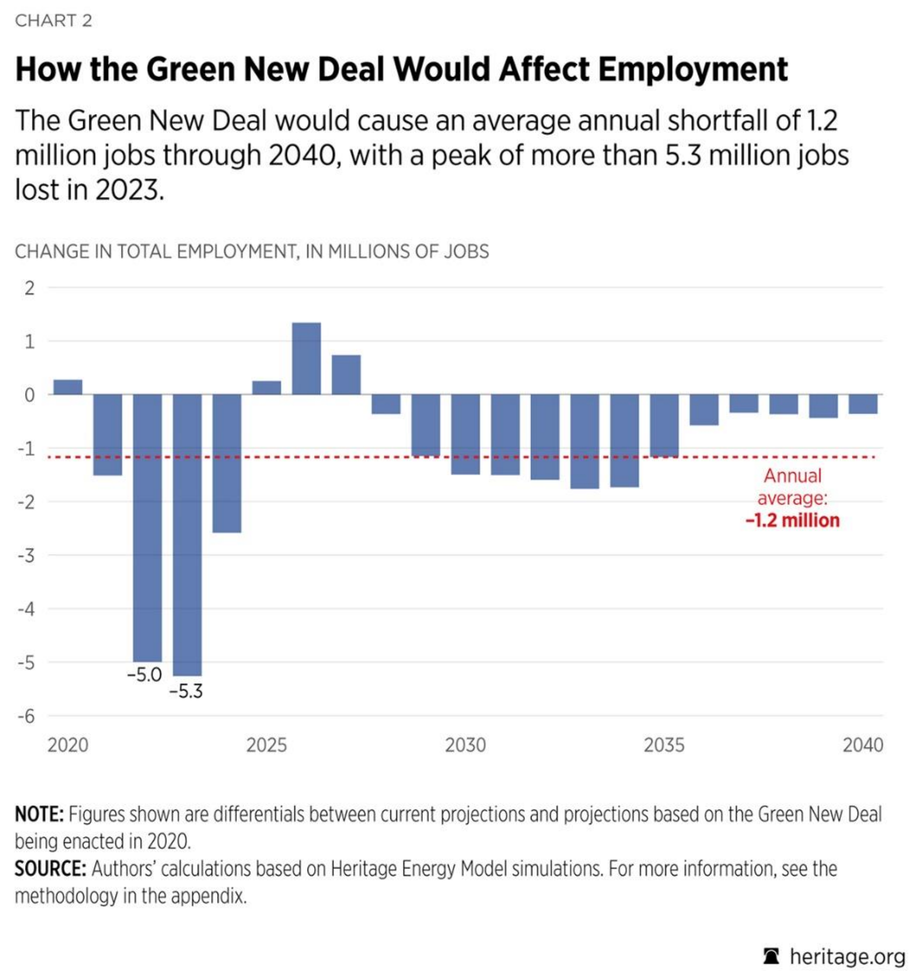
The Challenges of Modeling the GND



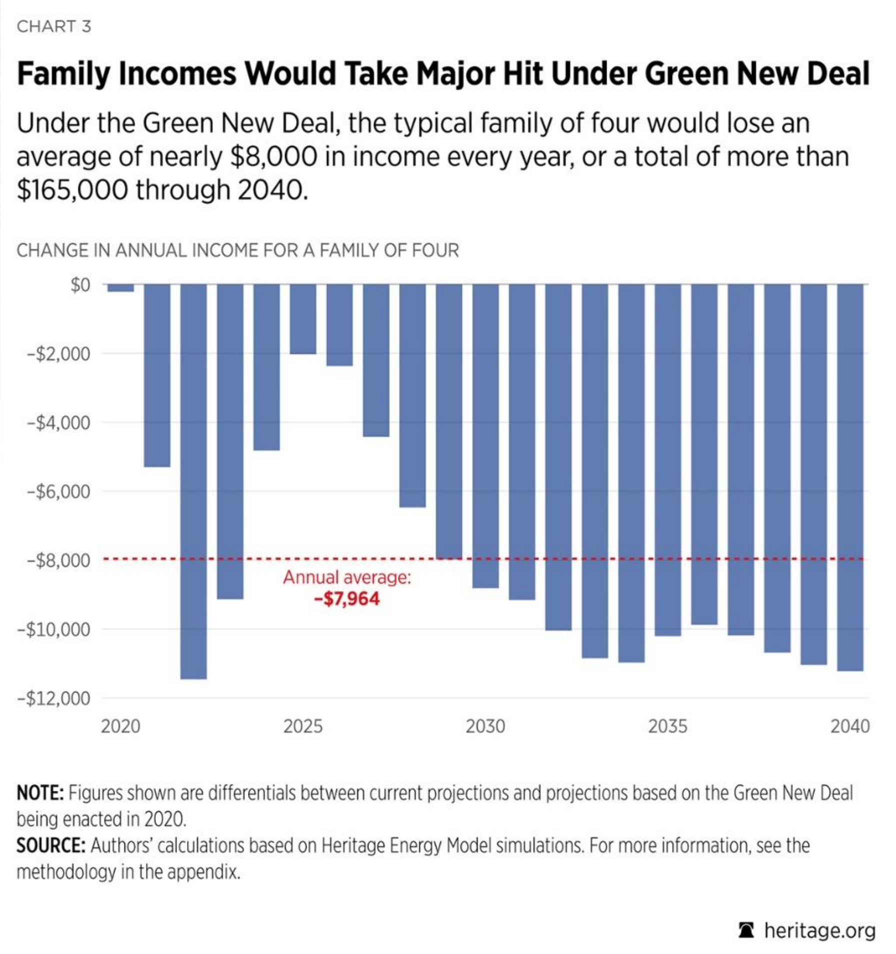
What can we realistically model?



Overall Employment



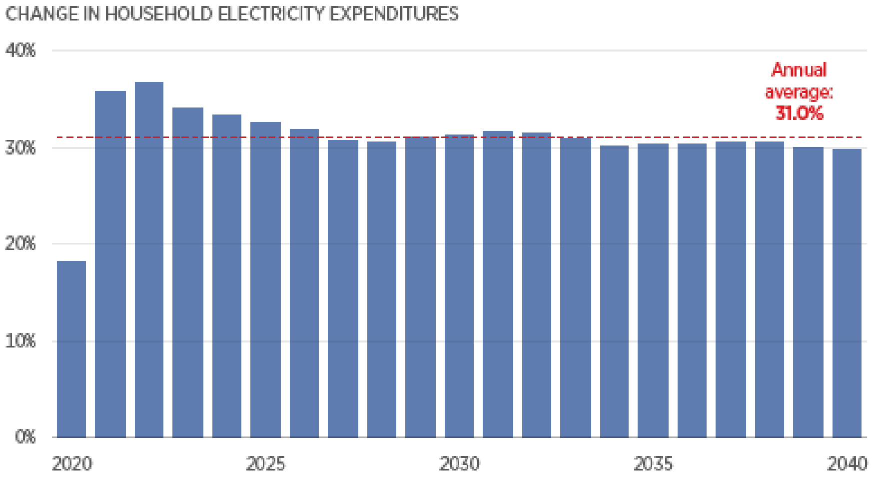
Family Income



Electricity Prices

Green New Deal Would Cause Household Electricity Expenditures to Skyrocket

Under the Green New Deal, household electricity expenditures would rapidly increase by well over 30 percent, and those increases would remain for the foreseeable future.



NOTE: Figures shown are differentials between current projections and projections based on the Green New Deal being enacted in 2020.
SOURCE: Authors' calculations based on Heritage Energy Model simulations. For more information, see the methodology in the appendix.

Green New Deal – Economic Impact

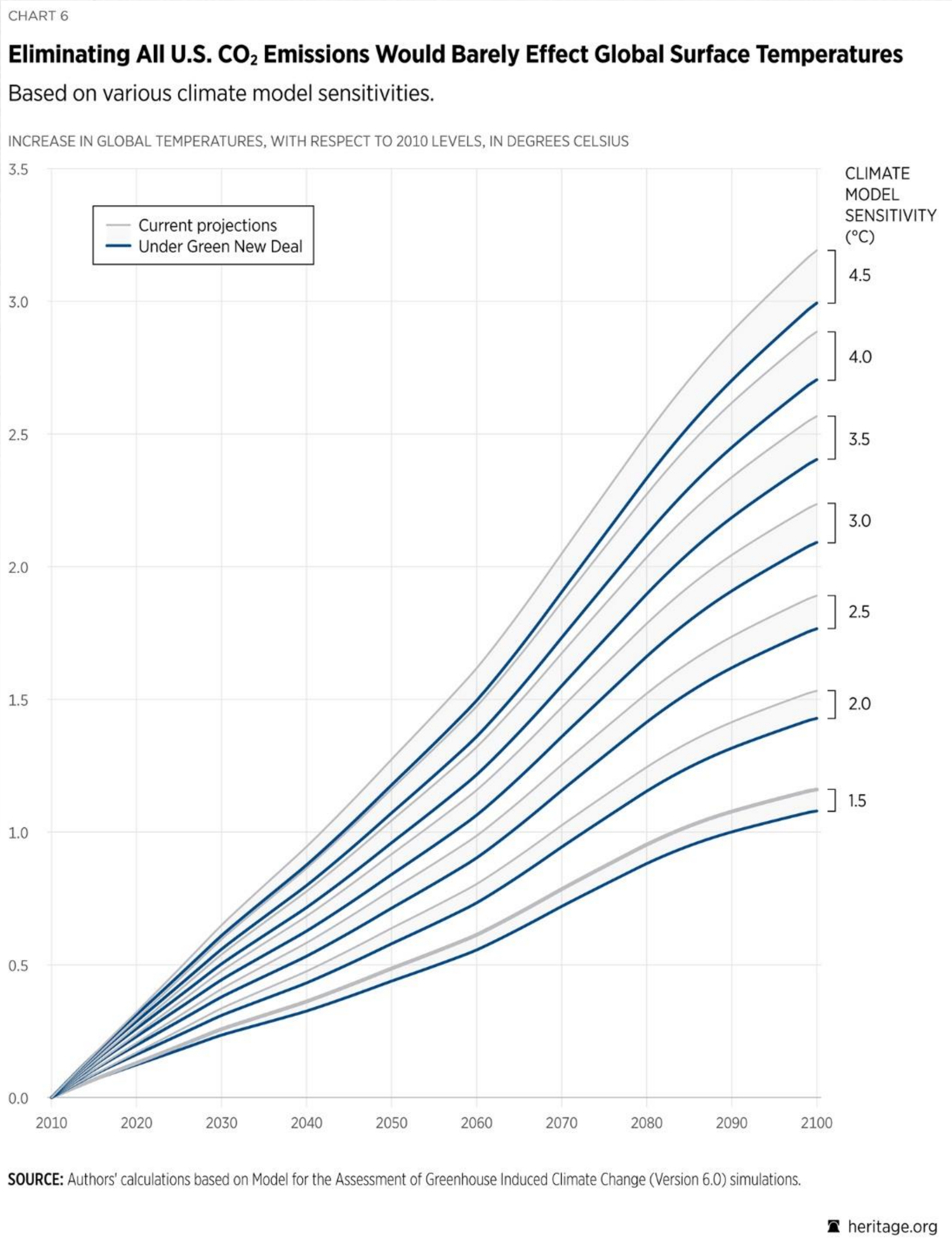
- Instituting carbon capture regulations by 2040 …
  - Average employment shortfall of over 1.1 million lost jobs
  - Loss of income of more than $160,000 for a family of four
  - Up to 30% increase in household electricity expenditures
  - Aggregate $15 trillion loss in GDP

How can we model the climate impact of the Green New Deal?

Modeling the climate impact of the GND

- Used the Model for the Assessment of Greenhouse Gas Induced Climate Change
  - Assumed commonly accepted projections
  - Varied climate sensitivity ranging from 1.5-4.5 degrees C

Climate impact of GND



How about climate impacts at the state level?

Global temperature impact of eliminating CO2 emissions from ...

- **Pennsylvania**
  - 0.0041 deg C temp mitigation by 2050
  - 0.0083 deg C temp mitigation by 2100

Sea level rise impact of eliminating CO_2 emissions from ...

- **Pennsylvania**
  - 0.0273 deg C temp mitigation by 2050
  - 0.0820 deg C temp mitigation by 2100

Advice for policymakers

- Avoid policies such as the GND/carbon capture related policies
- Stop using the SCC for cost benefit analysis
- Employ cost-benefit analysis as was done here

…

Thank you!

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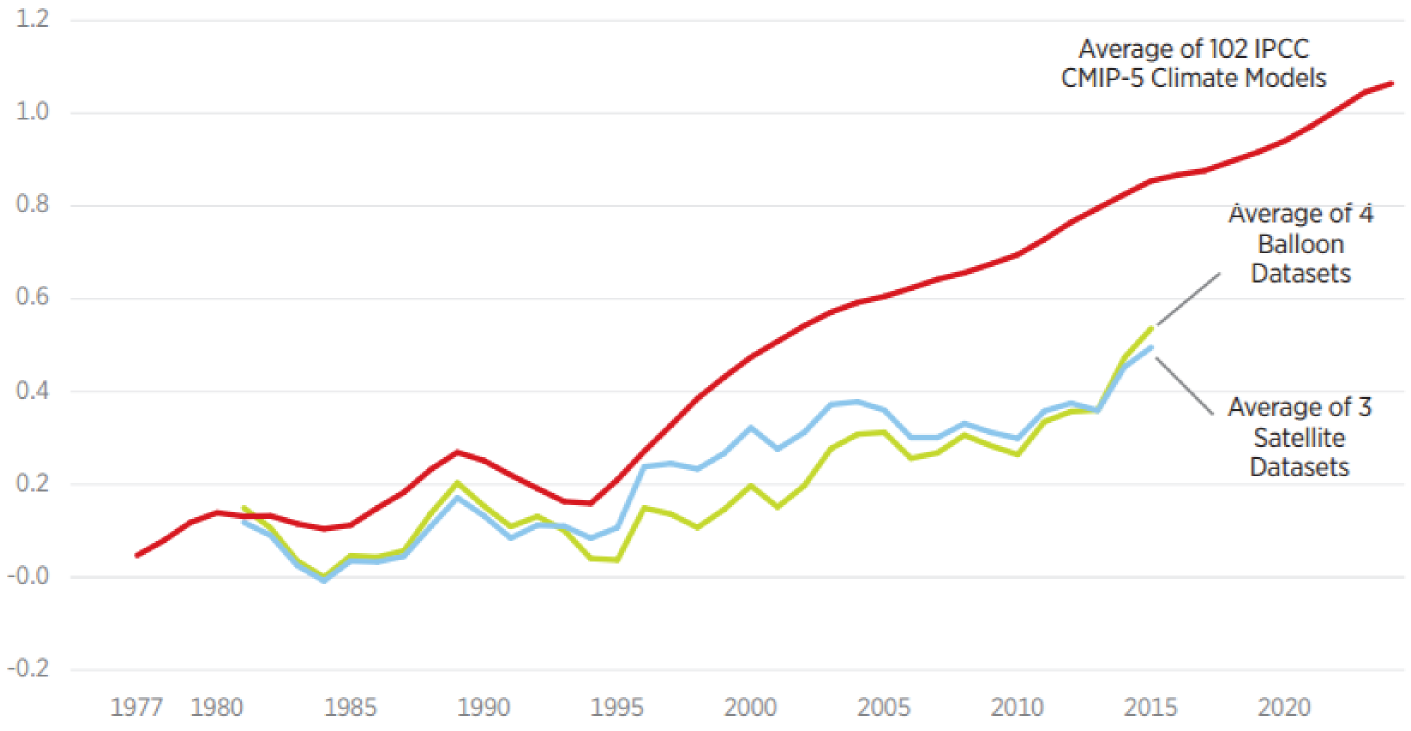
The accuracy of forecasts?

CHART 1

Global Mid-Tropospheric Temperature

FIVE YEAR RUNNING AVERAGE



NOTE: The linear trend (based on 1979-2016 only) of all time series intersects at zero in 1979.
SOURCE: John R. Christy, testimony before the Committee on Science, Space & Technology, U.S. House of Representatives, February 2, 2016, http://docs.house.gov/meetings/SY/SY00/20160202/104399/HHRG-114-SY00-Wstate-ChristyJ-20160202.pdf (accessed March 15, 2017).

The Heritage Foundation

BACKGROUNDER

No. 3427 | JULY 24, 2019
CENTER FOR DATA ANALYSIS

Assessing the Costs and Benefits of the Green New Deal's Energy Policies

Kevin D. Dayaratna, PhD, and Nicolas D. Loris

KEY TAKEAWAYS

The Green New Deal's government-managed energy plan poses the risk of expansive, disastrous damage to the economy—hitting working Americans the hardest.

Under the most modest estimates, just one part of this new deal costs an average family $165,000 and wipes out 5.2 million jobs with negligible climate benefit.

Removing government-imposed barriers to energy innovation would foster a stronger economy and, in turn, a cleaner environment.

On February 7, 2019, Representative Alexandria Ocasio-Cortez (D–NY) and Senator Ed Markey (D–MA) released their plan for a Green New Deal in a non-binding resolution. Two of the main goals of the Green New Deal are to achieve global reductions in greenhouse-gas emissions of 40 percent to 60 percent (from 2010 levels) by 2030, and net-zero emissions worldwide by 2050. The Green New Deal's emission-reduction targets are meant to keep global temperatures 1.5 degrees Celsius above pre-industrial levels.[1]

In what the resolution calls a "10-year national mobilization," the policy proposes monumental changes to America's electricity, transportation, manufacturing, and agricultural sectors. The resolution calls for sweeping changes to America's economy to reduce emissions, but is devoid of specific details as to how to do so. Although the Green New Deal also calls for universal health care, guaranteed jobs with a family sustaining wage, "healthy food security,"[2] and efficiency spending on all homes and buildings, the analysis in this *Backgrounder* focuses on the Green New Deal's energy-related policies, intended to reduce greenhouse-gas emissions.

To provide a broad estimate of the costs, Heritage Foundation analysts modeled the economic impact of an entire series of economy-wide carbon taxes, each increasing the tax gradually over time. We also included regulations and mandates to achieve the Green New Deal's goal of increased renewable energy generation. Our cost estimates constitute a significant underestimate of the true costs of the Green New Deal as the carbon tax and regulations do not completely achieve the policy objectives outlined in the non-binding resolution. Furthermore, the analysis does not account for the direct taxpayer costs, as advocates want to pay for the Green New Deal through a massive stimulus-style package. Layers of additional regulations and mandates, such as the proposal's objective to maximize energy efficiency for every new and existing building in the U.S., would drive costs even higher. Still, this analysis demonstrates how economically damaging the energy components of the Green New Deal would be for American families and businesses—all for no meaningful impact on the climate.

What Is the Green New Deal?

The Green New Deal is much more than just an energy and climate policy; it is a plan to fundamentally restructure the American economy. As stated in the non-binding resolution, "climate change, pollution, and environmental destruction have exacerbated systemic racial, regional, social, environmental, and economic injustices."[3] To correct those alleged injustices, the plan aims to change how people consume energy, develop crops, construct homes, and produce and transport goods. In other words, the government would use taxes and regulations to control actions and choices made by everyday Americans. Some of the plan's top-line energy goals are to:

- Derive 100 percent of America's electricity from "clean, renewable, and zero-emission" energy sources;[4]
- Eliminate greenhouse gas emissions from manufacturing, agricultural, and other industrial sectors to the extent it is technologically feasible;

- Spend massively on clean-energy manufacturing and renewable-energy manufacturing;
- Eliminate greenhouse gas emissions from transportation and other infrastructure as much as technologically feasible, by (among other means) increased government spending on clean infrastructure and high-speed rail;[5] and
- Maximize efficiency for every single new and existing residential and industrial building.

What Would a Green New Deal Cost Americans?

Credibly estimating the cost of the Green New Deal's energy policies for American taxpayers, households, and businesses is an exceedingly complex task. The resolution does not specify requiring the grid to transition to 100 percent renewables, and instead stipulates "100 percent clean, renewable, and zero-emission" energy sources. How companies would make large-scale investments to meet the mandate and how intermittent power sources would receive backup power is purely speculation and guesswork. Even projecting the cost of switching to 100 percent renewable power for electricity relies on a set of largely unknowable and untestable assumptions. The costs of stranded assets and lost shareholder value and the cost to taxpayers could easily surpass $5 trillion.[6] Without specific legislative detail, assessing the public and private costs is extremely difficult.

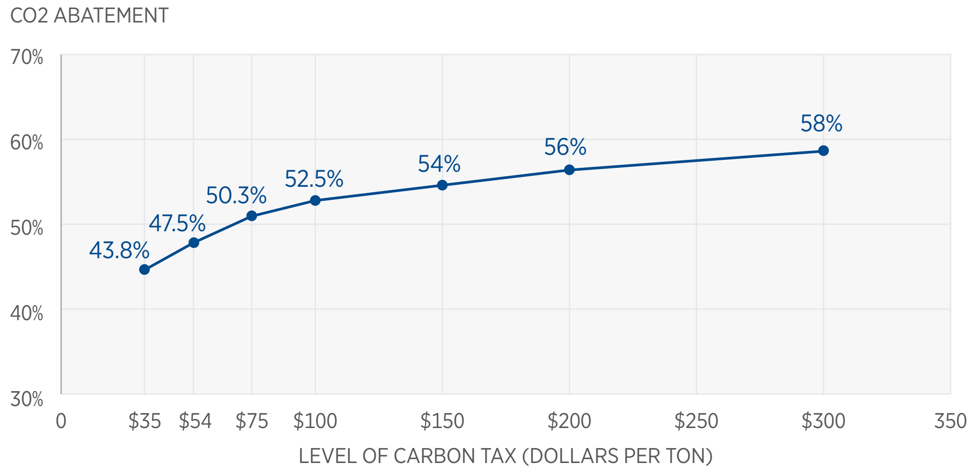
To estimate the economic impact of a Green New Deal, we used the Heritage Energy Model (HEM), a clone of the U.S. Energy Information Administration's National Energy Model. As mentioned on Representative's Cortez's website, the carbon tax constitutes only one of many policy measures that Green New Deal advocates hope to implement.[7] As a result, we implemented an economy-wide carbon tax (phased in over two years and increasing by 2.5 percent each year thereafter), a series of regulations on the manufacturing industry encouraging use of fewer carbon-emitting sources of energy, and mandates for more renewable energy, which currently provides 17 percent of America's electricity needs.[8] Further details of our modeling are described in the appendix.

As the policy's stated goal is to reduce carbon-dioxide (CO_2) emissions to zero by the middle of the century, the first step in our analysis was to ascertain HEM's capabilities of doing so. In particular, we ran a series of simulations with the mandates and regulations described above, gradually

CHART 1

CO_2 Abatement Using Carbon Taxes

A simulation of a phased-in carbon tax shows that CO_2 emissions would be reduced by only 58 percent once the tax reached $300 per ton.



NOTE: Figures shown are percentage reductions of CO_2 emissions in 2050 with respect to 2010 emissions levels based on the Green New Deal being enacted in 2020.
SOURCE: Authors' calculations based on Heritage Energy Model simulations. For more information, see the methodology in the appendix.

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increasing the level of the carbon tax. Chart 1 illustrates the levels of CO_2 abatement estimated by the model in the middle of the century.

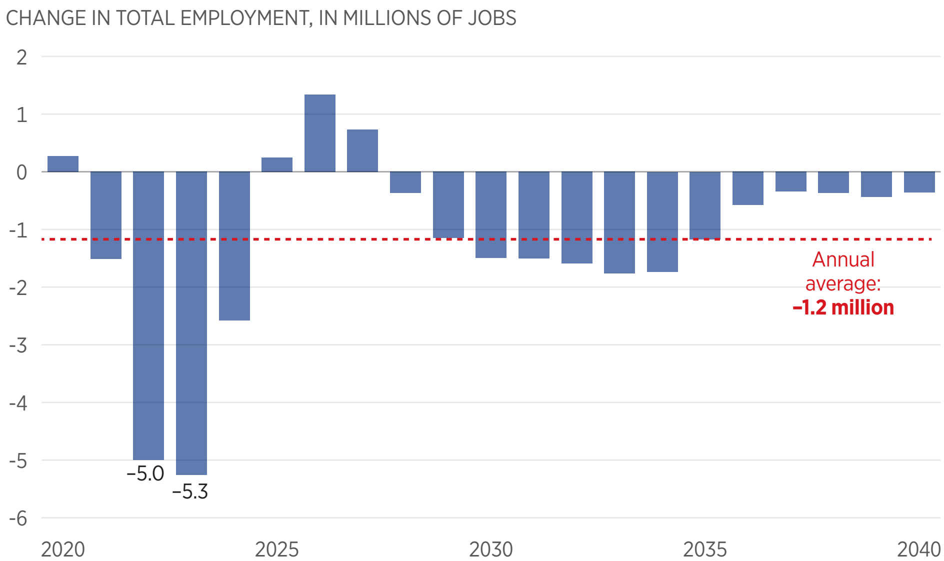
As seen in Chart 1, HEM predicts that reducing higher and higher amounts of carbon will not be as simple as instituting higher taxes. Specifically, as the taxes were incrementally increased, the marginal reduction in emissions shrank. In our simulations, a $35 carbon tax results in a 44 percent reduction in CO_2 emissions by 2050, a $100 carbon tax results in a 53 percent reduction, a $200 tax results in a 56 percent reduction, and a $300 tax results in a 58 percent reduction from 2010 levels. Carbon taxes above $300 (resulting in slightly above 50 percent CO_2 reductions by 2050) cause the model to crash, and thus a 58 percent CO_2 reduction from 2010 levels is the largest level we are able to model.

As a result of the $300 carbon tax, coupled with the regulations and mandates described in the appendix, our simulations find that by 2040, the country will incur:

CHART 2

How the Green New Deal Would Affect Employment

The Green New Deal would cause an average annual shortfall of 1.2 million jobs through 2040, with a peak of more than 5.3 million jobs lost in 2023.



NOTE: Figures shown are differentials between current projections and projections based on the Green New Deal being enacted in 2020.
SOURCE: Authors' calculations based on Heritage Energy Model simulations. For more information, see the methodology in the appendix.

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- An overall average shortfall of over 1.1 million jobs;
- A peak employment shortfall of over 5.2 million jobs;
- A total income loss of more than $165,000 for a family of four;
- An aggregate gross domestic product loss of over $15 trillion; and
- Increases in household electricity expenditures averaging 30 percent.

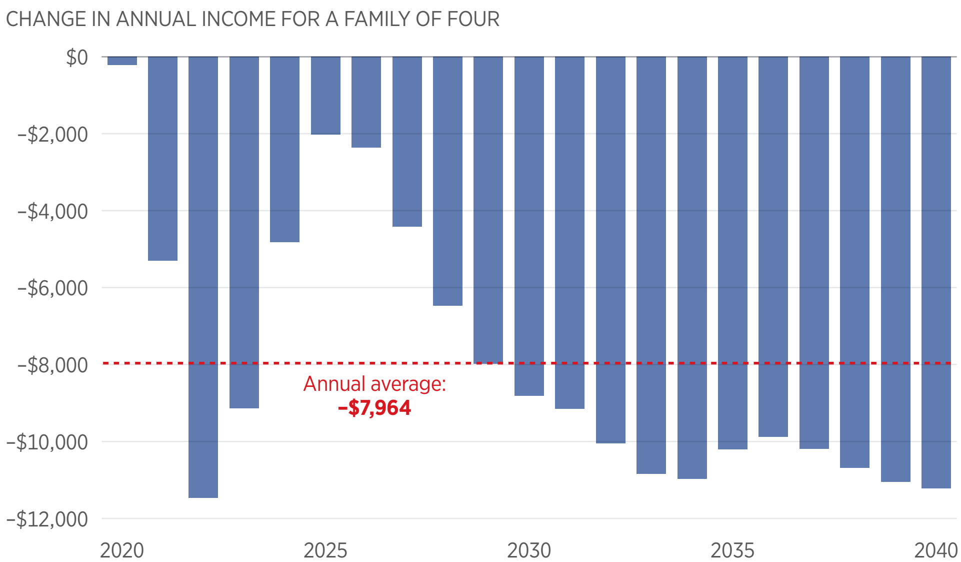
Chart 5 depicts a sector by sector analysis of the impact.

Unquestionably, as the policy only results in 58 percent CO_2 emissions reductions, these estimates significantly underestimate the costs of the

CHART 3

Family Incomes Would Take Major Hit Under Green New Deal

Under the Green New Deal, the typical family of four would lose an average of nearly $8,000 in income every year, or a total of more than $165,000 through 2040.



NOTE: Figures shown are differentials between current projections and projections based on the Green New Deal being enacted in 2020.
SOURCE: Authors' calculations based on Heritage Energy Model simulations. For more information, see the methodology in the appendix.

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Green New Deal. If policymakers spent, taxed, and regulated energy to truly achieve greenhouse-gas-free emission levels, the costs would almost surely be several orders of magnitude higher. And, more fundamentally, the policies proposed in the Green New Deal are highly regressive. Higher energy costs affect low-income households disproportionately, as they spend a higher percentage of their budget on energy.

What Impact Would a Green New Deal Have on Climate Warming?

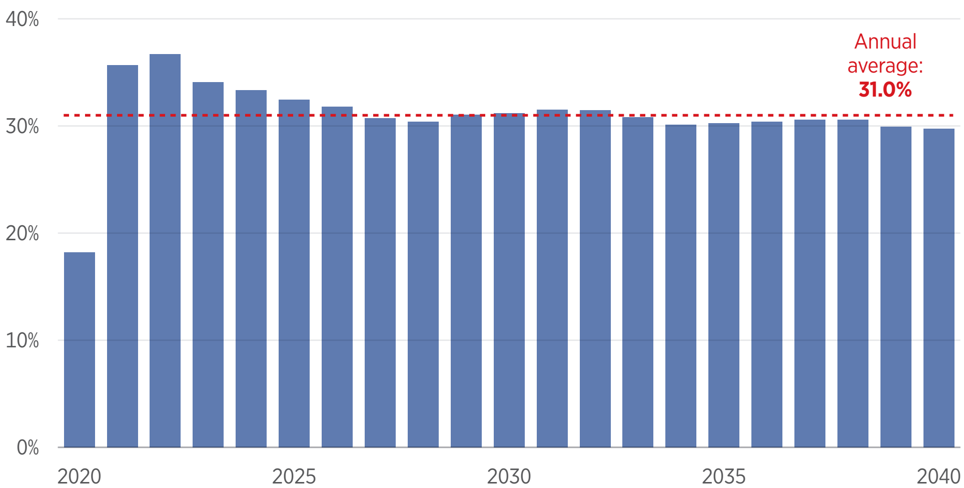
No matter where one stands on the urgency to combat climate change, the Green New Deal's policies would be ineffective in abating temperature increases and reducing sea-level rise. In fact, even if the U.S. were to cut

CHART 4

Green New Deal Would Cause Household Electricity Expenditures to Skyrocket

Under the Green New Deal, household electricity expenditures would rapidly increase by well over 30 percent, and those increases would remain for the foreseeable future.

CHANGE IN HOUSEHOLD ELECTRICITY EXPENDITURES



NOTE: Figures shown are differentials between current projections and projections based on the Green New Deal being enacted in 2020.
SOURCE: Authors' calculations based on Heritage Energy Model simulations. For more information, see the methodology in the appendix.

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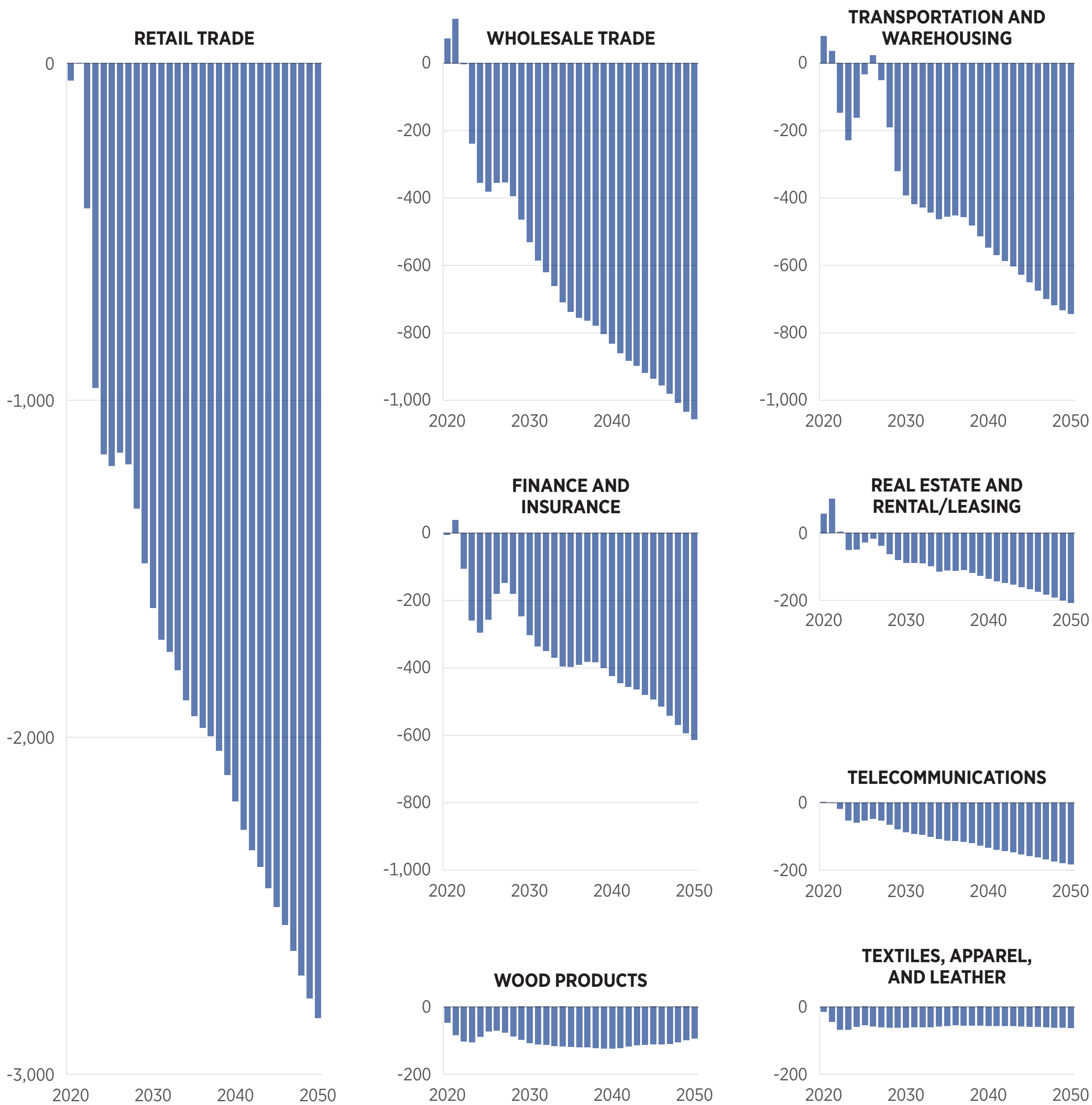
its CO_2 emissions 100 percent, it would have a negligible impact on global warming. Using the Model for the Assessment of Greenhouse Gas Induced Climate Change, we find that using a climate sensitivity (the warming effect of a doubling of CO_2 emissions) larger than that assumed by the Obama Administration's Interagency Working Group, the world would only be less than 0.2 degree Celsius cooler by the year 2100, and sea-level rise would be slowed by less than 2 centimeters.[9] Chart 6 provides the results from a series of simulations of various climate sensitivities, which demonstrate the negligible climate impact of these policies.

CHART 5

How the Green New Deal Would Affect Employment in Various Sectors

CHANGES IN EMPLOYMENT BY SECTOR, IN THOUSANDS OF JOBS

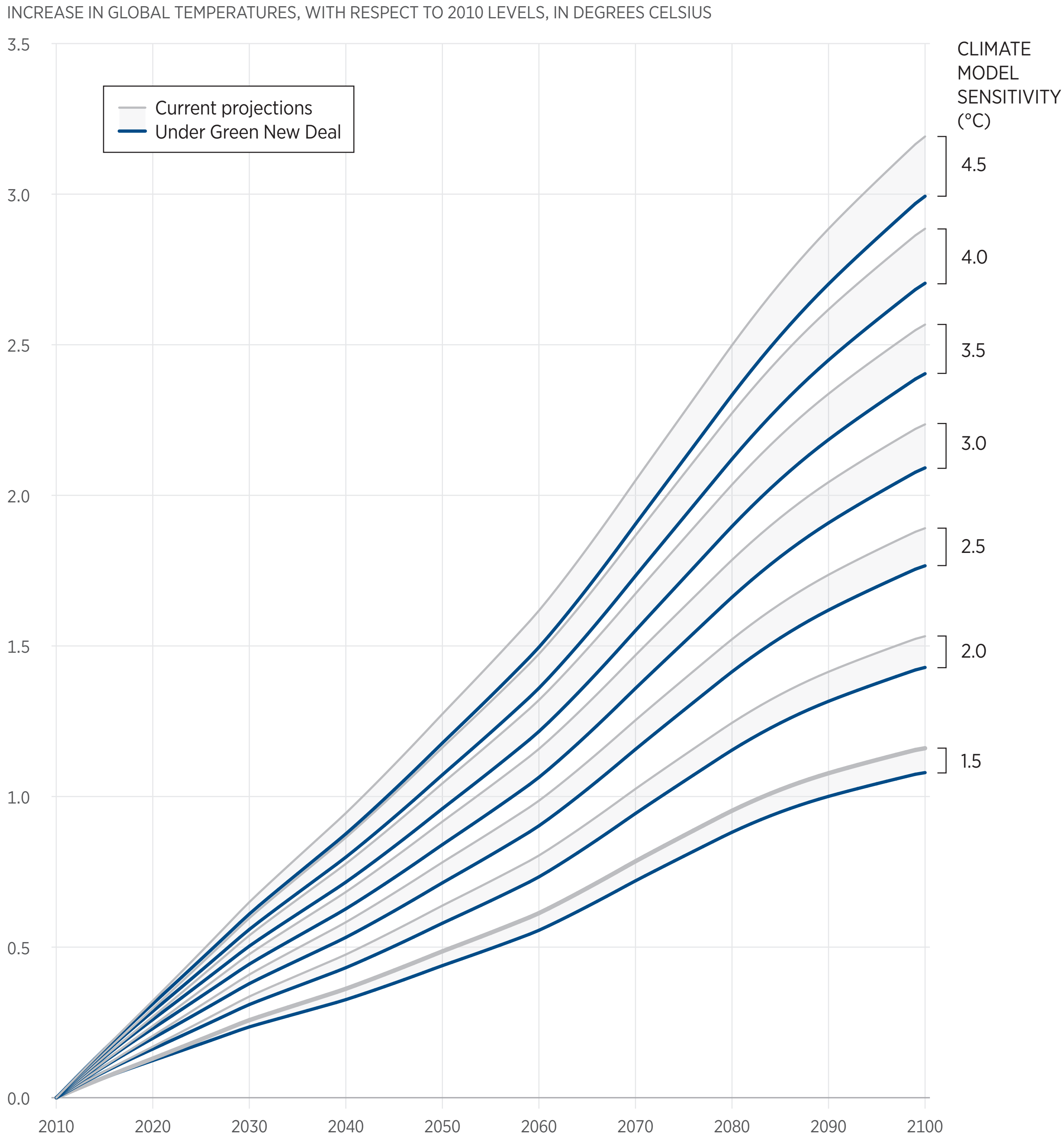


NOTE: Figures shown are differentials between current projections and projections based on the Green New Deal being enacted in 2020.
SOURCE: Authors' calculations based on Heritage Energy Model simulations. For more information, see the methodology in the appendix.

CHART 6

Eliminating All U.S. CO_2 Emissions Would Barely Affect Global Surface Temperatures

Based on various climate model sensitivities.



SOURCE: Authors' calculations based on Model for the Assessment of Greenhouse Induced Climate Change (Version 6.0) simulations.

Recommendations to Drive Energy and Environmental Innovation

The Green New Deal would amount to more centralization of power in Washington where the government would determine what type of energy Americans produce and consume. Congress should prevent unelected regulators from misleading the public on the "climate benefits" of greenhouse-gas regulations. Furthermore, policymakers should put forth policy improvements that will drive innovation among all forms of energy. Breaking down barriers to competition, freeing up innovative pathways for new technologies, and freely trading energy technologies will meet America's and the world's energy needs while helping the environment. Specifically, Congress should:

- **Require any greenhouse-gas regulation to include a separate global-temperature impact and a sea-level-rise impact.** If the purpose of climate-change regulation is to slow warming, then regulators should measure the benefits through the regulation's project impact on warming rather than aggregate emissions reduced, which mislead the public about the benefits of the policy.[10] The Model for the Assessment of Greenhouse Gas Induced Climate Change provides more useful information for regulators, Congress, and the public when assessing the climate benefits of greenhouse-gas regulation.

- **End the use of the social cost of carbon (SCC) in cost-benefit analyses.** Congress should prohibit any agency from using regulatory analysis metrics with the SCC or the "social cost" of other greenhouse-gas emissions in any cost-benefit analysis or environmental review. As has been extensively documented in research by Heritage Foundation analysts, the statistical models on which the federal government relies to estimate the so-called social cost of greenhouse gases are highly prone to user manipulation and are thus not credible tools for policymaking.[11] If federal courts force regulators into estimating the costs of climate change, they should not use SCC, but the Model for the Assessment of Greenhouse Gas Induced Climate Change, to calculate the global temperature change of regulations or new infrastructure, as has been done in this *Backgrounder*.

- **Restate and clarify in law that the Clean Air Act was never intended to regulate greenhouse gases as air pollutants.** Since conventional carbon-based fuels provide approximately 80 percent of

America's energy needs, climate-change regulations will drive electricity bills and gas prices higher. Cumulatively, they will cost hundreds of thousands of jobs and tens of thousands of dollars in lost household income and produce no discernable climate benefit.

- **Fix the regulatory and policy problems facing commercial nuclear power.** Facing a complex and burdensome regulatory system, commercial nuclear power in the U.S. has unnecessarily high construction costs. The regulatory system that licenses and permits nuclear reactors fails to keep up with technological innovations and overregulates existing nuclear technologies. Congress should instill regulatory discipline at the Nuclear Regulatory Commission (NRC), encourage the Environmental Protection Agency to right-size radiation-exposure standards, review foreign ownership caps, reform the NRC's cost-recovery structure, and introduce market principles into spent-fuel management.[12]

- **Fix the regulatory and policy problems facing renewable energy.** Like most other energy projects, renewable power projects face excessive and duplicative regulations that increase costs and cause unnecessary delays. Siting and permitting issues can be particularly problematic for wind and solar energy because the most advantageous locations for generation are in more remote areas. Congress should reform outdated environmental statutes, such as the National Environmental Policy Act and the Endangered Species Act, to create a more efficient permitting process for all energy projects, including renewables.[13]

- **Expand energy innovation internationally.** Congress and the Trump Administration should work with other countries to open up their energy markets. These reforms should include pursuing a zero-tariff policy, engaging in technology transfer to unlock natural resources in other countries, and engaging in commercial nuclear trade that would incentivize both cooperation and competition, bringing new nuclear technologies to the market.[14]

Green New Deal: More about Government Control than Climate Control

A Green New Deal would be incredibly costly for American families and businesses—all for no meaningful climate benefit. Moreover, the plan would introduce a completely new level of cronyism and corporate welfare that would harm consumers multiple times over. The policies proposed in the Green New Deal would disrupt energy markets and skew investment decisions toward politically connected projects, as has been the case with politically favored energy projects in the past.[15] Instead of implementing economically destructive policies of more taxes, regulations, and subsidies, federal and state policymakers should remove government-imposed barriers to energy innovation. Allowing all forms of energy to compete equally in a free market will enable the U.S. to make tremendous strides in terms of a healthy economy as well as a healthy environment.[16]

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Appendix: Methodology

The Heritage Energy Model

The analysis in this *Backgrounder* uses the Heritage Energy Model (HEM), a clone of the National Energy Model System (NEMS) 2018 Full Release.[17] NEMS is used by the Energy Information Administration (EIA) in the Department of Energy as well as various nongovernmental organizations for a variety of purposes, including forecasting the effects of energy policy changes on a plethora of leading economic indicators.

The methodologies, assumptions, conclusions, and opinions in this *Backgrounder* are entirely the work of statisticians and economists in the Center for Data Analysis (CDA) at The Heritage Foundation, and have not been endorsed by, and do not necessarily reflect the views of, the developers of NEMS.

HEM is based on well-established economic theory as well as historical data, and contains a variety of modules that interact with each other for long-term forecasting. In particular, HEM focuses on the interactions among

1. The supply, conversion, and demand of energy in its various forms;
2. American energy and the overall American economy;
3. The American energy market and the world petroleum market; and
4. Current production and consumption decisions as well as expectations about the future.[18]

These modules are the:

- Macroeconomic Activity Module,[19]
- Transportation Demand Module,
- Residential Demand Module,
- Industrial Demand Module,
- Commercial Demand Module,
- Coal Market Module,

- Electricity Market Module,
- Liquid Fuels Market Module,
- Oil and Gas Supply Module,
- Renewable Fuels Module,
- Natural Gas Market Module, and
- International Energy Activity Module.

HEM is identical to the EIA's NEMS with the exception of the Commercial Demand Module. The Commercial Demand Module makes projections regarding commercial floor-space data of pertinent commercial buildings. Other than HEM not having this module, it is identical to the NEMS.

Overarching these modules is an Integrating Module, which consistently cycles, iteratively executing and allowing these various modules to interact with each other. Unknown variables that are related, such as a component of a particular module, are grouped together, and a pertinent subsystem of equations and inequalities corresponding to each group is solved via a variety of commonly used numerical analytic techniques, using approximate values for the other unknowns. Once a group's values are computed, the next group is solved similarly, and the process iterates. After all group values for the current cycle are determined, the next cycle begins. At each particular cycle, a variety of pertinent statistics is obtained.[20] HEM provides a number of diagnostic measures, based on differences between cycles, to indicate whether a stable solution has been achieved.

This *Backgrounder* uses HEM to analyze the impact of a carbon tax as well as carbon-related regulations on the economy. As illustrated in Chart 1 of this *Backgrounder*, we modeled $35, $54, $75, $100, $200, and $300 carbon taxes (per ton of carbon). The carbon tax begins in 2020, with half of the specified value per ton of CO_2, doubles to its full value the following year, and increases annually by 2.5 percent each year thereafter. In our simulations, each consisting of four cycles, we rebated the revenue collected from the tax back to consumers in a deficit-neutral manner. We also implemented regulations on the manufacturing industry by more rapidly retiring CO_2-intensive technologies as well as discouraging their use. Lastly, we required that renewable forms of energy constitute a much larger fraction of the energy portfolio than is currently the case, stipulating that at least 20 percent of renewable electric generation in 2020 come from particular renewable forms of energy and have this percentage gradually increase to 64 percent in 2050. The specific forms of renewable energy we mandated in our simulations included biomass, geothermal, wind, solar, and other forms of intermittent energy.

The Model for the Assessment of Greenhouse Gas Induced Climate Change

The analysis in this *Backgrounder* also uses the Model for the Assessment of Greenhouse Gas Induced Climate Change (MAGICC) versions 5.3 and 6.[21] The MAGICC model quantifies the relationship between atmospheric radiative forcing, oceanic heat content, and surface temperature perturbation via the following relationship:[22]

$$\Delta Q_G = \lambda_G \Delta T_G + \frac{dH}{dt}$$

where ΔQ_G represents the global-mean radiative forcing at the upper level of the troposphere. This extra energy influx is decomposed into increased outgoing energy flux and heat content changes in the ocean via the derivative $\frac{dH}{dt}$. The outgoing energy flux is related to the global-mean feedback factor λ_G as well as surface temperature perturbation ΔT_G .

Climate sensitivity, denoted in the MAGICC model as ΔT_{2x} , is defined as the equilibrium global-mean warming after a doubling of CO_2 concentrations and specified via a reciprocal relationship to a feedback factor λ :

$$\Delta T_{2x} = \frac{\Delta Q_{2x}}{\lambda}.$$

In the above equation, ΔT_{2x} represents the climate sensitivity and ΔQ_{2x} represents the radiative forcing following a doubling of CO_2 concentrations. The time or state-dependent effective climate sensitivity S^t is defined by combining the above two equations as follows:

$$S^t = \frac{\Delta Q_{2x}}{\lambda^t} = \Delta Q_{2x} \frac{\Delta T_G^t}{\Delta Q^t - \frac{dH}{dt}|^t}$$

where ΔQ_{2x} represents the model-specific forcing corresponding to doubled CO_2 concentration, λ^t represents the time-variable feedback factor, ΔQ^t represents the radiative forcing, ΔT_G^t represents the global-mean temperature perturbation, and $\frac{dH}{dt}|^t$ represents the climate system's heat uptake at time t .

MAGICC also contains a carbon-cycle model that incorporates temperature-feedback effects. One of the *a priori* specifications pertaining to this model is a greenhouse-gas-emissions trajectory. We assumed trajectories specified in the model based on the most recent Intergovernmental Panel on Climate Change (IPCC) Assessment Reports.

We ran MAGICC simulations using the most two recent versions, 5.3 and 6. Upon modifying emissions trajectories and specifying a climate sensitivity, one can run the MAGICC model to generate these forecasts. In our simulations using MAGICC 5.3, we used and modified the A1B trajectory, specified in the IPCC's *Special Report* on "Emissions Scenarios" and used in the IPCC's "Third Assessment Report" and "Fourth Assessment Report." In our simulations using MAGICC 6, we used and modified Representative Concentration Pathway 6.0, specified in the IPCC's "Fifth Assessment Report."[23]

Using data from the Environmental Protection Agency, we found that the United States emitted approximately 40 percent of CO_2 emissions with respect to all Organization for Economic Co-operation and Development (OECD) member nations.[24] In our simulations, we altered OECD projections accordingly, assuming this fraction to be constant over time. We also assumed climate sensitivities varying between 1.5 degrees Celsius and 4.5 degrees Celsius, which encompass the range of "likely" sensitivities specified in the IPCC's "Fifth Assessment Report."[25] The upper bound of this range is significantly higher than that assumed by the Obama Administration's Interagency Working Group in its analysis.[26]

Endnotes

1. "Recognizing the Duty of the Federal Government to Create a Green New Deal," Draft resolution, 116th Cong., 1st Sess., https://assets.documentcloud.org/documents/5729033/Green-New-Deal-FINAL.pdf (accessed February 7, 2019). Several Democratic presidential candidates have also called for a target of net-zero emissions for the United States by 2050. See, for example, "Climate Change and the 2020 Presidential Candidates: Where Do They Stand?" NRDC Action Fund, February 22, 2019, https://www.nrdcactionfund.org/climate-change-and-the-2020-presidential-candidates-where-do-they-stand/ (accessed July 8, 2019).
2. Healthy food security refers to the resolution's call for a "more sustainable food system that ensures universal access to healthy food." See resolution, "Recognizing the Duty of the Federal Government to Create a Green New Deal," 116th Cong., 1st Sess., https://assets.documentcloud.org/documents/5729033/Green-New-Deal-FINAL.pdf (accessed February 7, 2019).
3. Resolution, "Recognizing the Duty of the Federal Government to Create a Green New Deal," pp. 3 and 4.
4. Sixty-three percent of electricity came from CO_2–emitting conventional fuels in 2017.
5. Petroleum accounted for 92 percent of America's transportation fuel in 2017. U.S. Energy Information Administration, "Use of Energy in the United States Explained: Energy Use for Transportation," May 23, 2018, https://www.eia.gov/energyexplained/?page=us_energy_transportation (accessed February 1, 2019).
6. Philip Rossetti, "What it Costs to Go 100 Percent Renewable," American Action Forum, January 25, 2019, https://www.americanactionforum.org/research/what-it-costs-go-100-percent-renewable/ (accessed July 10, 2019).
7. Alexandria Ocasio-Cortez, "Green New Deal FAQ," February 5, 2019, https://ocasio-cortez.house.gov/media/blog-posts/green-new-deal-faq (accessed February 7, 2019). As of February 8, 2019, the referenced webpage was no longer available; an archived copy can be found at https://web.archive.org/web/20190207191119/https://ocasio-cortez.house.gov/media/blog-posts/green-new-deal-faq (accessed March 21, 2019).
8. U.S. Energy Information Administration, "Frequently Asked Questions: What Is U.S. Electricity Generation by Energy Source?" March 1, 2019, https://www.eia.gov/tools/faqs/faq.php?id=427&t=3 (accessed July 3, 2019).
9. Interagency Working Group on Social Cost of Carbon, "Technical Update of the Social Cost of Carbon for Regulatory Impact Analysis," Technical Support Document Under Executive Order 12866, May 2013, https://obamawhitehouse.archives.gov/sites/default/files/omb/assets/inforeg/technical-update-social-cost-of-carbon-for-regulator-impact-analysis.pdf (accessed July 2, 2019), and M. Meinshausen, S. C. B. Raper, and T. M. L. Wigley, "Emulating Coupled Atmosphere-Ocean and Carbon Cycle Models with a Simpler Model, MAGICC6–Part I: Model Description and Calibration," *Atmospheric Chemistry and Physics*, Vol. 11 (2011), pp. 1417–1456, https://www.atmos-chem-phys.net/11/1417/2011/acp-11-1417-2011.html (accessed July 10, 2019), and University Corporation for Atmospheric Research, "MAGICC/SCENGEN," http://www.cgd.ucar.edu/cas/wigley/magicc/ (accessed July 10, 2019).
10. See, for example, Kevin D. Dayaratna, Nicolas D. Loris, and David W. Kreutzer, "Consequences of Paris Protocol: Devastating Economic Costs, Essentially Zero Environmental Benefits," Heritage Foundation *Backgrounder* No. 3080, April 13, 2016, https://www.heritage.org/environment/report/consequences-paris-protocol-devastating-economic-costs-essentially-zero.
11. See, for example, Kevin D. Dayaratna and David W. Kreutzer, "Loaded DICE: An EPA Model Not Ready for the Big Game," Heritage Foundation *Backgrounder* No. 2860, November 21, 2013, https://www.heritage.org/environment/report/loaded-dice-epa-model-not-ready-the-big-game; Kevin D. Dayaratna and David W. Kreutzer, "Unfounded FUND: Yet Another EPA Model Not Ready for the Big Game," Heritage Foundation *Backgrounder* No. 2897, April 29, 2014, https://www.heritage.org/environment/report/unfounded-fund-yet-another-epa-model-not-ready-the-big-game; Kevin D. Dayaratna and Nicolas D. Loris, "Rolling the DICE on Environmental Regulations: A Close Look at the Social Cost of Methane and Nitrous Oxide," Heritage Foundation *Backgrounder* No. 3184, January 19, 2017, https://www.heritage.org/energy-economics/report/rolling-the-dice-environmental-regulations-close-look-the-social-cost; Kevin D. Dayaratna, "At What Cost? Examining the Social Cost of Carbon," testimony before the Subcommittee on Environment and Oversight, Committee on Science and Technology, U.S. House of Representatives, February 27, 2017, https://docs.house.gov/meetings/SY/SY18/20170228/105632/HHRG-115-SY18-Wstate-DayaratnaK-20170228.pdf (accessed July 8, 2019); Kevin D. Dayaratna, "The Flimsy Statistical Models Obama Administration Used to Justify Environmental Agenda," The Daily Signal, March 29, 2017, https://www.dailysignal.com/2017/03/29/the-flimsy-statistical-models-obama-administration-used-to-justify-environmental-agenda/; and Kevin D. Dayaratna, Ross McKitrick, and David W. Kreutzer, "Empirically-Constrained Climate Sensitivity and the Social Cost of Carbon," *Climate Change Economics*, Vol. 8, No. 2 (April 2017), https://www.worldscientific.com/doi/abs/10.1142/S2010007817500063 (accessed July 10, 2019).
12. Katie Tubb, Nicolas D. Loris, and Rachel Zissimos, "Taking the Long View: How to Empower the Coal and Nuclear Industries to Compete and Innovate," Heritage Foundation *Backgrounder* No. 3341, September 5, 2018, https://www.heritage.org/energy-economics/report/taking-the-long-view-how-empower-the-coal-and-nuclear-industries-compete.
13. Nicolas Loris and Katie Tubb, "Regulatory Reform Is the Key to Unlocking Infrastructure Investment," Heritage Foundation *Backgrounder* No. 3384, February 5, 2019, https://www.heritage.org/government-regulation/report/regulatory-reform-the-key-unlocking-infrastructure-investment.
14. Tori Whiting, "Time for Trump to Make Good on His Zero-Tariff Offer," Heritage Foundation *Commentary*, September 14, 2018, https://www.heritage.org/trade/commentary/time-trump-make-good-his-zero-tariffs-offer.
15. See, for example, Nicolas D. Loris, "At Solyndra, More Jobs Lost—and Even More Jobs Lost," The Daily Signal, June 14, 2012, https://www.dailysignal.com/2012/06/14/at-solyndra-more-jobs-lost-and-even-more-jobs-lost/.

16. Nicolas D. Loris, "Free Markets Supply Affordable Energy and a Clean Environment," Heritage Foundation *Backgrounder* No. 2966, October 31, 2014, https://www.heritage.org/environment/report/free-markets-supply-affordable-energy-and-clean-environment.
17. U.S. Department of Energy, Energy Information Administration, "The National Energy Modeling System: An Overview," October 2009, http://www.eia.gov/oiaf/aeo/overview/pdf/0581(2009).pdf (accessed April 3, 2013).
18. Ibid., pp. 3 and 4.
19. HEM's Macroeconomic Activity Module uses the IHS Global Insight Model, which is used by government agencies and Fortune 500 organizations to forecast the effects of economic events and policy changes on notable economic indicators. As with NEMS, the methodologies, assumptions, conclusions, and opinions in this *Backgrounder* are entirely the work of CDA statisticians and economists, and have not been endorsed by, and do not necessarily reflect the view of, the owners of the IHS Global Insight model.
20. Steven A. Gabriel, Andy S. Kydes, and Peter Whitman, "The National Energy Modeling System: A Large-Scale Energy-Economic Equilibrium Model," *Operations Research*, Vol. 49, No. 1 (January–February 2001), pp. 14–25, http://pubsonline.informs.org/doi/pdf/10.1287/opre.49.1.14.11195 (accessed December 23, 2014).
21. Meinshausen, Raper, and Wigley, "Emulating Coupled Atmosphere-Ocean and Carbon Cycle Models with a Simpler Model," and University Corporation for Atmospheric Research, "MAGICC/SCENGEN."
22. Discussion of the model is based on documentation for version 6, for which the authors state that version 5.3 is a special case with the exception of version 6's updated carbon cycle.
23. U.N. Intergovernmental Panel on Climate Change, "Emissions Scenarios," *Special Report*, 2000, https://www.ipcc.ch/site/assets/uploads/2018/03/emissions_scenarios-1.pdf (accessed July 3, 2019); U.N. Intergovernmental Panel on Climate Change, "Climate Change 2001: Synthesis Report," 0-521-80770-0, 2001, http://www.grida.no/publications/267 (accessed July 3, 2019); U.N. Intergovernmental Panel on Climate Change, "Climate Change 2007," *Synthesis Report*, 2008, https://www.ipcc.ch/site/assets/uploads/2018/02/ar4_syr_full_report.pdf (accessed July 3, 2019); and U.N. Intergovernmental Panel on Climate Change, "Climate Change 2014," *Synthesis Report*, 2015, https://www.ipcc.ch/site/assets/uploads/2018/02/SYR_AR5_FINAL_full.pdf (accessed July 3, 2019).
24. U.S. Environmental Protection Agency, "Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990–2017," April 12, 2019, https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks-1990-2017 (accessed July 10, 2019).
25. U.N. Intergovernmental Panel on Climate Change, "Climate Change 2014," *Synthesis Report*, 2015, p. 62, https://www.ipcc.ch/site/assets/uploads/2018/02/SYR_AR5_FINAL_full.pdf, (accessed July 16, 2019).
26. Interagency Working Group on Social Cost of Carbon, "Technical Update of the Social Cost of Carbon for Regulatory Impact Analysis."

BACKGROUNDER

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Loaded DICE: An EPA Model Not Ready for the Big Game

Kevin D. Dayaratna and David W. Kreutzer, PhD

Abstract

The Environmental Protection Agency (EPA) uses three statistical models of the environment and economy, called integrated assessment models (IAMs), to determine the value of the social cost of carbon (SCC), defined by the EPA as the economic damage that a ton of CO_2 emitted today will cause over the next 300 years. This study analyzes the IAM that generates the intermediate EPA results (the DICE model) and finds it flawed beyond use for policymaking. In addition to more fundamental problems outlined by others, we find that reasonable changes in a few assumptions lead to order-of-magnitude changes in estimates of the SCC.

The "social cost of carbon" (SCC) is a metric used by the Environmental Protection Agency (EPA) to quantify the economic impact associated with carbon emissions.[1] The EPA uses three statistical models to estimate the SCC: FUND (Climate Framework for Uncertainty, Negotiation and Distribution), DICE (Dynamic Integrated Climate-Economy), and PAGE (Policy Analysis of the Greenhouse Effect).[2] Although policymakers often refer to the results generated by these models to justify imposing burdensome regulations on the energy sector of the U.S. economy, the fundamental assumptions underlying these models have a number of serious deficiencies.[3] In this study, we look at several of these shortcomings in the DICE model.

In particular, aside from the serious questions concerning the core of integrated assessment models (IAMs) in general, the DICE estimates of the SCC shift substantially with reasonable

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Key Points

- Using the OMB-mandated discount rate that the EPA omitted reduces the 2020 estimate of the "social cost of carbon" (SCC) by more than 80 percent.
- An updated estimate of the ECS distribution (CO_2's temperature impact) reduces the 2020 estimate of the SCC by more than 40 percent.
- With an updated ECS distribution, a time horizon up to 2150, and with the omitted discount rate, the 2020 estimate of the SCC falls to $4.03 from $37.79—a drop of nearly 90 percent.
- Since moderate and defensible changes in assumptions lead to such large changes in the resulting estimates of the SCC, the entire process is susceptible to political gaming.
- While running the DICE model (and similar integrated assessment models) may be a useful academic exercise, the results at this time are nowhere near reliable enough to justify trillions of dollars of government policies and burdensome regulations.

alternatives to just a few assumptions.[4] For instance, our analysis shows that:

- Using a discount rate (a measure of the time value of money) mandated by the Office of Management and Budget (OMB) that the EPA omitted reduces the 2020 estimate of SCC by more than 80 percent;
- An updated estimate of the equilibrium climate sensitivity distribution (ECS)—a measure of CO_2's temperature impact—reduces the 2020 estimate of SCC by more than 40 percent; and
- With an updated ECS distribution, a time horizon up to 2150, and with the omitted discount rate, the 2020 estimate of SCC falls by nearly 90 percent, from $37.79 to $4.03.

Originally devised by William Nordhaus in the early 1990s, the DICE model estimates the SCC based on five scenarios of economic growth projections, population growth projections, forecast CO_2 emissions, and forecasts of non-CO_2 forcings.[5] We recently published a comment to the Department of Energy, investigating how changes to the discount rate, time horizon, and ECS distribution affect the DICE model's computation of the SCC under one such scenario.[6] This study represents a considerably more comprehensive analysis, averaging the results across all five scenarios.

An Overview of the DICE Model

The DICE model attempts to quantify how the atmospheric concentration of CO_2 negatively affects economic output through its impact on global average surface temperature. In the model, a series of equations represents world economic activity, the CO_2 levels that activity generates, and the impact of the resulting CO_2 levels. Each SCC estimate is the average of numerous iterations (10,000 in the EPA's assessment, which we reproduce here) of the model using different potential values for climate sensitivity (how much warming a doubling of CO_2 will generate).[7]

For each year, the model looks at the future incomes and environmental losses for the business-as-usual case and compares it with one with higher CO_2 emissions. The aggregated difference in these values determines the SCC.

Discount Rate

Economists use cost-benefit analysis to determine whether an action or rule makes economic sense. The goal is to use measures of costs and benefits closest to those of the people affected by the rule or action. The economist's role is not to establish how much people *should* value items gained or lost, but to calculate based on observing how much these people actually value these items.

Because people prefer benefits sooner rather than later and costs later rather than sooner, it is necessary to adjust the values of costs and benefits when they occur at different times. For instance, few people would accept an offer of $1 per year for the next 50 years in exchange for $50 right now. There is a risk that the full $50 will not be repaid. There may be investment opportunities that will repay more than $50, and there is simply a very human preference for earlier satisfaction. Interest rates on loans and investments reflect these preferences to receive benefits now and pay costs later. Interest rates are used in the discounting process to put the costs and benefits on an equivalent time basis according to people's observed preferences.

The interest or discount rate that economists choose is not prescriptive, but descriptive. If a 7 percent discount rate makes people indifferent between a benefit now versus a benefit later (for example, indifferent between $100 today versus $107 a year from now), then 7 percent is the appropriate discount rate to use.

The Office of Management and Budget stipulates that government agencies should bracket their cost-benefit analyses by using discount rates of both 3 percent per year and 7 percent per year. Although there may be some flexibility to use discount rates outside these two percentages, cost-benefit estimates using other discount rates are to be in addition to the 3 percent and 7 percent estimates, not in place of them. However, the EPA has presented SCC computations based only on 2.5 percent, 3 percent, and 5 percent discount rates.[8] In Table 1, we present the results using the EPA's 2.5 percent, 3 percent, and 5 percent discount rates as well as using a 7 percent discount rate. Although we do not believe that 2.5 percent is an appropriate rate to use, we include estimates using 2.5 percent so that our results can be fully compared to those of the EPA.

Our estimates for 2.5 percent, 3 percent, and 5 percent discount rates are in line with results that

TABLE 1

Average SCC Baseline, End Year 2300

Year	Discount Rate: 2.5%	Discount Rate: 3%	Discount Rate: 5%	Discount Rate: 7%
2010	$46.57	$30.04	$8.81	$4.02
2015	$52.35	$34.32	$10.61	$5.03
2020	$56.92	$37.79	$12.10	$5.87
2025	$61.48	$41.26	$13.60	$6.70
2030	$66.52	$45.14	$15.33	$7.70
2035	$71.57	$49.03	$17.06	$8.70
2040	$76.95	$53.25	$19.02	$9.85
2045	$82.34	$57.48	$20.97	$11.00
2050	$87.69	$61.72	$23.06	$12.25

Source: Calculations based on Heritage Foundation Monte Carlo simulation results using the DICE model. B 2860 heritage.org

TABLE 2

SCC Average 95th Percentile Baseline, End Year 2300

Year	Discount Rate: 2.5%	Discount Rate: 3%	Discount Rate: 5%	Discount Rate: 7%
2010	$90.67	$56.70	$14.74	$6.18
2015	$101.78	$64.75	$17.79	$7.79
2020	$110.02	$70.92	$20.32	$9.12
2025	$118.18	$77.10	$22.81	$10.45
2030	$127.09	$83.88	$25.68	$12.04
2035	$135.97	$90.65	$28.55	$13.63
2040	$145.43	$97.95	$31.77	$15.45
2045	$154.76	$105.22	$34.98	$17.29
2050	$164.57	$112.89	$38.48	$19.32

Source: Calculations based on Heritage Foundation Monte Carlo simulation results using the DICE model. B 2860 heritage.org

the EPA published earlier this year.[9] The introduction of a 7 percent discount rate markedly lowers the DICE model's SCC estimates. Estimates based on this 7 percent discount rate therefore significantly weakens the EPA's case for adding regulations to limit CO_2 emissions.

Time Horizon

As discussed earlier, the DICE model operates by summing damages over an extended time horizon. Specifically, the EPA's estimates of the SCC are based on summing damages through the year 2300. Economists have great difficulty generating forecasts decades into the future, much less centuries. Therefore, it is highly suspect for the government to claim the capacity to base policy decisions on statistical forecasts extending nearly 300 years into the future.

We re-estimated DICE's SCC values by summing damages through 2150 instead of 2300. Although we believe that even an end year of 2150 is still too far in the future to base meaningful policy, we compared

TABLE 3

Average SCC, End Year 2150

Year	Discount Rate: 2.5%	Discount Rate: 3%	Discount Rate: 5%	Discount Rate: 7%
2010	$36.78	$26.01	$8.66	$4.01
2015	$41.24	$29.65	$10.42	$5.02
2020	$44.41	$32.38	$11.85	$5.85
2025	$47.57	$35.11	$13.28	$6.68
2030	$50.82	$38.00	$14.92	$7.67
2035	$54.07	$40.89	$16.56	$8.66
2040	$57.17	$43.79	$18.36	$9.79
2045	$60.27	$46.68	$20.16	$10.92
2050	$62.81	$49.20	$22.00	$12.13

Source: Calculations based on Heritage Foundation Monte Carlo simulation results using the DICE model. B 2860 heritage.org

TABLE 4

SCC Average 95th Percentile, End Year 2150

Year	Discount Rate: 2.5%	Discount Rate: 3%	Discount Rate: 5%	Discount Rate: 7%
2010	$69.19	$47.89	$14.39	$6.16
2015	$77.44	$54.53	$17.36	$7.77
2020	$82.71	$59.12	$19.73	$9.09
2025	$87.92	$63.67	$22.12	$10.41
2030	$93.09	$68.37	$24.80	$11.98
2035	$98.22	$73.05	$27.47	$13.54
2040	$102.97	$77.61	$30.37	$15.33
2045	$107.63	$82.13	$33.27	$17.13
2050	$111.55	$86.20	$36.25	$19.08

Source: Calculations based on Heritage Foundation Monte Carlo simulation results using the DICE model. B 2860 heritage.org

such estimates to the baseline SCC estimates. Our results for overall means and 95th percentiles averaged over all five scenarios are in Table 3 and Table 4.

TABLE 5

Average SCC Percentage Changes as a Result of Changing End Year from 2300 to 2150

Year	Discount Rate: 2.5%	Discount Rate: 3%	Discount Rate: 5%	Discount Rate: 7%
2010	–21.04%	–13.43%	–1.77%	–0.20%
2015	–21.22%	–13.61%	–1.84%	–0.21%
2020	–21.98%	–14.32%	–2.10%	–0.27%
2025	–22.62%	–14.90%	–2.30%	–0.31%
2030	–23.60%	–15.82%	–2.66%	–0.39%
2035	–24.45%	–16.59%	–2.94%	–0.46%
2040	–25.71%	–17.78%	–3.45%	–0.60%
2045	–26.80%	–18.78%	–3.86%	–0.71%
2050	–28.37%	–20.28%	–4.58%	–0.94%

Source: Authors' calculations based on Heritage Foundation simulation results.

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TABLE 6

Average 95th Percentile SCC Percentage Changes as a Result of Changing End Year from 2300 to 2150

Year	Discount Rate: 2.5%	Discount Rate: 3%	Discount Rate: 5%	Discount Rate: 7%
2010	–23.70%	–15.55%	–2.35%	–0.28%
2015	–23.91%	–15.79%	–2.44%	–0.30%
2020	–24.82%	–16.63%	–2.93%	–0.37%
2025	–25.60%	–17.41%	–3.01%	–0.43%
2030	–26.76%	–18.49%	–3.42%	–0.54%
2035	–27.76%	–19.41%	–3.77%	–0.63%
2040	–29.20%	–20.77%	–4.40%	–0.81%
2045	–30.45%	–21.94%	–4.91%	–0.96%
2050	–32.22%	–23.65%	–5.78%	–1.26%

Source: Authors' calculations based on Heritage Foundation simulation results.

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Table 5 and Table 6 and show the resulting percent changes.

Again, we notice significantly lower estimates as a result of changing the end year.

Equilibrium Climate Sensitivity

CO_2 levels are widely believed, along with many other variables, to affect the earth's temperature. The important question is the magnitude of the impact.

As mentioned earlier, the DICE model accounts for the impact of CO_2 emissions on warming by computing Monte Carlo simulations based on certain assumptions about temperature sensitivity to CO_2 emissions. In particular, the model is based on an ECS distribution defined as a random variable modeling "the equilibrium global average surface warming following a doubling of CO_2 concentration."[10]

However, the EPA used an ECS distribution that was not up to date with the recent literature, creating a problem with its estimates based on the DICE model.[11] A number of recent studies offer more updated ECS distributions.[12] We chose the distribution

TABLE 7

Average SCC-ECS Distribution Updated in Accordance with Otto et al. (2013), End Year 2300

Year	Discount Rate: 2.5%	Discount Rate: 3%	Discount Rate: 5%	Discount Rate: 7%
2010	$26.64	$17.72	$5.73	$2.80
2015	$29.96	$20.24	$6.87	$3.48
2020	$32.65	$22.32	$7.82	$4.04
2025	$35.35	$24.41	$8.78	$4.59
2030	$38.33	$26.74	$9.88	$5.26
2035	$41.31	$29.08	$10.99	$5.93
2040	$44.54	$31.63	$12.24	$6.69
2045	$47.77	$34.18	$13.48	$7.45
2050	$51.19	$36.91	$14.84	$8.29

Source: Calculations based on Heritage Foundation Monte Carlo simulation results using the DICE model.

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TABLE 8

Average 95th Percentile SCC-ECS Distribution Updated in Accordance with Otto et al. (2013), End Year 2300

Year	Discount Rate: 2.5%	Discount Rate: 3%	Discount Rate: 5%	Discount Rate: 7%
2010	$53.33	$34.50	$10.06	$4.57
2015	$59.96	$39.42	$12.13	$5.74
2020	$65.24	$43.42	$13.84	$6.69
2025	$70.51	$47.42	$15.55	$7.65
2030	$76.30	$51.86	$17.52	$8.79
2035	$82.08	$56.30	$19.50	$9.93
2040	$88.31	$61.14	$21.73	$11.23
2045	$94.53	$65.97	$23.95	$12.54
2050	$101.09	$71.13	$26.38	$13.99

Source: Calculations based on Heritage Foundation Monte Carlo simulation results using the DICE model.

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from the Otto et al. study because it is closest distributionally to the ECS distribution assumed by the EPA in their DICE model simulations. Furthermore, almost all of the authors of the Otto study have collaborated on the Intergovernmental Panel on Climate Change's recent "Fifth Assessment Report."[13] Table 7 and Table 8 show our results using the Otto assumptions regarding equilibrium climate sensitivity.

TABLE 9

Average SCC Percentage Changes as a Result of Updating ECS Distribution in Accordance with Otto et al. (2013), End Year 2300

Year	Discount Rate: 2.5%	Discount Rate: 3%	Discount Rate: 5%	Discount Rate: 7%
2010	–42.79%	–41.00%	–35.02%	–30.39%
2015	–42.77%	–41.03%	–35.26%	–30.84%
2020	–42.63%	–40.93%	–35.37%	–31.20%
2025	–42.50%	–40.85%	–35.45%	–31.46%
2030	–42.38%	–40.77%	–35.52%	–31.71%
2035	–42.27%	–40.70%	–35.58%	–31.91%
2040	–42.12%	–40.61%	–35.65%	–32.13%
2045	–41.99%	–40.54%	–35.70%	–32.30%
2050	–41.62%	–40.20%	–35.62%	–32.33%

Source: Authors' calculations based on Heritage Foundation simulation results.

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TABLE 10

Average 95th Percentile SCC Percentage Changes as a Result of Updating ECS Distribution in Accordance with Otto et al. (2013), End Year 2300

Year	Discount Rate: 2.5%	Discount Rate: 3%	Discount Rate: 5%	Discount Rate: 7%
2010	–41.19%	–39.16%	–31.72%	–26.02%
2015	–41.09%	–39.12%	–31.85%	–26.35%
2020	–40.70%	–38.77%	–31.92%	–26.64%
2025	–40.34%	–38.50%	–31.83%	–26.81%
2030	–39.97%	–38.17%	–31.77%	–27.01%
2035	–39.63%	–37.89%	–31.70%	–27.15%
2040	–39.28%	–37.58%	–31.62%	–27.30%
2045	–38.92%	–37.30%	–31.54%	–27.49%
2050	–38.57%	–36.99%	–31.44%	–27.56%

Source: Authors' calculations based on Heritage Foundation simulation results.

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Table 9 and Table 10 show the resulting percentage changes.

Using this more current distribution dramatically alters the SCC estimates. The ECS distribution from the Otto study is also the most conservative of the updated ECS distributions mentioned in the sense that it is closest in distribution to the Roe and Baker distribution used by the EPA. Since the other two distributions (Aldrin et al. and Lewis) are skewed even further to the left than the Otto distribution, using either of them would likely result in even lower SCC estimates.

TABLE 11

Average SCC-ECS Distribution Updated in Accordance with Otto et al. (2013), End Year 2150

Year	Discount Rate: 2.5%	Discount Rate: 3%	Discount Rate: 5%	Discount Rate: 7%
2010	$21.60	$15.64	$5.65	$2.79
2015	$24.23	$17.82	$6.77	$3.48
2020	$26.20	$19.52	$7.69	$4.03
2025	$28.16	$21.22	$8.61	$4.58
2030	$30.21	$23.04	$9.67	$5.24
2035	$32.26	$24.86	$10.73	$5.90
2040	$34.28	$26.71	$11.90	$6.66
2045	$36.30	$28.56	$13.06	$7.41
2050	$38.16	$30.34	$14.29	$8.23

Source: Calculations based on Heritage Foundation Monte Carlo simulation results using the DICE model.

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TABLE 12

SCC Average 95th Percentile-ECS Distribution Updated in Accordance with Otto et al. (2013), End Year 2150

Year	Discount Rate: 2.5%	Discount Rate: 3%	Discount Rate: 5%	Discount Rate: 7%
2010	$42.42	$29.99	$9.89	$4.56
2015	$47.60	$34.20	$11.91	$5.73
2020	$51.28	$37.36	$13.55	$6.68
2025	$54.96	$40.51	$15.19	$7.63
2030	$58.69	$43.82	$17.06	$8.75
2035	$62.42	$47.13	$18.93	$9.88
2040	$66.01	$50.44	$20.98	$11.17
2045	$69.59	$53.75	$23.03	$12.45
2050	$72.76	$56.84	$25.17	$13.86

Source: Calculations based on Heritage Foundation Monte Carlo simulation results using the DICE model.

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Changing the ECS Distribution and Changing the End Year

We can amalgamate the changes in assumptions made in the previous two sections to estimate the SCC by assuming a more current ECS distribution in accordance with the Otto distribution and changing the end year to 2150. (See Table 11 and Table 12.)

TABLE 13

Average SCC Percentage Changes as a Result of Updating ECS Distribution in Accordance with Otto et al. (2013), End Year 2150

Year	Discount Rate: 2.5%	Discount Rate: 3%	Discount Rate: 5%	Discount Rate: 7%
2010	-53.63%	-47.94%	-35.93%	-30.49%
2015	-53.73%	-48.08%	-36.21%	-30.95%
2020	-53.98%	-48.35%	-36.45%	-31.33%
2025	-54.19%	-48.57%	-36.64%	-31.62%
2030	-54.59%	-48.97%	-36.90%	-31.92%
2035	-54.93%	-49.31%	-37.10%	-32.14%
2040	-55.46%	-49.85%	-37.44%	-32.44%
2045	-55.92%	-50.31%	-37.71%	-32.67%
2050	-56.48%	-50.84%	-38.02%	-32.82%

Source: Authors' calculations based on Heritage Foundation simulation results.

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TABLE 14

Average 95th Percentile SCC Percentage Changes as a Result of Updating ECS Distribution in Accordance with Otto et al. (2013), End Year 2150

Year	Discount Rate: 2.5%	Discount Rate: 3%	Discount Rate: 5%	Discount Rate: 7%
2010	–53.21%	–47.11%	–32.91%	–26.16%
2015	–53.23%	–47.18%	–33.08%	–26.50%
2020	–53.39%	–47.32%	–33.32%	–26.83%
2025	–53.50%	–47.45%	–33.38%	–27.03%
2030	–53.82%	–47.75%	–33.56%	–27.30%
2035	–54.09%	–48.01%	–33.69%	–27.49%
2040	–54.61%	–48.50%	–33.96%	–27.74%
2045	–55.03%	–48.92%	–34.18%	–28.00%
2050	–55.79%	–49.65%	–34.58%	–28.25%

Source: Authors' calculations based on Heritage Foundation simulation results.

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Table 13 and Table 14 show the percentage changes.

Table 14 illustrates that changing the ECS distribution in conjunction with changing the end year to 2150 results in even lower SCC estimates.

Conclusions

Our results clearly illustrate that the DICE model used by the EPA to estimate the SCC is extremely sensitive to the assumptions that we examined.

In fact, the assumptions examined in this study are not the only sensitive aspects of the DICE model. In particular, the loss functions of the DICE model and the FUND model are arbitrarily chosen, and we have yet to see sufficient justification for these functions themselves. Since the statistics estimated from these models are dependent on the model's loss function, such justification is important because different loss functions will almost surely yield different results.

Since moderate and defensible changes in assumptions lead to such large changes in the resulting estimates of the SCC, the entire process is susceptible to political gaming. This problem exacerbates the model's more fundamental and more serious shortcomings in estimating damages in the first place. While running the DICE model (and similar integrated assessment models) may be a useful academic exercise in anticipation of solving these very serious problems, the results at this time are nowhere near reliable enough to justify trillions of dollars of government policies and burdensome regulations.

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Endnotes

1. The official definition of the social cost of carbon is the economic damages per metric ton of CO_2 emissions. For further discussion, see U.S. Environmental Protection Agency, "The Social Cost of Carbon," updated September 9, 2013, http://www.epa.gov/climatechange/EPAactivities/economics/scc.html (accessed September 14, 2013).
2. For the DICE model, see William D. Nordhaus, "RICE and DICE Models of Economics of Climate Change," Yale University, November 2006, http://www.econ.yale.edu/~nordhaus/homepage/dicemodels.htm (accessed November 6, 2013). For the FUND model, see "FUND—Climate Framework for Uncertainty, Negotiation and Distribution," http://www.fund-model.org/ (accessed November 6, 2013). For the PAGE model, see Climate CoLab, "PAGE," http://climatecolab.org/resources/-/wiki/Main/PAGE (accessed November 6, 2013).
3. The magnitude and even the sign of the SCC are very much in question. For a discussion of positive benefits of warming and CO_2, see Matt Ridley, "Why Climate Change Is Good for the World," *The Spectator*, October 19, 2013, http://www.spectator.co.uk/features/9057151/carry-on-warming/ (accessed October 25, 2013).
4. For instance, Robert Pindyck says, "IAM-based analyses of climate policy create a perception of knowledge and precision, but that perception is illusory and misleading." Robert S. Pindyck, "Climate Change Policy: What Do the Models Tell Us?" *Journal of Economic Literature*, Vol. 51, No. 3 (September 2013), pp. 860–872.
5. William D. Nordhaus, "The 'DICE' Model: Background and Structure of a Dynamic Integrated Climate-Economy Model of the Economics of Global Warming," Yale University, Cowles Foundation for Research in Economics *Discussion Paper* No. 1009, February 1992. The EPA provided us with the MATLAB code to run the recent version of DICE used in this analysis, but is not responsible for our results.
6. David Kreutzer and Kevin Dayaratna, "Scrutinizing the Social Cost of Carbon: Comment to the Energy Department," The Heritage Foundation, The Foundry, September 16, 2013, http://blog.heritage.org/2013/09/16/scrutinizing-the-social-cost-of-carbon-comment-to-the-energy-department/.
7. Each individual estimate of the SCC is the realization of a Monte Carlo simulation based on a draw from an equilibrium climate sensitivity distribution to model the impact of CO_2 emissions on temperature. Economic output is modeled "using a Cobb-Douglas production function using physical capital and labor as inputs." Labor and total factor productivity increase exogenously over the model's time horizon. During each period, a certain amount of output is lost in accordance with a particular climate-change damage function. Each period's output is subsequently divided among consumption, savings, and emissions reductions' expenditures. The DICE model then "solves for the optimal path on savings and emissions reductions" over an extended time horizon. This optimal path is determined by optimizing an objective function equal to the "discounted sum of all future utilities" based on consumption. The model computes total utility across the entire population as its estimate of the SCC. Recent updates to the DICE model include updates to the carbon cycle model as well as the model's sea level rise representation and its various manifestations. Stephen C. Newbold, "Summary of the Dice Model," U.S. Environmental Protection Agency, http://yosemite.epa.gov/ee/epa/eerm.nsf/vwan/ee-0564-114.pdf/$file/ee-0564-114.pdf (accessed November 5, 2013). See also U.S. Interagency Working Group on Social Cost of Carbon, "Technical Support Document: Technical Update of the Social Cost of Carbon for Regulatory Impact Analysis Under Executive Order 12866," May 2013, revised November 2013, http://www.whitehouse.gov/sites/default/files/omb/assets/inforeg/technical-update-social-cost-of-carbon-for-regulator-impact-analysis.pdf (accessed November 6, 2013).
8. U.S. Office of Management and Budget, "Regulatory Analysis," Circular A-4, September 17, 2003, http://www.whitehouse.gov/omb/circulars_a004_a-4/ (accessed September 14, 2013), and Paul C. "Chip" Knappenberger, "An Example of the Abuse of the Social Cost of Carbon," Cato Institute, August 23, 2013, http://www.cato.org/blog/example-abuse-social-cost-carbon (accessed September 14, 2013).
9. U.S. Interagency Working Group on Social Cost of Carbon, "Technical Support Document" (accessed November 6, 2013).
10. Intergovernmental Panel on Climate Change, "Climate Change 2007: Synthesis Report," http://www.ipcc.ch/pdf/assessment-report/ar4/syr/ar4_syr.pdf (accessed November 5, 2013).
11. Gerard H. Roe and Marcia B. Baker, "Why Is Climate Sensitivity So Unpredictable?" *Science*, Vol. 318, No. 5850 (October 26, 2007), pp. 629–632.
12. Magne Aldrin et al., "Bayesian Estimation of Climate Sensitivity Based on a Simple Climate Model Fitted to Observations of Hemispheric Temperatures and Global Ocean Heat Content," *Environmetrics*, Vol. 23, No. 3 (May 2012), pp. 253–271; Nicholas Lewis, "An Objective Bayesian Improved Approach for Applying Optimal Fingerprint Techniques to Estimate Climate Sensitivity," *Journal of Climate*, Vol. 26, No. 19 (October 2013), pp. 7414–7429, doi: 10.1175/JCLI-D-12-00473.1; and Alexander Otto et al., "Energy Budget Constraints on Climate Response," *Nature Geoscience*, Vol. 6, No. 6 (June 2013), pp. 415–416.
13. Intergovernmental Panel on Climate Change, "Fifth Assessment Report (AR5) Authors and Review Editors," October 29, 2013, http://www.ipcc.ch/pdf/ar5/ar5_authors_review_editors_updated.pdf (accessed September 14, 2013).

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BACKGROUNDER

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Unfounded FUND: Yet Another EPA Model Not Ready for the Big Game

Kevin Dayaratna and David Kreutzer, PhD

Abstract

The Environmental Protection Agency (EPA) calls upon three statistical models, known as integrated assessment models, to estimate the value of the social cost of carbon, defined as the economic damage that one ton of CO_2 emitted today will cause over the next 300 years. In 2013, the Heritage Foundation's Center for Data Analysis (CDA) rigorously examined one of these models—the DICE model—and found it to be "flawed beyond use for policymaking." This study examines another model the EPA uses—the FUND model. As with the DICE model, the CDA finds the FUND model to be extremely sensitive to assumptions. In fact, the FUND model is so sensitive to assumptions that at times it even suggests net economic benefits to CO_2 emissions. Consequently, the CDA researchers believe that both models are fundamentally unsound as a basis for justifying significant regulations of the American economy.

Unable to enact cap-and-trade legislation, even when he was supported by filibuster-proof majorities in Congress, President Barack Obama famously claimed, "Cap and trade was just one way of skinning the cat; it was not the only way."[1] The primary alternative way to skin the cat is regulation by federal agencies, especially by the Environmental Protection Agency (EPA). A disturbing tool used to justify an increasing number of costly regulations is something called the social cost of carbon (SCC) that, for regulatory benefit-cost analysis, assigns a dollar cost to every ton of CO_2 emitted, which can dramatically tilt the cost-benefit calculus toward more expensive regulation.

Key Points

- Using the OMB-mandated discount rate of 7 percent, the Climate Framework for Uncertainty, Negotiation and Distribution (FUND) model suggests an average social cost of carbon (SCC) of essentially zero dollars, suggesting no net economic damages of global warming.
- Upon using the OMB-mandated discount rate in conjunction with updating the equilibrium climate sensitivity distribution, the model reduces its estimate of the SCC for 2020 by nearly $34 a ton (a drop of more than 102 percent).
- The FUND model even allows negative estimates of the SCC. In some instances, the chance of the SCC's being negative is nearly 70 percent.
- With such great sensitivity to assumptions producing results all over the map, the FUND model may remain an interesting academic exercise, but it is almost certainly not reliable enough to justify trillions of dollars' worth of additional economic regulations with which to burden the economy.

This paper, in its entirety, can be found at **http://report.heritage.org/bg2897**

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The regulatory use of the SCC is disturbing because the method for determining the value of the SCC, despite the seemingly sophisticated process for estimating it, is almost completely arbitrary. It is a classic case of "garbage in, garbage out." Others have ably pointed out the fundamental and fatal flaws in the damage functions of the computer models used to estimate the SCC.[2] The damage functions are the very core of the models, and the models cannot provide meaningful SCC estimates without theoretically and empirically sound damage functions.[3] In addition, the process appears to have suffered from assumptions that are biased to give exaggerated values of the SCC. However, the EPA (the primary keeper of the SCC) appears to be completely immune to these criticisms.

This paper takes a different approach to show that the SCC estimates are so unstable regarding reasonable changes in assumptions as to make the SCC entirely unsuitable for regulatory policy even if the core damage function were actually legitimate.

Estimating the Social Cost of Carbon

The SCC is a statistic used by several agencies within the federal government to quantify the economic damages associated with carbon dioxide emissions.[4] These metrics are estimated through the use of three integrated assessment models (IAMs)—the Dynamic Integrated Climate-Economy (DICE) model; the Climate Framework for Uncertainty, Negotiation and Distribution (FUND) model; and the Policy Analysis of the Greenhouse Effect (PAGE) model.[5] As with any statistical models, these IAMs depend on a variety of assumptions. In an earlier study, we examined the DICE model and found it to be extremely sensitive to assumptions. As a result of this sensitivity, we have recommended that the DICE model not be used as a source for justifying trillions of dollars of economic regulations.[6]

In this study, we perform a similarly rigorous analysis of the FUND model. Developed by Richard Tol and David Anthoff, the FUND model is another IAM used for estimating the SCC. Just like the other IAMs used by the EPA, the FUND model's estimates of the SCC are based on Monte Carlo simulations.[7] The EPA reports averages and 95th percentile values over the course of these simulations. As we did with the DICE model, we performed a sensitivity analysis, examining how simple changes to a few fundamental assumptions (in particular, discount rates and equilibrium climate sensitivity distributions) affect these estimates.

Unlike the DICE model, however, the FUND model allows its estimates of the SCC to be negative. We also investigated this negativity. The Interagency Working Group's (IWG's) recent report, used for justifying the SCC as a basis for pervasive regu-

1. News release, "Press Conference by the President," The White House, November 3, 2010, http://www.whitehouse.gov/the-press-office/2010/11/03/press-conference-president (accessed March 11, 2014).
2. For instance, Robert Pindyck says that "IAM-based analyses of climate policy create a perception of knowledge and precision, but that perception is illusory and misleading." Robert Pindyck, "Climate Change Policy: What Do the Models Tell Us?" *Journal of Economic Literature*, September 2013, pp. 860–872. Also see Anne Smith et al., "A Review of the Damage Functions Used in Estimating the Social Cost of Carbon," American Petroleum Institute, February 20, 2014, http://www.afpm.org/WorkArea/DownloadAsset.aspx?id=4111 (accessed March 11, 2014).
3. Damage functions translate temperature increases and sea-level rise to economic impacts within the IAMs.
4. The official definition of the social cost of carbon is the economic damages per metric ton of CO_2 emissions. For further discussion, see U.S. Environmental Protection Agency, "The Social Cost of Carbon," September 9, 2013, http://www.epa.gov/climatechange/EPAactivities/economics/scc.html (accessed September 14, 2013).
5. For the DICE model, see William D. Nordhaus, "RICE and DICE Models of Economics of Climate Change," Yale University, November 2006, http://www.econ.yale.edu/~nordhaus/homepage/dicemodels.htm (accessed November 6, 2013). For the FUND model, see "FUND—Climate Framework for Uncertainty, Negotiation and Distribution," http://www.fund-model.org/ (accessed November 6, 2013). For the PAGE model, see Climate CoLab, "PAGE," http://climatecolab.org/resources/-/wiki/Main/PAGE (accessed November 6, 2013).
6. David Kreutzer and Kevin Dayaratna, "Scrutinizing the Social Cost of Carbon: Comment to the Energy Department," The Heritage Foundation, *The Foundry*, September 16, 2013, http://blog.heritage.org/2013/09/16/scrutinizing-the-social-cost-of-carbon-comment-to-the-energy-department/, and Kevin Dayaratna and David Kreutzer, "Loaded DICE: An EPA Model Not Ready for the Big Game," Heritage Foundation *Backgrounder* No. 2860, November 21, 2013, http://www.heritage.org/research/reports/2013/11/loaded-dice-an-epa-model-not-ready-for-the-big-game.
7. David Anthoff and Richard S. J. Tol, "The Uncertainty About the Social Cost of Carbon: A Decomposition Analysis Using Fund," *Climatic Change*, Vol. 117, No. 3 (2013), pp. 515–530.

lation,[8] glosses over this fact without discussing its implication in detail. Thus, in addition to the above analysis, we also estimate the probability that the SCC can be negative and discuss the resulting implications. Some of these results were presented as a component of a public comment regarding the SCC that we submitted to the Office of Management and Budget (OMB) earlier this year.[9]

An Overview of the FUND Model

In the FUND model, a series of equations and probability densities represent "projections of populations, economic activity and emissions, carbon cycle and climate model responses, and estimates of the monetized welfare impacts of climate change" to estimate the SCC.[10] Each SCC estimate is based on the averaging of 10,000 Monte Carlo iterations based on a number of variables, including different potential values of how much warming a doubling of CO_2 will generate. This distribution, known as the equilibrium climate sensitivity (ECS) distribution, statistically models the probability of different temperature increases caused by a doubling of CO_2 emissions. The model is estimated over five different scenarios projecting economic growth.

Discount Rate. As discussed in our DICE model analysis, economists often call upon cost-benefit analysis to decide whether an action or rule has net economic benefits.[11] The objective is to use measures of costs and benefits closest to those of the people actually affected by the action.

Due to the fact that people prefer benefits earlier instead of later and costs later instead of earlier, it is necessary to normalize costs and benefits to a common time whenever these costs and benefits occur at different times. For example, few people would accept an offer of $4 per year for the next 25 years in exchange for $100 immediately, in part because there is a risk that the full $100 would not be repaid and in part because there are opportunities to earn a positive return that would repay more than $100 over time. In addition, interest rates (or discount rates) manifest the human desire for benefits now and costs later.

The discount rate is a choice made a priori by the researcher. For example, if a 7 percent discount rate makes people indifferent to a benefit now versus a benefit later (for example, $100 today versus $107 a year from now), then 7 percent is the appropriate discount rate to use.

The OMB has stipulated that government agencies should bound their cost-benefit analyses by using discount rates of 3 percent per year and 7 percent per year.[12] The OMB directive allows the use of additional rates when justified. However, the EPA ignored the OMB's recommendation and instead used rates of 2.5 percent, 3 percent, and 5 percent per year. We re-estimated the FUND model to regenerate the EPA's estimates and also to generate estimates using the mandated 7 percent discount rate. Our results are presented in Tables 1 and 2.

Tables 1 and 2 show a number of interesting points. Using the 7 percent discount rate as recommended by the OMB results in an estimated SCC averaging to essentially zero dollars. Thus, under the OMB's own recommendations, this model suggests that there are no economic damages associated with CO_2 emissions.

The average standard deviations are also interesting, quantifying the uncertainty associated with

8. U.S. Interagency Working Group on Social Cost of Carbon, "Technical Support Document: Technical Update of the Social Cost of Carbon for Regulatory Impact Analysis Under Executive Order 12866," May 2013, revised November 2013, http://www.whitehouse.gov/sites/default/files/omb/assets/inforeg/technical-update-social-cost-of-carbon-for-regulator-impact-analysis.pdf (accessed November 6, 2013).

9. Kreutzer and Dayaratna, "Scrutinizing the Social Cost of Carbon"; Dayaratna and Kreutzer, "Loaded DICE"; and Kevin Dayaratna and David Kreutzer, "Building on Quicksand: The Social Cost of Carbon," The Heritage Foundation, *The Foundry*, February 12, 2014, http://blog.heritage.org/2014/02/12/building-quicksand-social-cost-carbon/.

10. Anthoff and Tol, "The Uncertainty About the Social Cost of Carbon," which references P. Michael Link and Richard S. J. Tol, "The Economic Impact of a Shutdown of the Thermohaline Circulation: An Application of FUND," *Climate Change*, Vol. 104, No. 2 (2011), pp. 287–304, and Richard S. J. Tol, "On the Optimal Control of Carbon Dioxide Emissions: An Application of FUND," *Environmental Modeling & Assessment*, Vol. 2 (1997), pp. 151–163.

11. Kreutzer and Dayaratna, "Scrutinizing the Social Cost of Carbon," and Dayaratna and Kreutzer, "Loaded DICE."

12. U.S. Office of Management and Budget, "Regulatory Analysis," Circular A-4, September 17, 2003, http://www.whitehouse.gov/omb/circulars_a004_a-4/ (accessed September 14, 2013), and Paul C. Knappenberger, "An Example of the Abuse of the Social Cost of Carbon," Cato Institute, August 23, 2013, http://www.cato.org/blog/example-abuse-social-cost-carbon (accessed September 14, 2013).

these probability distributions.[13] Although assumptions regarding lower discount rates suggest higher estimates of the SCC than do higher discount rates, the associated standard deviations are, on average, also notably higher. These statistics signify the strong uncertainty associated with the SCC estimates at lower discount rates and, therefore, their lack of reliability.

As a result, these low discount rates result in SCC probability distributions with equally likely (or unlikely) high and low estimates of the SCC. Table 3 shows the average 5th and 95th percentiles, respectively, averaged across all five scenarios.

Under all four discount rates, there is a non-zero probability of negative SCC. The negative SCC would signify a net economic benefit to CO_2 emissions (discussed in more detail under the heading "Negativity of the SCC").

Equilibrium Climate Sensitivity. Although global-warming activists, including President Obama, consistently claim that the science on global warming is settled, anyone who has any familiarity with the scientific process would understand that research is a constant, ongoing process.[14] For instance, one critical component of unsettled science is how much warming will be generated by a given increase in atmospheric CO_2 levels. This important (possibly all-important) relationship is called the ECS. The ECS typically gives an expected warming in degrees centigrade for a doubling of atmospheric CO_2 levels.

Instead of using a single number, or point estimate, for the ECS, the integrated assessment models use a distribution of possible values for the ECS. In essence, the distribution is a spectrum of values in which potential temperatures are weighted by their probability of occurrence. Because of the myriad factors that affect measured temperatures, estimates of ECS distributions are themselves uncertain and evolve as new data and theory are added to the process.

The IAMs used by the IWG to estimate the SCC are grounded on the specification of such an ECS distribution. Since 2010, the IWG has used an ECS distribution based on an academic paper by Gerard Roe and Marcia Baker published seven years ago.[15] Since then, a number of updated ECS distributions have been estimated, suggesting lower probabilities of extreme global warming.[16]

Further, in the IWG's original 2013 report,[17] the use of the Roe–Baker distribution in the FUND model was specified incorrectly. After informing them of this misspecification, the EPA corrected the report and opened up the SCC for public comment.[18] We re-estimated the FUND model using two updated ECS distributions from studies in the peer-reviewed academic literature.[19] Tables 5–8 show estimates of the average SCC as well as the average standard deviation across all five scenarios for two more recent choices of ECS distributions compared to the outdated Roe–Baker distribution used by the IWG.

These tables show a number of interesting changes in the SCC. In particular, the average SCC estimate is markedly lower, and sometimes even negative, using these newer ECS distributions. There is also the continued lack of certainty associated with lower discount rates quantified by their high average standard deviations, as was the case with the outdated Roe–Baker distribution.

The IWG reports the overall 95th percentile at the 3 percent discount rate across all three models.

13. Of course, although averages across standard deviations are not standard deviations themselves, they enable us to quantify the uncertainty associated with the five probability distributions used to estimate the SCC.

14. News release, "President Barack Obama's State of the Union Address," The White House, January 28, 2014, http://www.whitehouse.gov/the-press-office/2014/01/28/president-barack-obamas-state-union-address (accessed March 17, 2014).

15. Gerard H. Roe and Marcia B. Baker, "Why Is Climate Sensitivity So Unpredictable?" *Science*, Vol. 318, No. 5850 (October 26, 2007), pp. 629–632.

16. Nicholas Lewis, "An Objective Bayesian Improved Approach for Applying Optimal Fingerprint Techniques to Estimate Climate Sensitivity," *Journal of Climate*, Vol. 26, No. 19 (October 2013), pp. 7414–7429; Alexander Otto et al., "Energy Budget Constraints on Climate Response," *Nature Geoscience*, Vol. 6, No. 6 (June 2013), pp. 415–416; Magne Aldrin et al., "Bayesian Estimation of Climate Sensitivity Based on a Simple Climate Model Fitted to Observations of Hemispheric Temperatures and Global Ocean Heat Content," *Environmetrics*, Vol. 23, No. 3 (May 2012), pp. 253–271.

17. U.S. Interagency Working Group on Social Cost of Carbon, "Technical Support Document."

18. Kevin Dayaratna and David Kreutzer, "Heritage Contributes to the Reopening of the White House's Social Cost of Carbon Discussion," The Heritage Foundation, *The Foundry*, November 6, 2013, http://blog.heritage.org/2013/11/06/white-house-reopens-the-scc/.

19. Lewis, "An Objective Bayesian Improved Approach for Applying Optimal Fingerprint Techniques to Estimate Climate Sensitivity," and Otto et al., "Energy Budget Constraints on Climate Response."

The agency uses this statistic to represent an upper threshold on the economic damages associated with CO_2 emissions. To illustrate the sensitivity to changes in the ECS distributions, we present both the 5th and 95th percentiles. (See Tables 9 and 10.) These statistics represent the extremities of the distributions modeling the SCC as estimated by the FUND model.

Clearly, the more up-to-date distributions offer vastly different estimates of the SCC. Furthermore, there is more negativity and just as much, if not more, variability of the SCC, especially for the lower discount rates. This variability clearly illustrates the FUND model's sensitivity to assumptions and resulting unreliability as a meaningful methodology for justifying potentially onerous economic regulations.

Negativity of the SCC. As mentioned, of the three statistical models the EPA uses to estimate the SCC, only the FUND model allows the SCC to be negative. We noticed that the 5th percentiles of the SCC indicate negative estimates of the SCC. A worthwhile exercise for such models is to estimate the probability of a negative SCC. These estimates are given in Tables 11, 12, and 13, averaging across all five of the model's economic growth scenarios:

All of these probabilities are non-zero. In fact, for the 7 percent discount rate recommended by the OMB, the chance for a negative SCC is nearly 70 percent for 2020. If one were to take these results seriously, they would suggest that CO_2 emissions are likely to yield a net benefit. Using the 7 percent discount rate required by the OMB and using the more recent ECS distributions, the FUND model indicates that there is a nearly 70 percent chance that, in addition to their costly compliance burden, climate policies will create economic damage in the future.

The policy prescription implied by negative values of the SCC would be to subsidize CO_2 emissions. We do not take such a position here, but merely present these results to illustrate how unsuitable for regulatory purposes a statistical model is that suggests both positive and negative economic affects of global warming.

Charts 1–6 are histograms illustrating the wide range of estimates that the FUND model's estimates of the SCC can take on for 2020 based on one of the model's five different economic growth scenarios.[20]

These probability distributions illustrate a number of important aspects regarding the SCC. In particular, for the low 2.5 percent discount rates, Charts 1, 3, and 5 illustrate the great uncertainty associated with such a model. The distributions are greatly spread out and have notable components of their probability mass around zero. Additionally, when compared across different assumptions regarding discount rates as well as equilibrium climate sensitivity, these probability distributions clearly illustrate how the SCC estimates are scattered all over the map with the overall distributions changing markedly after tweaking of the model's most fundamental assumptions.

Using a model with such uncertainty is a flawed way of devising policy to justify trillions of dollars of economic regulations. Table 14 shows how much the average estimates of the SCC change as a result of simple alterations in ECS distributions and discount rates.

Conclusion

As with any statistical model, IAMs are grounded in assumptions that researchers make. As illustrated here, the FUND model is extremely sensitive to many assumptions. Altering the discount rate to 7 percent as recommended by the OMB and employing more recent peer-reviewed ECS distributions delivers drastically lower estimates of the SCC. Furthermore, changes in the assumptions suggest large probabilities of a negative SCC. Other potential changes, such as altering the end year to something less than the model's unrealistically distant projections of economic damages (which extend nearly 300 years into the future) as well as alterations to the model's loss function, have the potential to change the model's results drastically.[21]

As a result of this sensitivity we conclude, as we did with the DICE model, that the FUND model, although an interesting academic exercise, is at least at this point completely unfit as a tool to justify trillions of dollars of economic regulations.[22]

20. These distributions are based on the model's "IMAGE" scenario, depicting particular projections about economic growth for subsequent decades.

21. Kreutzer and Dayaratna, "Scrutinizing the Social Cost of Carbon," and Dayaratna and Kreutzer, "Loaded DICE."

22. The third IAM used by the EPA, the PAGE model, is proprietary; its creator, Christopher Hope, insists on the right to be a coauthor of any publication using his model. This makes independent verification impossible. Thus, we do not plan to analyze the PAGE model and believe that the conditions imposed on its use should exclude it from any official process to estimate the SCC.

*—**Kevin D. Dayaratna** is Research Programmer and Policy Analyst, and **David W. Kreutzer, PhD**, is a Research Fellow for Energy Economics and Climate Change, in the Center for Data Analysis at The Heritage Foundation.* *The authors would like to thank Pat Michaels and Chip Knappenberger of the Cato Institute for their assistance with this study.*

Appendix: Tables 1–14

TABLE 1

Average SCC, Using Outdated Roe Baker (2007) Distribution

	DISCOUNT RATE			
Year	**2.5%**	**3%**	**5%**	**7%**
2010	$29.69	$16.98	$1.87	–$0.53
2020	$32.90	$19.33	$2.54	–$0.37
2030	$36.16	$21.78	$3.31	–$0.13
2040	$39.53	$24.36	$4.21	$0.19
2050	$42.98	$27.06	$5.25	$0.63

Source: Calculations based on Heritage Foundation Monte Carlo simulation results using the FUND model.

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TABLE 2

Average Standard Deviation of SCC Averaged Across All Five Scenarios, Using Outdated Roe Baker (2007) Distribution

	DISCOUNT RATE			
Year	**2.5%**	**3%**	**5%**	**7%**
2010	$64.24	$31.45	$5.19	$2.24
2020	$70.66	$35.68	$6.28	$2.79
2030	$77.28	$40.24	$7.48	$3.40
2040	$84.05	$45.14	$8.78	$4.05
2050	$90.75	$50.31	$10.22	$4.76

Source: Calculations based on Heritage Foundation Monte Carlo simulation results using the FUND model.

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TABLE 3

SCC Average 5th Percentile Averaged Across All Five Scenarios, Using Outdated Roe Baker (2007) Distribution

	DISCOUNT RATE			
Year	**2.5%**	**3%**	**5%**	**7%**
2010	–$3.22	–$4.21	–$4.58	–$3.80
2020	–$3.31	–$4.48	–$5.15	–$4.42
2030	–$3.26	–$4.63	–$5.66	–$5.03
2040	–$3.06	–$4.63	–$6.11	–$5.58
2050	–$2.74	–$4.48	–$6.41	–$6.07

Source: Calculations based on Heritage Foundation Monte Carlo simulation results using the FUND model.

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TABLE 4

SCC Average 95th Percentile Averaged Across All Five Scenarios, Using Outdated Roe Baker (2007) Distribution

	DISCOUNT RATE			
Year	**2.5%**	**3%**	**5%**	**7%**
2010	$81.63	$49.06	$10.23	$3.23
2020	$89.70	$55.33	$12.54	$4.28
2030	$97.69	$61.54	$15.03	$5.46
2040	$105.55	$67.76	$17.61	$6.74
2050	$113.54	$74.11	$20.35	$8.14

Source: Calculations based on Heritage Foundation Monte Carlo simulation results using the FUND model.

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TABLE 5

Average SCC, Using Otto et al. (2013) Distribution

	DISCOUNT RATE			
Year	**2.5%**	**3%**	**5%**	**7%**
2010	$11.28	$6.27	$0.05	–$0.93
2020	$12.66	$7.30	$0.36	–$0.87
2030	$14.01	$8.35	$0.74	–$0.75
2040	$17.94	$11.08	$1.50	–$0.49
2050	$19.94	$12.69	$2.21	–$0.14

Source: Calculations based on Heritage Foundation Monte Carlo simulation results using the FUND model.

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TABLE 6

Average Standard Deviation of SCC Averaged Across All Five Scenarios, Using Otto et al. (2013) Distribution

	DISCOUNT RATE			
Year	**2.5%**	**3%**	**5%**	**7%**
2010	$160.74	$87.99	$10.51	$2.56
2020	$200.36	$114.99	$15.61	$3.65
2030	$250.02	$150.49	$23.51	$5.44
2040	$61.38	$35.42	$7.91	$3.90
2050	$67.59	$40.07	$9.28	$4.56

Source: Calculations based on Heritage Foundation Monte Carlo simulation results using the FUND model.

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TABLE 7

Average SCC, Using Lewis (2013) Distribution

	DISCOUNT RATE			
Year	**2.5%**	**3%**	**5%**	**7%**
2010	$5.20	$2.84	–$0.54	–$1.06
2020	$6.20	$3.65	–$0.30	–$1.03
2030	$7.01	$4.39	$0.03	–$0.93
2040	$7.83	$5.18	$0.47	–$0.73
2050	$8.63	$6.01	$1.03	–$0.41

Source: Calculations based on Heritage Foundation Monte Carlo simulation results using the FUND model.

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TABLE 8

Average Standard Deviation of SCC Averaged Across All Five Scenarios, Using Lewis (2013) Distribution

	DISCOUNT RATE			
Year	**2.5%**	**3%**	**5%**	**7%**
2010	$84.59	$51.36	$8.50	$2.47
2020	$105.64	$66.98	$12.51	$3.53
2030	$106.40	$70.69	$15.53	$4.70
2040	$106.32	$73.95	$19.10	$6.27
2050	$105.15	$76.53	$23.25	$8.39

Source: Calculations based on Heritage Foundation Monte Carlo simulation results using the FUND model.

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TABLE 9

SCC Average 5th Percentile Averaged Across All Five Scenarios, Assuming 3% Discount Rate

Year	Outdated Roe-Baker (2007) Distribution	Otto et al. (2013) Distribution	Lewis (2013) Distribution
2010	–$4.21	–$10.97	–$11.40
2020	–$4.48	–$12.33	–$12.79
2030	–$4.63	–$13.60	–$14.09
2040	–$4.63	–$14.72	–$15.27
2050	–$4.48	–$15.73	–$16.21

Source: Calculations based on Heritage Foundation Monte Carlo simulation results using the FUND model.

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TABLE 10

SCC Average 95th Percentile Averaged Across All Five Scenarios, Assuming 3% Discount Rate

Year	Outdated Roe-Baker (2007) Distribution	Otto et al. (2013) Distribution	Lewis (2013) Distribution
2010	$49.06	$32.80	$19.73
2020	$55.33	$37.37	$22.69
2030	$61.54	$41.97	$25.60
2040	$67.76	$46.85	$28.43
2050	$74.11	$51.65	$30.94

Source: Calculations based on Heritage Foundation Monte Carlo simulation results using the FUND model.

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TABLE 11

Probability of Negative SCC Averaged Across All Five Scenarios Using Outdated Roe Baker (2007) Distribution

	DISCOUNT RATE			
Year	2.5%	3%	5%	7%
2010	0.087	0.121	0.372	0.642
2020	0.084	0.115	0.344	0.601
2030	0.080	0.108	0.312	0.555
2040	0.075	0.101	0.282	0.507
2050	0.071	0.093	0.251	0.455

Source: Calculations based on Heritage Foundation Monte Carlo simulation results using the FUND model.

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TABLE 12

Probability of Negative SCC Averaged Across All Five Scenarios Using Otto et al. (2013) Distribution

	DISCOUNT RATE			
Year	2.5%	3%	5%	7%
2010	0.278	0.321	0.529	0.701
2020	0.268	0.306	0.496	0.661
2030	0.255	0.291	0.461	0.619
2040	0.244	0.274	0.425	0.571
2050	0.228	0.256	0.386	0.517

Source: Calculations based on Heritage Foundation Monte Carlo simulation results using the FUND model.

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TABLE 13

Probability of Negative SCC Averaged Across All Five Scenarios Using Lewis (2013) Distribution

	DISCOUNT RATE			
Year	**2.5%**	**3%**	**5%**	**7%**
2010	0.390	0.431	0.598	0.722
2020	0.375	0.411	0.565	0.685
2030	0.361	0.392	0.530	0.645
2040	0.344	0.371	0.491	0.598
2050	0.326	0.349	0.449	0.545

Source: Calculations based on Heritage Foundation Monte Carlo simulation results using the FUND model.

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TABLE 14

Differences in SCC Estimates

	Comparing 2.5% Discount Rate Assuming the Roe Baker (2007) ECS Distribution to the 7% Discount Rate Assuming the Otto et al. (2013) Distribution	Comparing 2.5% Discount Rate Assuming the Roe Baker (2007) ECS Distribution to the 7% Discount Rate Assuming the Lewis (2013) Distribution
2010	–$30.62	–$30.75
2020	–$33.77	–$33.93
2030	–$36.91	–$37.09
2040	–$40.02	–$40.26
2050	–$43.12	–$43.39

Source: Calculations based on Heritage Foundation Monte Carlo simulation results using the FUND model.

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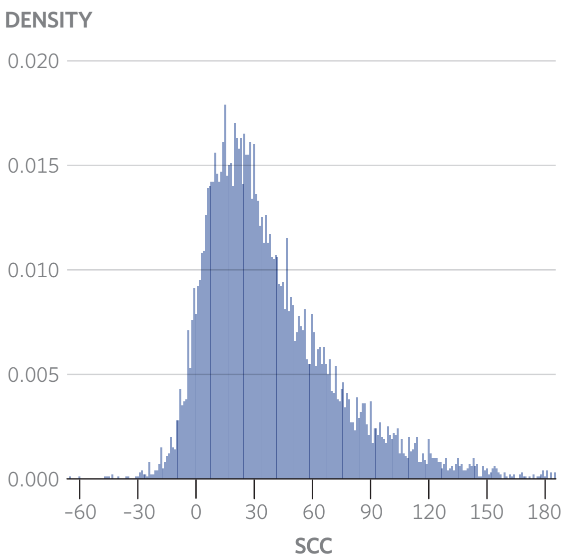
Appendix: Charts 1–6

CHART 1

2020 SCC Monte Carlo Estimates at 2.5% Discount Rate Assuming the Outdated Roe Baker (2007) ECS Distribution



Source: Calculations based on Heritage Foundation Monte Carlo simulation results using the FUND model.

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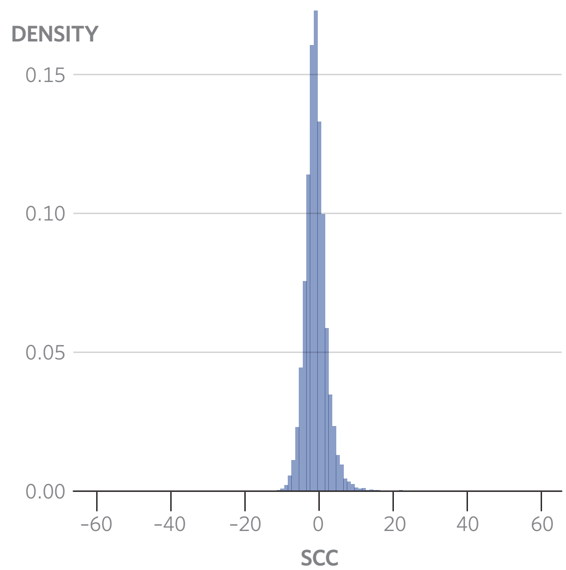
CHART 2

2020 SCC Monte Carlo Estimates at 7% Discount Rate Assuming the Outdated Roe Baker (2007) ECS Distribution



Source: Calculations based on Heritage Foundation Monte Carlo simulation results using the FUND model.

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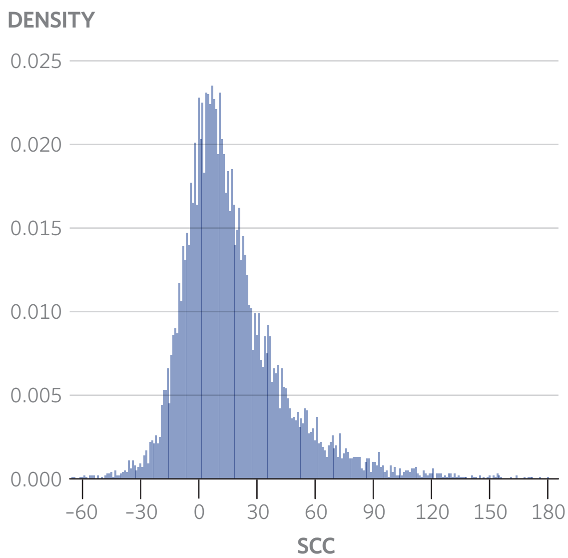
CHART 3

2020 SCC Monte Carlo Estimates at 2.5% Discount Rate Assuming the Otto et al. ECS Distribution



Source: Calculations based on Heritage Foundation Monte Carlo simulation results using the FUND model.

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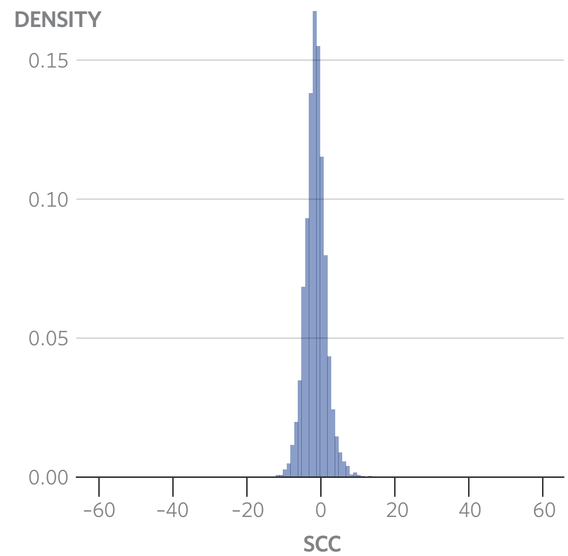
CHART 4

2020 SCC Monte Carlo Estimates at 7% Discount Rate Assuming the Otto et al. ECS Distribution



Source: Calculations based on Heritage Foundation Monte Carlo simulation results using the FUND model.

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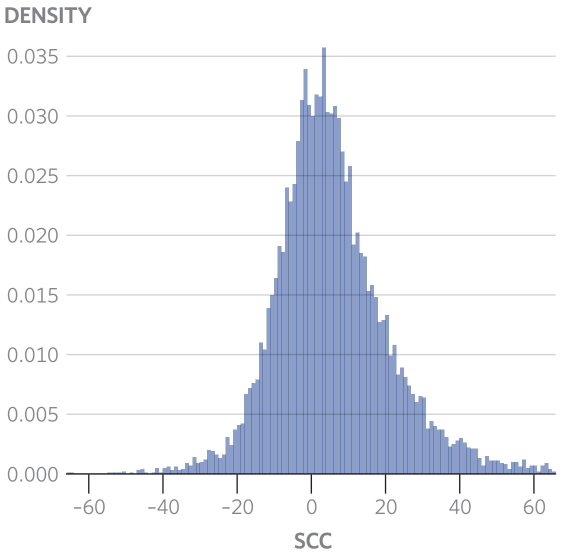
CHART 5

2020 SCC Monte Carlo Estimates at 2.5% Discount Rate Assuming the Lewis ECS Distribution



Source: Calculations based on Heritage Foundation Monte Carlo simulation results using the FUND model.

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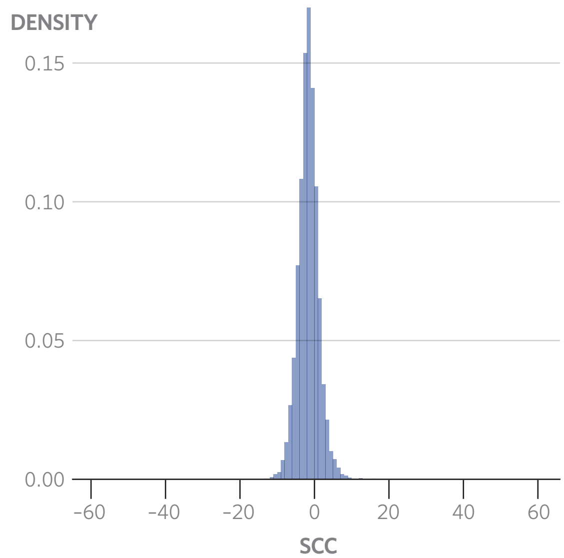
CHART 6

2020 SCC Monte Carlo Estimates at 7% Discount Rate Assuming the Lewis ECS Distribution



Source: Calculations based on Heritage Foundation Monte Carlo simulation results using the FUND model.

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BACKGROUNDER

No. 2990 | FEBRUARY 17, 2015

The Obama Administration's Climate Agenda Will Hit Manufacturing Hard: A State-by-State Analysis

Kevin D. Dayaratna, PhD, Nicolas D. Loris, and David W. Kreutzer, PhD

Abstract

Building on an earlier study of the economic impact of Obama Administration climate policies, this study breaks down the employment impacts of new regulations by state and congressional district. The climate regulations disproportionately and negatively impact states and districts with higher-than-average employment in manufacturing or mining.

In an earlier study, we examined the economic impact of climate change–related regulations at the national level and found devastating job losses over the course of the next two decades. In this study, we quantify this impact by state and congressional district. Not surprisingly, we find that all states would suffer from this policy. Given these results and the regulations' negligible positive impact on the climate and the environment, policymakers should avoid instituting these potentially burdensome regulations.

Overview

The Obama Administration has put forward a variety of rules and goals aimed at cutting carbon dioxide emissions. These rules would drive up energy costs, reduce economic activity, and disrupt job markets. A previous Heritage Foundation study outlined the projected economic impact of such policy.[1] It found by 2030:

- An average employment shortfall of nearly 300,000 jobs,
- A peak employment shortfall of more than 1 million jobs,
- 500,000 jobs lost in manufacturing,

KEY POINTS

- The Obama Administration has put forward a variety of rules and goals aimed at cutting carbon dioxide emissions by regulating motor vehicles and new and existing power plants.
- Even though the regulations would have a negligible positive impact on the climate and the environment, the Obama Administration has moved ahead.
- These rules would drive up energy costs, reduce economic activity, and disrupt job markets.
- Every state would experience overwhelmingly negative impacts as a result of these regulations.
- Because the regulations would disproportionately affect manufacturing jobs, state economies that are manufacturing-intensive can expect disproportionate employment losses.
- The Heritage Foundation has modeled how the regulations will affect manufacturing jobs in each state and congressional district.

This paper, in its entirety, can be found at **http://report.heritage.org/bg2990**

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- Destruction of more than 45 percent of coal-mining jobs,
- A loss of more than $2.5 trillion (inflation-adjusted) in aggregate gross domestic product, and
- A total income loss of more than $7,000 (inflation-adjusted) per person.

In the current study, job impacts are disaggregated to show potential effects by state and by congressional district. Because manufacturing jobs are disproportionately affected, state economies that are manufacturing-intensive can expect disproportionate employment losses.

The Proposed Regulations

For decades, environmental activist organizations have pushed to regulate carbon dioxide emissions. Even though such regulations would have a negligible positive impact on the climate and the environment, the Obama Administration has introduced a series of measures aimed at controlling emissions from motor vehicles and power plants, both new and existing.[2] The economic basis for these regulations has been the social cost of carbon (SCC).

Derived from integrated assessment models (IAMs), the SCC supposedly quantifies the economic damages associated with carbon dioxide emissions. Although conceptually appealing and technically sophisticated in many ways, the IAMs suffer from inherent flaws, including unrealistic assumptions about the costs of future damages, the temperature changes caused by increased carbon dioxide emissions into the atmosphere, and the time horizon (nearly 300 years into the future). Because of these flaws, the IAMs are fundamentally unsuitable for regulatory application.[3]

The Economic Impact by State

In the earlier study, we used the Heritage Energy Model (HEM) to quantify the economic impact that such regulations based on the SCC would have on the American economy.[4] To estimate the economic impact of the Administration's regulatory scheme, based on an estimated SCC of $37 per ton, we modeled the impact of an equivalent tax of $37 per ton of carbon emissions[5] instituted in 2015 and increasing according to the EPA's annual SCC estimates.[6] Taxing CO_2-emitting energy incentivizes businesses and consumers to change production processes, technologies, and behavior in a manner comparable to the Administration's regulatory scheme. To neutralize the analytical impacts of a tax's income transfer, we model a scenario in which 100 percent of carbon-tax revenue is returned to taxpayers.

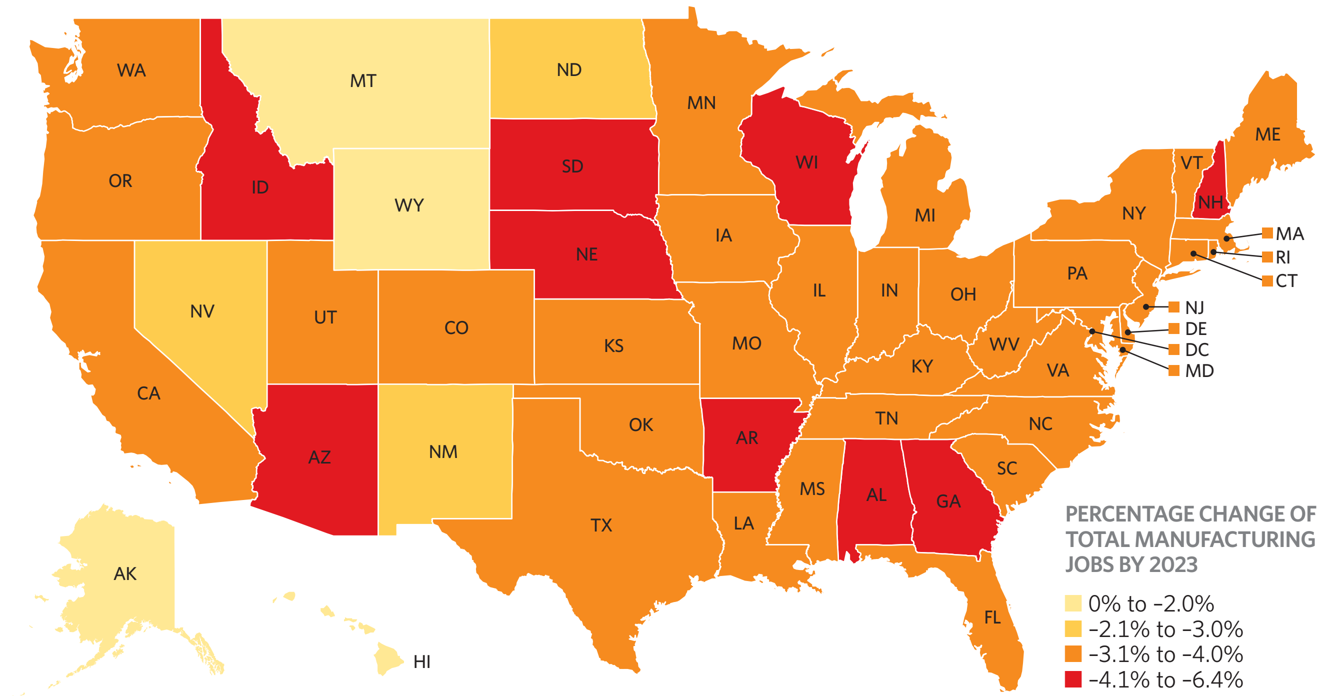
Map 1 shows the impact of such a regulatory scheme on manufacturing jobs by state eight years from now (the midpoint of the period analyzed).[7]

1. Kevin D. Dayaratna, Nicolas D. Loris, and David W. Kreutzer, "The Obama Administration's Climate Agenda: Underestimated Costs and Exaggerated Benefits," Heritage Foundation *Backgrounder* No. 2975, http://www.heritage.org/research/reports/2014/11/the-obama-administrations-climate-agenda-underestimated-costs-and-exaggerated-benefits.
2. Ibid.
3. Kevin D. Dayaratna and David W. Kreutzer, "Unfounded FUND: Yet Another EPA Model Not Ready for the Big Game," Heritage Foundation *Backgrounder* No. 2897, http://www.heritage.org/research/reports/2014/04/unfounded-fund-yet-another-epa-model-not-ready-for-the-big-game, and Kevin D. Dayaratna and David W. Kreutzer, "Loaded DICE: An EPA Model Not Ready for the Big Game," Heritage Foundation *Backgrounder* No. 2860, November 21, 2013, http://www.heritage.org/research/reports/2013/11/loaded-dice-an-epa-model-not-ready-for-the-big-game.
4. Dayaratna et al., "The Obama Administration's Climate Agenda."
5. Although we refer to a "$37 carbon tax," this is shorthand for the SCC schedule produced by the Interagency Working Group in 2013. It is $37 per ton of CO_2 in 2020, but lower in earlier years and higher in subsequent years.
6. U.S. Interagency Working Group on Social Cost of Carbon, "Technical Support Document: Technical Update of the Social Cost of Carbon for Regulatory Impact Analysis Under Executive Order 12866," The White House, revised November 2013, p. 18, http://www.whitehouse.gov/sites/default/files/omb/assets/inforeg/technical-update-social-cost-of-carbon-for-regulator-impact-analysis.pdf (accessed December 23, 2014).
7. Our analysis covered the period to 2030. We chose 2023 in this study because it is a reasonable representation of the average economic impact of the policy across the entire time horizon. These results were calculated using results from the Heritage Energy Model, using employment data from the American Community Survey in order to calculate the impact in various congressional districts. U.S. Census Bureau, American Community Survey, http://www.census.gov/acs/www/ (accessed December 23, 2014). For a more detailed explanation of HEM's methodology, see the Appendix.

MAP 1

EPA Regulations Would Eliminate 586,000 Manufacturing Jobs

EPA regulations on carbon dioxide emissions would significantly impact the U.S. manufacturing sector. By 2023, 34 states would lose 3–4 percent of their manufacturing jobs, and nine other states would lose more.



State	Jobs Lost	% Total
Alabama	10,718	-4.14%
Alaska	524	-1.59%
Arizona	7,964	-4.02%
Arkansas	6,826	-4.16%
California	65,330	-3.62%
Colorado	7,116	-3.80%
Connecticut	7,571	-3.94%
Delaware	1,605	-3.47%
District of Columbia	147	-0.34%
Florida	17,314	-3.77%
Georgia	18,082	-4.10%
Hawaii	773	-0.97%
Idaho	2,695	-5.76%
Illinois	29,868	-3.72%
Indiana	21,848	-3.76%
Iowa	8,968	-3.74%
Kansas	6,871	-3.72%

State	Jobs Lost	% Total
Kentucky	9,819	-3.40%
Louisiana	6,288	-3.53%
Maine	2,371	-3.30%
Maryland	5,893	-3.36%
Massachusetts	12,080	-3.82%
Michigan	28,294	-3.71%
Minnesota	14,771	-3.67%
Mississippi	6,068	-3.80%
Missouri	12,500	-3.76%
Montana	839	-1.75%
Nebraska	3,974	-4.32%
Nevada	2,006	-2.40%
New Hampshire	3,452	-6.39%
New Jersey	14,827	-3.58%
New Mexico	1,727	-2.39%
New York	24,196	-3.89%
North Carolina	20,996	-3.63%

State	Jobs Lost	% Total
North Dakota	1,037	-2.33%
Ohio	31,747	-3.82%
Oklahoma	6,497	-3.09%
Oregon	7,643	-3.84%
Pennsylvania	28,926	-3.69%
Rhode Island	2,260	-3.16%
South Carolina	10,731	-3.70%
South Dakota	1,622	-5.05%
Tennessee	14,159	-3.51%
Texas	42,760	-3.74%
Utah	5,431	-3.51%
Vermont	1,378	-3.41%
Virginia	11,503	-3.41%
Washington	13,077	-3.79%
West Virginia	2,467	-3.25%
Wisconsin	20,421	-4.19%
Wyoming	489	-0.58%

Source: Authors' calculations based on data from the Heritage Energy Model. For more information, see the Appendix.

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As the numbers illustrate, all states would experience overwhelmingly negative impacts as a result of these regulations.

The Appendix includes these results by congressional district.

Although the economic damages from the Obama Administration's energy-stifling carbon policy will be overarching, these damages will clearly impact manufacturing jobs all across the country. Most notably, states with manufacturing-intensive economies will suffer a great deal as a result of this policy. As a result, policymakers should avoid imposing these destructive policies on such an integral component of the American economy.

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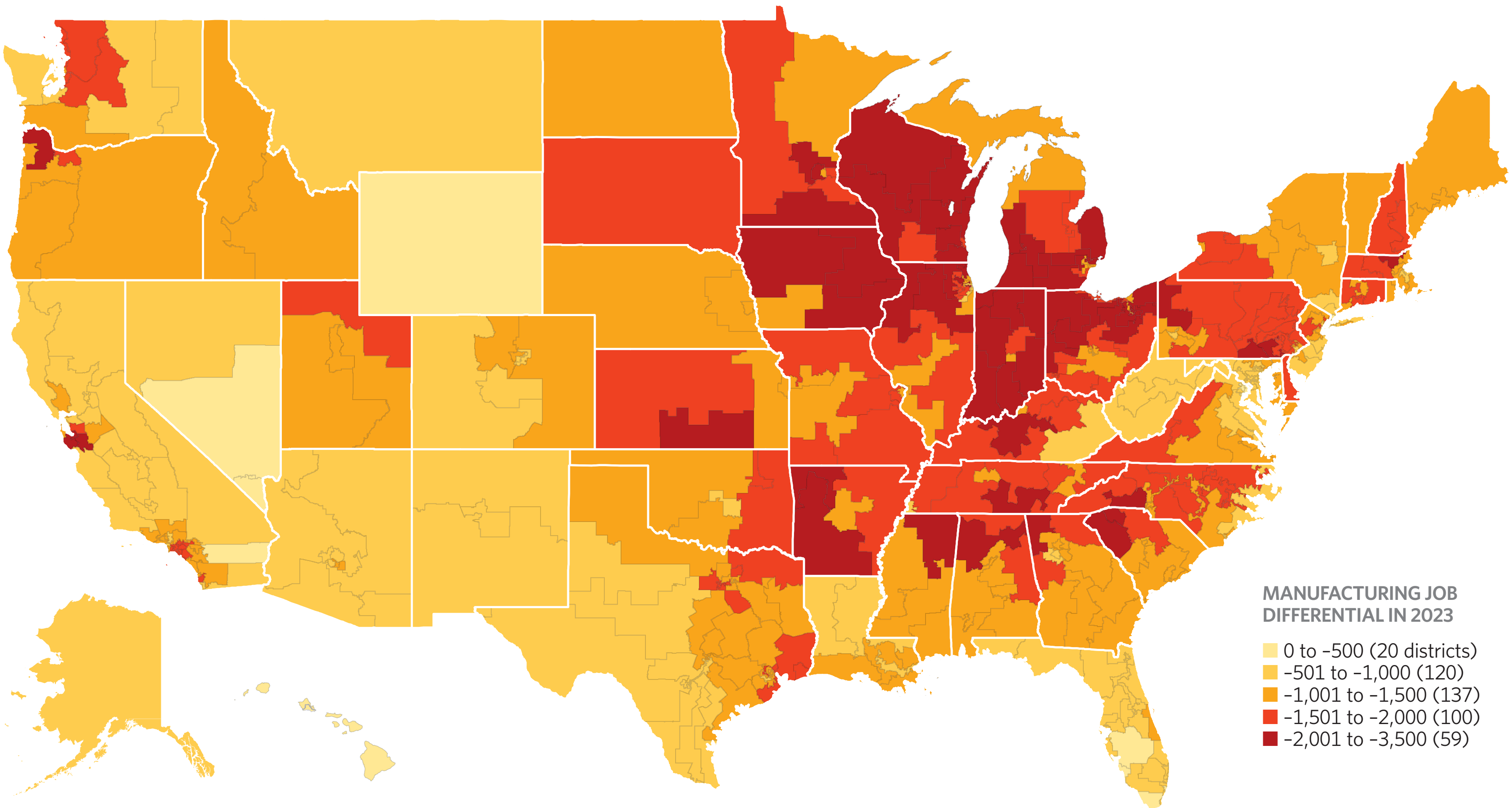
MAP 2

Where EPA Regulations Would Hit the Hardest

States in the Midwest would lose the largest number of manufacturing jobs due to proposed EPA regulations on carbon dioxide emissions. A total of 296 U.S. congressional districts would lose 1,000 or more jobs.



Source: Authors' calculations based on data from the Heritage Energy Model. For more information, see the Appendix.

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Appendix

Appendix Table 1 shows the economic impact of the regulations modeled in this study by congressional district.

Methodology

Overview of Heritage Energy Model. This analysis utilizes the Heritage Energy Model (HEM), a derivative of the National Energy Model System 2014 Full Release (NEMS).[8] NEMS is used by the Energy Information Administration (EIA) in the Department of Energy as well as various nongovernmental organizations for a variety of purposes, including forecasting the effects of energy policy changes on a plethora of leading economic indicators. The methodologies, assumptions, conclusions, and opinions in this report are entirely the work of statisticians and economists in the Center for Data Analysis (CDA) at The Heritage Foundation and have not been endorsed by, and do not necessarily reflect the views of, the developers of NEMS.

HEM is based on well-established economic theory as well as historical data and contains a variety of modules that interact with each other for long-term forecasting. In particular, HEM focuses on the interactions among (1) the supply, conversion, and demand of energy in its various forms; (2) American energy and the overall American economy; (3) the American energy market and the world petroleum market; and (4) current production and consumption decisions as well as expectations about the future.[9] These modules include:

- Macroeconomic Activity Module,[10]
- Transportation Demand Module,
- Residential Demand Module,
- Industrial Demand Module,
- Commercial Demand Module,
- Coal Market Module,
- Electricity Market Module,
- Liquid Fuels Market Module,
- Oil and Gas Supply Module,
- Renewable Fuels Module,
- International Energy Activity Module, and
- Natural Gas Transmission and Distribution Module.

HEM is identical to the EIA's NEMS with the exception of the Commercial Demand Module. Unlike NEMS, this module does not make projections regarding commercial floor-space data of pertinent commercial buildings. Other than that, HEM is identical to NEMS.

Overarching the modules is the Integrating Module, which consistently cycles, iteratively executing and allowing these various modules to interact with each other. Unknown variables that are related, such as a component of a particular module, are grouped together, and a pertinent subsystem of equations and inequalities corresponding to each group is solved via a variety of commonly used numerical analytic techniques, using approximate values for the other unknowns. Once these group's values are computed, the next group is solved similarly and the process iterates. Convergence checks are performed for each statistic to determine whether subsequent changes in that particular statistic fall within a given tolerance. After all group values for the current cycle are determined, the next cycle begins. For example, at cycle j, a variety of n pertinent statis-

8. U.S. Department of Energy, Energy Information Administration, "The National Energy Modeling System: An Overview," October 2009, http://www.eia.gov/oiaf/aeo/overview/pdf/0581(2009).pdf (accessed April 3, 2013).
9. Ibid., pp. 3–4.
10. HEM's Macroeconomic Activity Module uses the IHS Global Insight model, which is used by government agencies and Fortune 500 organizations to forecast the effects of economic events and policy changes on notable economic indicators. As with NEMS, the methodologies, assumptions, conclusions, and opinions in this report are entirely the work of CDA statisticians and economists and have not been endorsed by, and do not necessarily reflect the views of, the owners of the IHS Global Insight model.

tics represented by the vector, $\left(x_1^j, x_2^j, \ldots, x_n^j\right) \in R^n$ is obtained.[11] HEM provides a number of diagnostic measures, based on differences between cycles, to indicate whether a stable solution has been achieved.

Carbon Tax Simulations and Diagnostics. We used the HEM to analyze the economic effects of instituting a $37 carbon tax based on the EPA's estimation of the SCC assuming a 3 percent discount rate. HEM is appropriate for this analysis because similar models have been used in the past to understand the economic effects of other carbon tax proposals.[12] In particular, we conducted simulations running a carbon fee that started in 2015 at $37 (in 2007 dollars per metric ton of carbon dioxide) and followed the schedule presented by the Obama Administration through the year 2040.[13] We chose a revenue-neutral carbon tax that returns 100 percent of the carbon tax revenues directly to taxpayers. We ran the HEM for 12 cycles to get consistent feedback into the Macroeconomic Activity Module, which provided us with the figures presented in this study. Since we are modeling the proposed regulations as a tax, the economic impact is likely understated because actual regulations would have a more stifling impact on the economy.

The diagnostic tests suggested that the forecasts provided by the model had stabilized at the end of the 12 runs, based on differences between cycles. The 12 cycles were therefore sufficient to attain meaningful convergence, thus providing us with macroeconomic statistics from which we could make informative statistical inferences.

Translating National Employment Impacts to Local Impacts. To estimate employment differentials, two employment trajectories were created for each state and congressional district: a baseline trajectory and a policy trajectory. Initial manufacturing employment levels for each state or district were multiplied by the national manufacturing employment growth factors for each year for both the baseline and policy cases estimated using the HEM.[14] The three categories were totaled to calculate total employment for the baseline and policy cases.

11. Steven A. Gabriel, Andy S. Kydes, and Peter Whitman, "The National Energy Modeling System: A Large-Scale Energy-Economic Equilibrium Model," *Operations Research*, Vol. 49, No. 1 (January–February 2001), pp. 14–25, http://pubsonline.informs.org/doi/pdf/10.1287/opre.49.1.14.11195 (accessed December 23, 2014).

12. For example, the Department of Energy has used NEMS to evaluate some policy proposals. See U.S. Department of Energy, Energy Information Administration, "AEO Table Browser," http://www.eia.gov/oiaf/aeo/tablebrowser/ (accessed January 2, 2015).

13. U.S. Interagency Working Group on Social Cost of Carbon, "Technical Support Document," p. 18.

14. Initial employment levels for the three employment categories were taken from the U.S. Census Bureau, American Community Survey.

APPENDIX TABLE 1

The Effect of EPA Regulations on Manufacturing Jobs, by Congressional District (Page 1 of 2)

MANUFACTURING JOB DIFFERENTIAL IN 2023

Alabama	
1	-1,276
2	-1,418
3	-1,788
4	-2,050
5	-1,809
6	-1,167
7	-1,209
Total	−10,718

Alaska	
	-524

Arizona	
1	-667
2	-776
3	-715
4	-619
5	-1,366
6	-853
7	-972
8	-788
9	-1,208
Total	−7,964

Arkansas	
1	-1,687
2	-1,042
3	-2,095
4	-2,002
Total	−6,826

California	
1	-622
2	-816
3	-814
4	-755
5	-1,280
6	-603
7	-745
8	-632
9	-938
10	-1,385
11	-820
12	-955
13	-927
14	-1,021
15	-1,721
16	-934
17	-3,174
18	-2,230
19	-2,224
20	-755
21	-649
22	-740
23	-715
24	-920
25	-1,441
26	-1,248
27	-1,091
28	-875
29	-1,324
30	-1,059
31	-1,115
32	-1,562
33	-1,310
34	-1,452
35	-1,675
36	-451
37	-819
38	-1,678
39	-1,718
40	-1,990
41	-1,192
42	-1,397
43	-1,364
44	-1,644
45	-1,758
46	-1,954
47	-1,507
48	-1,690
49	-1,217
50	-1,159
51	-792
52	-1,510
53	-968
Total	−65,330

Colorado	
1	-900
2	-1,349
3	-635
4	-1,270
5	-831
6	-936
7	-1,196
Total	−7,116

Connecticut	
1	-1,477
2	-1,774
3	-1,606
4	-1,013
5	-1,701
Total	−7,571

Delaware	
	-1,605

District of Columbia	
Total	-147

Florida	
1	-585
2	-515
3	-577
4	-754
5	-693
6	-686
7	-719
8	-1,116
9	-532
10	-627
11	-509
12	-633
13	-997
14	-691
15	-765
16	-708
17	-433
18	-613
19	-381
20	-500
21	-527
22	-650
23	-687
24	-487
25	-883
26	-461
27	-588
Total	−17,314

Georgia	
1	-1,125
2	-1,087
3	-1,587
4	-1,028
5	-726
6	-1,056
7	-1,238
8	-1,105
9	-1,794
10	-1,274
11	-1,299
12	-1,314
13	-966
14	-2,484
Total	−18,082

Hawaii	
1	-447
2	-326
Total	−773

Idaho	
1	-1,392
2	-1,303
Total	−2,695

Illinois	
1	-863
2	-1,172
3	-1,572
4	-2,189
5	-1,415
6	-1,938
7	-926
8	-2,285
9	-1,152
10	-2,025
11	-1,761
12	-1,263
13	-1,248
14	-2,139
15	-1,844
16	-2,238
17	-2,143
18	-1,695
Total	−29,868

Indiana	
1	-2,059
2	-3,271
3	-3,397
4	-2,447
5	-1,742
6	-2,660
7	-1,483
8	-2,593
9	-2,197
Total	−21,848

Iowa	
1	-2,682
2	-2,568
3	-1,364
4	-2,353
Total	−8,968

Kansas	
1	-1,682
2	-1,455
3	-1,295
4	-2,439
Total	−6,871

Kentucky	
1	-1,891
2	-2,110
3	-1,420
4	-1,808
5	-953
6	-1,638
Total	−9,819

Louisiana	
1	-1,015
2	-966
3	-1,149
4	-949
5	-823
6	-1,385
Total	−6,288

Maine	
1	-1,252
2	-1,120
Total	−2,371

Maryland	
1	-1,170
2	-901
3	-786
4	-512
5	-527
6	-815
7	-609
8	-574
Total	−5,893

Massachusetts	
1	-1,530
2	-1,683
3	-2,186
4	-1,379
5	-1,071
6	-1,431
7	-785
8	-988
9	-1,028
Total	−12,080

Michigan	
1	-1,245
2	-2,791
3	-2,310
4	-1,816
5	-1,505
6	-2,560
7	-2,171
8	-2,061
9	-2,256
10	-2,661
11	-2,496
12	-1,734
13	-1,395
14	-1,293
Total	−28,294

Minnesota	
1	-2,291
2	-1,801
3	-2,109
4	-1,684
5	-1,393
6	-2,227
7	-1,981
8	-1,284
Total	−14,771

Note: Figures may not sum to totals due to rounding.
Source: Authors' calculations based on data from the Heritage Energy Model.

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APPENDIX TABLE 1

The Effect of EPA Regulations on Manufacturing Jobs, by Congressional District (Page 2 of 2)

MANUFACTURING JOB DIFFERENTIAL IN 2023

Mississippi

1	-2,091
2	-1,201
3	-1,298
4	-1,478
Total	–6,068

Missouri

1	-1,155
2	-1,647
3	-1,901
4	-1,379
5	-1,336
6	-1,782
7	-1,537
8	-1,763
Total	–12,500

Montana

Total	-839

Nebraska

1	-1,466
2	-1,077
3	-1,431
Total	–3,974

Nevada

1	-332
2	-847
3	-459
4	-368
Total	–2,006

New Hampshire

1	-1,618
2	-1,834
Total	–3,452

New Jersey

1	-1,081
2	-870
3	-921
4	-902
5	-1,352
6	-1,277
7	-1,761
8	-1,318
9	-1,616
10	-794
11	-1,481
12	-1,455
Total	–14,827

New Mexico

1	-670
2	-525
3	-532
Total	–1,727

New York

1	-883
2	-1,330
3	-701
4	-644
5	-546
6	-569
7	-801
8	-369
9	-398
10	-593
11	-477
12	-599
13	-507
14	-619
15	-414
16	-462
17	-744
18	-930
19	-1,027
20	-864
21	-1,143
22	-1,467
23	-1,877
24	-1,386
25	-1,656
26	-1,291
27	-1,900
Total	–24,196

North Carolina

1	-1,515
2	-1,830
3	-975
4	-1,072
5	-1,932
6	-1,937
7	-1,451
8	-1,937
9	-1,460
10	-2,308
11	-1,629
12	-1,315
13	-1,635
Total	–20,996

North Dakota

Total	-1,037

Ohio

1	-1,805
2	-1,812
3	-1,067
4	-2,937
5	-2,857
6	-1,747
7	-2,635
8	-2,561
9	-1,855
10	-1,502
11	-1,249
12	-1,558
13	-2,033
14	-2,505
15	-1,402
16	-2,221
Total	–31,747

Oklahoma

1	-1,671
2	-1,537
3	-1,232
4	-1,070
5	-987
Total	–6,497

Oregon

1	-2,487
2	-1,092
3	-1,528
4	-1,210
5	-1,324
Total	–7,643

Pennsylvania

1	-819
2	-512
3	-2,036
4	-2,088
5	-1,933
6	-1,975
7	-1,593
8	-1,882
9	-1,593
10	-1,760
11	-1,602
12	-1,482
13	-1,316
14	-956
15	-1,979
16	-2,158
17	-1,761
18	-1,480
Total	–28,926

Rhode Island

1	-1,147
2	-1,113
Total	–2,260

South Carolina

1	-1,126
2	-1,249
3	-2,132
4	-2,099
5	-1,817
6	-1,127
7	-1,180
Total	–10,731

South Dakota

Total	-1,622

Tennessee

1	-1,880
2	-1,305
3	-1,823
4	-2,097
5	-1,066
6	-1,733
7	-1,561
8	-1,729
9	-966
Total	–14,159

Texas

1	-1,316
2	-1,624
3	-1,530
4	-1,553
5	-1,099
6	-1,643
7	-1,349
8	-1,242
9	-977
10	-1,443
11	-986
12	-1,540
13	-1,270
14	-1,563
15	-624
16	-785
17	-1,261
18	-1,245
19	-735
20	-672
21	-873
22	-1,382
23	-685
24	-1,439
25	-1,159
26	-1,399
27	-1,049
28	-526
29	-1,465
30	-1,050
31	-1,199
32	-1,398
33	-1,555
34	-535
35	-846
36	-1,743
Total	–42,760

Utah

1	-1,726
2	-1,130
3	-1,090
4	-1,486
Total	–5,431

Vermont

Total	-1,378

Virginia

1	-794
2	-1,042
3	-1,208
4	-1,345
5	-1,366
6	-1,602
7	-886
8	-398
9	-1,611
10	-756
11	-497
Total	–11,503

Washington

1	-1,820
2	-1,801
3	-1,363
4	-959
5	-919
6	-967
7	-1,166
8	-1,631
9	-1,547
10	-903
Total	–13,077

West Virginia

1	-991
2	-895
3	-581
Total	–2,467

Wisconsin

1	-2,733
2	-1,847
3	-2,270
4	-1,717
5	-2,829
6	-3,489
7	-2,457
8	-3,080
Total	–20,421

Wyoming

Total	-489

Note: Figures may not sum to totals due to rounding.
Source: Authors' calculations based on data from the Heritage Energy Model.

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BACKGROUNDER

No. 3080 | APRIL 13, 2016

Consequences of Paris Protocol: Devastating Economic Costs, Essentially Zero Environmental Benefits

Kevin D. Dayaratna, PhD, Nicolas D. Loris, and David W. Kreutzer, PhD

Abstract

During the 2015 United Nations Climate Change Conference in Paris, President Obama met with world leaders from around the globe to discuss plans to combat climate change. He submitted a plan to reduce total greenhouse gas emissions by 26 percent to 28 percent from 2005 levels by the year 2025. Though the emission-reduction targets are nonbinding, the Obama Administration has set in place numerous domestic regulations that would aim to meet the target. Heritage Foundation researchers have modeled the impact of the Administration's climate change agenda as well as plans resulting from this conference, and have determined that these regulations will result in lost jobs, a decline in economic growth, and a marked increase in unemployment. This economic sacrifice is not worth making: These policies and efforts of the industrialized world will result in a negligible impact on global temperatures. Policymakers should reject the Paris Protocol and undo the Administration's domestic regulations to reduce carbon dioxide and other greenhouse gas emissions.

During the 2015 United Nations Climate Change Conference in Paris, President Barack Obama met with world leaders from around the globe to discuss plans to combat climate change. The general consensus from the summit was that the use of natural resources, such as coal, oil, and natural gas—which provide 80 percent of the world's energy needs—should be avoided. Furthermore, industrialized, rich countries should pay for poor countries to build more renewable power and address climate change. In effect, the framework is a push for *un*-development for the industrialized world and a major obstacle for growth for the developing world. The economic impact of instituting the regulations associated with the Paris agree-

Key Points

- Policies adopted from the 2015 Paris climate change protocol will hurt a variety of sectors of the American economy.
- These policies will result in over $2.5 trillion in lost GDP by 2035. They will increase electricity expenditures for a family of four by at least 13 percent a year.
- These climate change policies will also cost American families over $20,000 of lost income by 2035—with little, if any, environmental benefit in return.
- Energy is a key building block for economic opportunity. Carbon-emitting fuels, such as coal, oil, and natural gas, provided 87 percent of America's energy needs in the past decade. Restricting the use of conventional energy sources as laid out by the Obama Administration will significantly harm the U.S. economy—and average Americans.
- Policymakers should make every effort to prevent implementation of these harmful environmental regulations.

This paper, in its entirety, can be found at **http://report.heritage.org/bg3080**

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ment will be severe. Policies that restrict the use of carbon-based energy in America will kill jobs and stifle economic growth. Regardless of one's opinions on the impact of carbon dioxide (CO_2) emissions on global temperatures the economic sacrifices will generate a negligible impact on global temperatures.

The Climate Summit in Paris and Domestic Regulations

Leaders from around the world convened at the 2015 U.N. Climate Change Conference in Paris to discuss how to combat climate change. President Obama began the summit by addressing the attendees: "For all the challenges we face, the growing threat of climate change could define the contours of this century more dramatically than any other."[1] The goal of the conference was for the various countries attending to reach an agreement to limit CO_2 emissions in order to reduce global temperatures.

A central element to the U.S. commitment as part of the Paris agreement is the intended nationally determined contribution (INDC) to reduce greenhouse gas emissions. Countries must make specific, measurable commitments to curb carbon dioxide emissions and submit them to the United Nations Framework Convention on Climate Change (UNFCCC) secretariat. The Obama Administration's INDC aims to reduce U.S. greenhouse gas emissions by 26 percent to 28 percent below 2005 levels by the year 2025.[2] While the INDC is non-binding and the Administration emphasizes that the U.S. "does not intend to utilize international market mechanisms," the plan outlines the litany of domestic regulations that the Administration proposed and implemented during President Obama's time in office so far, including:

- Carbon dioxide regulations for new and existing power plants. Combined, these two regulations serve as a major component of the Administration's global warming agenda.
- Fuel-efficiency and greenhouse gas regulations for light and heavy-duty vehicles.
- Energy-efficiency regulations for commercial and residential buildings as well as appliances.[3]
- Environmental Protection Agency (EPA)-approved alternatives to hydrochlorofluorocarbons.
- Methane regulations for landfills and the oil and gas sector.
- Executive orders to reduce greenhouse gas emissions by the federal government.[4]

The Economic Impact of the Plan

Energy is a key building block for economic opportunity. Carbon-dioxide-emitting fuels, such as coal, oil, and natural gas, provided 87 percent of America's energy needs in the past decade, and have been the overwhelming supplier for over a century.[5] Restricting the use of conventional energy sources as laid out by the Obama Administration's INDC will significantly harm the U.S. economy. Americans feel the pain of higher energy prices directly, but also indirectly through almost all of the goods and services they buy, because energy is a necessary component of production and service. Higher energy prices will disproportionately hurt the poorest Americans, who spend the highest percentage of their budget on energy bills.

Companies will pass higher costs on to consumers or absorb the costs, which prevents hiring and new investment. As prices rise, consumers buy less, and companies will drop employees, close entirely, or move to other countries where the cost of doing business is lower. The result is fewer opportunities for American workers, lower incomes, less economic growth, and higher unemployment.

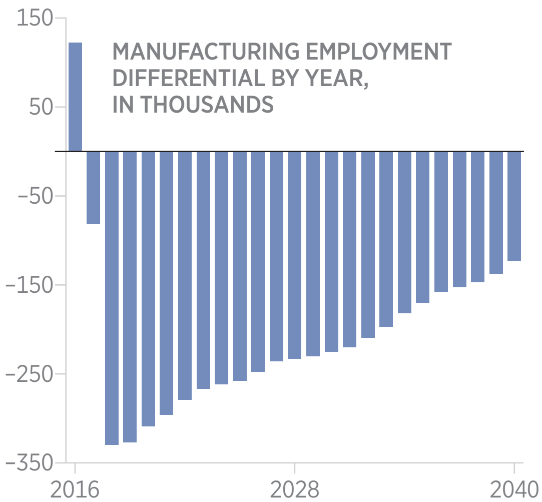
In order to estimate the impact on the economy of the Paris Protocol policies, we estimated the eco-

1. David Hudson, "President Obama: 'No Nation Is Immune' to Climate Change," The White House blog, September 23, 2014, https://www.whitehouse.gov/blog/2014/09/23/president-obama-no-nation-immune-climate-change (accessed March 25, 2016).
2. UNFCCC, "Party: United States of America—Intended Nationally Determined Contribution," March 31, 2015, http://www4.unfccc.int/submissions/INDC/Published%20Documents/United%20States%20of%20America/1/U.S.%20Cover%20Note%20INDC%20and%20Accompanying%20Information.pdf (accessed March 25, 2016).
3. While energy-efficiency regulations date back to the 1970s, the Obama Administration has increased the stringency of the standards.
4. UNFCCC, "Party: United States of America—Intended Nationally Determined Contribution."
5. U.S. Energy Information Administration, "Energy Sources Have Changed Throughout the History of the United States," *Today in Energy*, July 3, 2013, http://www.eia.gov/todayinenergy/detail.cfm?id=11951 (accessed March 25, 2016).

CHART 1

How the Paris Agreement Would Affect U.S. Jobs

If the U.S. abided by the provisions of the Paris Agreement, there would be 206,104 fewer manufacturing jobs between 2016 and 2040.



SOURCE: Heritage Foundation calculations using the Heritage Energy Model. See methodology for details.

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nomic impact of a tax equivalent to the EPA's annual estimates of the social cost of carbon (SCC) in a manner similar to one of our previous studies.[6] Since the crude oil export ban has been lifted, however, we incorporated this change into our simulations of both current policy as well as the Paris agreement. The SCC purports to quantify the economic damages associated with a single metric ton of carbon dioxide emissions over the course of a 300-year time horizon. At their core, these models are fundamentally flawed because their damage functions are arbitrary. Heritage research has also found that these models are extremely sensitive to reasonable changes in assumptions; in fact, under some assumptions one of the models provides a negative SCC, suggesting net economic benefits to carbon dioxide emissions. The Administration insists on using these models anyway.[7]

We used the Heritage Energy Model (HEM),[8] a clone of the National Energy Modeling System 2015 Full Release (NEMS),[9] to quantify the economic impact of instituting the regulations associated with the policies stemming from the Paris agreement. We did so by modeling a $36 carbon tax increasing in conjunction with the EPA's annual estimates of the SCC. Modeling tax changes as a substitute for quantifying the economic impact of regulatory proposals is a widely accepted practice. To negate the analytical impacts of a tax's income transfer, 100 percent of carbon-tax revenue is returned to taxpayers.[10]

Policies adapted from domestic regulations emphasized in the Paris agreement will affect a vari-

6. Kevin D. Dayaratna, Nicolas Loris, and David W. Kreutzer, "The Obama Administration's Climate Agenda: Underestimated Costs and Exaggerated Benefits," Heritage Foundation *Backgrounder* No. 2975, November 13, 2014, http://www.heritage.org/research/reports/2014/11/the-obama-administrations-climate-agenda-underestimated-costs-and-exaggerated-benefits.

7. Kevin D. Dayaratna and David W. Kreutzer, "Unfounded FUND: Yet Another EPA Model Not Ready for the Big Game," Heritage Foundation *Backgrounder* No. 2897, April 29, 2014, http://www.heritage.org/research/reports/2014/04/unfounded-fund-yet-another-epa-model-not-ready-for-the-big-game; Kevin D. Dayaratna and David W. Kreutzer, "Loaded DICE: An EPA Model Not Ready for the Big Game," Heritage Foundation *Backgrounder* No. 2860, November 21, 2013, http://www.heritage.org/research/reports/2013/11/loaded-dice-an-epa-model-not-ready-for-the-big-game; and U.S. Interagency Working Group on Social Cost of Carbon, "Technical Update of the Social Cost of Carbon for Regulatory Impact Analysis Under Executive Order 12866," The White House, July 2015, p. 18, https://www.whitehouse.gov/sites/default/files/omb/inforeg/scc-tsd-final-july-2015.pdf (accessed March 25, 2016).

8. The Heritage Foundation, "Models and Data," http://www.heritage.org/about/staff/departments/center-for-data-analysis/models-and-data.

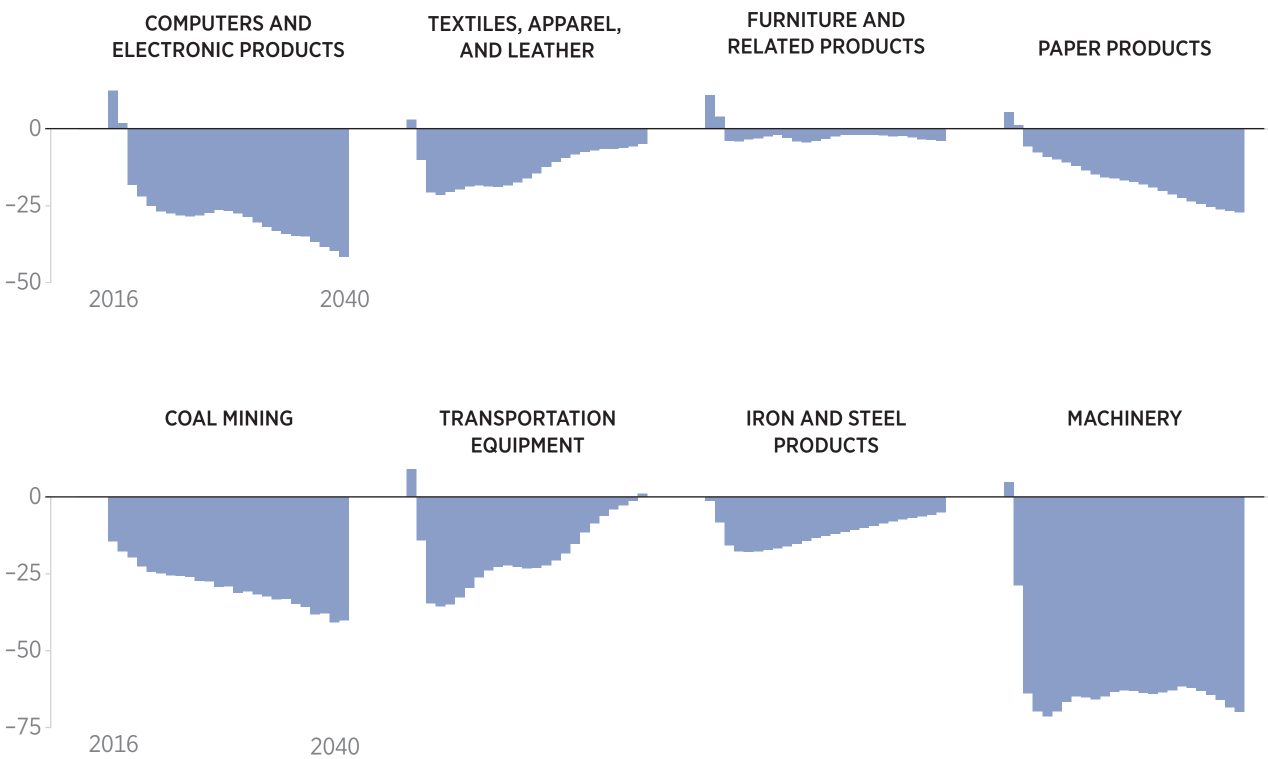
9. U.S. Energy Information Administration, *Annual Energy Outlook 2015*, April 14, 2015, http://www.eia.gov/forecasts/aeo/index.cfm (accessed March 28, 2016).

10. In fact, this impact of a $36 tax underestimates the effects of the Administration's global warming regulations and the Paris agreement. This underestimation is due to inefficiencies that drive up costs associated with enacting carbon dioxide regulations, as opposed to a straightforward carbon tax, though neither are good policies. Our simulations illustrate that a tax of this magnitude would only achieve 60 percent of Obama's goal outlined in the Paris agreement. Interagency Working Group on Social Cost of Carbon, "Technical Support Document:Technical Update of the Social Cost of Carbon for Regulatory Impact Analysis Under Executive Order 12866," revised July 2015, https://www.whitehouse.gov/sites/default/files/omb/inforeg/scc-tsd-final-july-2015.pdf (accessed April 5, 2016).

CHART 2

Paris Agreement: Job Loss by Sector

MANUFACTURING EMPLOYMENT DIFFERENTIAL BY YEAR, IN THOUSANDS



SOURCE: Heritage Foundation calculations using the Heritage Energy Model. See methodology for details.

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ety of aspects of the American economy. As a result of the plan, one can expect that by 2035, there will be:

- An overall average shortfall of nearly 400,000 jobs;
- An average manufacturing shortfall of over 200,000 jobs;
- A total income loss of more than $20,000 for a family of four;
- An aggregate gross domestic product (GDP) loss of over $2.5 trillion; and
- Increases in household electricity expenditures between 13 percent and 20 percent.

Chart 1 illustrates the impact that American policies adopted from the Paris Protocol will have on employment.

As Chart 1 shows, the impact of the Paris agreement on manufacturing is quite devastating. In terms of overall employment, the agreement ends up killing more than 300,000 jobs by 2035. Chart 2 provides sector-by-sector analysis of this impact.

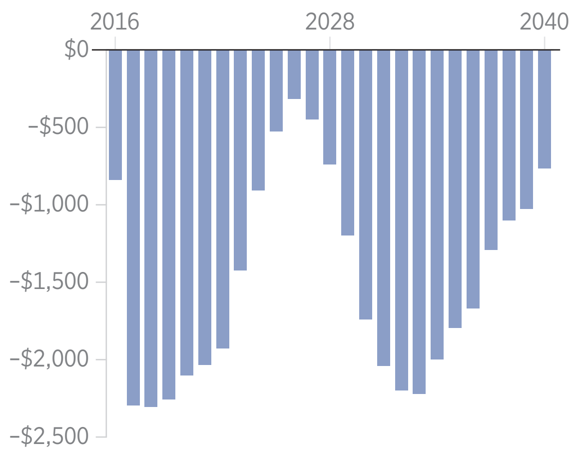
The impact on personal income that an average family of four would incur is also quite significant, especially toward the end of the next decade. (See Chart 3.)

As global warming regulations stifle the use of the most efficient and inexpensive forms of electricity, businesses as well as households will incur higher electricity costs. Chart 4 shows the average change

CHART 3

Paris Agreement: Income Change for Family of Four

PERSONAL INCOME DIFFERENTIAL BY YEAR, IN THOUSANDS OF INFLATION-ADJUSTED DOLLARS



SOURCE: Heritage Foundation calculations using the Heritage Energy Model. See methodology for details.

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in annual electricity prices that a typical household will incur.

More results regarding the economic impact are contained in the Appendix.

Negligible Benefits

In his 2015 State of the Union Address, President Obama claimed that "no challenge—no challenge—poses a greater threat to future generations than climate change."[11] In that case, the President's policies have missed their mark. Regardless of one's opinions on the degree to which climate change is occurring, there is compelling evidence that policies like those resulting from the Paris agreement will have little impact on global temperatures.[12] In fact, using the Model for the Assessment of Greenhouse Gas Induced Climate Change developed by researchers at the National Center for Atmospheric Research, even if all carbon dioxide emissions in the United States were effectively eliminated, there would be *less than two-tenths of a degree Celsius reduction in global temperatures*.[13] In fact, the entire industrialized world could cut carbon emissions down to zero, and the climate impact would still be less than four-tenths of a degree Celsius in terms of averted warming by the year 2100.

In addition, the various country-specific emissions targets for all the countries in the Paris agreement do not offer much hope for climate impact even if all the countries comply perfectly with their promised cuts.[14] History, however, gives little confidence that such compliance will even occur. For instance, China is building 350 coal-fired power plants, and has plans for another 800.[15] Further, if China is not addressing its harmful smog and poor water quality, there is justification for doubting its commitment to addressing global warming. Many developing countries have shown an unwillingness to curb economic growth to reduce greenhouse gas emissions.

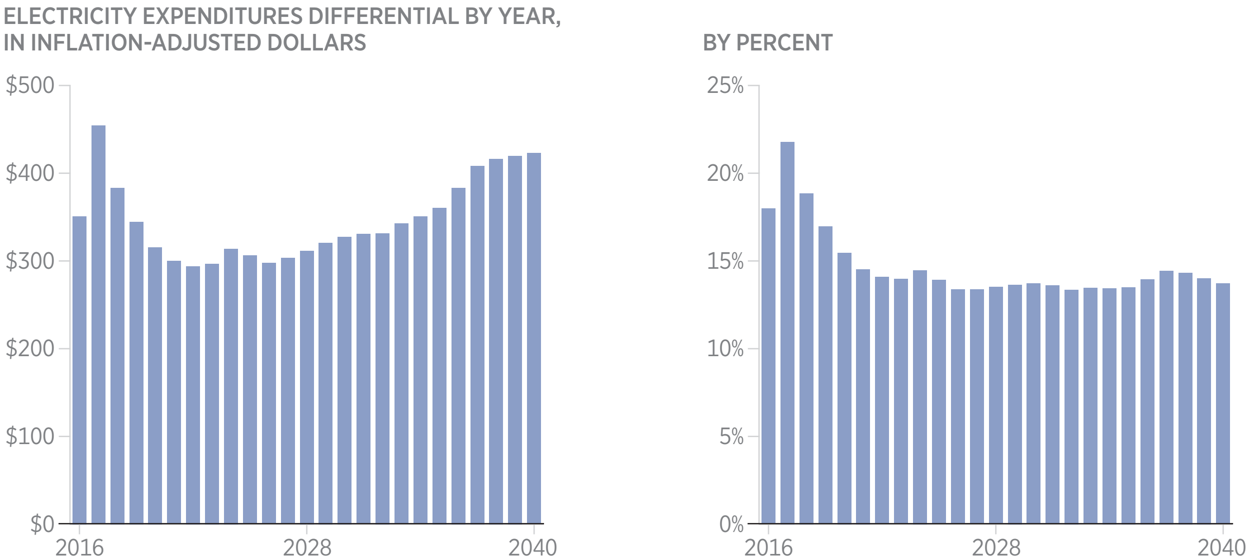
Conclusion

Heritage's clone of the Energy Information Administration's energy model shows that restricting energy production to meet targets like those of

11. News release, "Remarks by the President in State of the Union Address," January 20, 2015, https://www.whitehouse.gov/the-press-office/2015/01/20/remarks-president-state-union-address-january-20-2015 (accessed March 25, 2016).
12. Dayaratna, Loris, and Kreutzer, "The Obama Administration's Climate Agenda: Underestimated Costs and Exaggerated Benefits."
13. Patrick J. Michaels and Paul C. Knappenberger, "Current Wisdom: We Calculate, You Decide: A Handy-Dandy Carbon Tax Temperature-Savings Calculator," Cato Institute, July 23, 2013, http://www.cato.org/blog/current-wisdom-we-calculate-you-decide-handy-dandy-carbon-tax-temperature-savings-calculator (accessed March 25, 2016).
14. Stephen D. Eule, "UNFCCC Report on Country Pledges and Global GHG Emissions: Gonna Take You Higher," U.S. Chamber of Commerce, http://www.energyxxi.org/sites/default/files/UNFCCC%20Analysis%20of%20INDCs%20FINAL.pdf (accessed February 23, 2016).
15. Anthony Watts, "The Truth About China–2,400 New Coal Plants Will Thwart Any Paris #COP21 Pledges," Watts Up with That? December 2, 2015, http://wattsupwiththat.com/2015/12/02/the-truth-about-china-2400-new-coal-plants-will-thwart-any-paris-cop21-pledges/ (accessed March 28, 2016).

CHART 4

Paris Agreement: Typical Household Change in Electricity Expenditures



SOURCE: Heritage Foundation calculations using the Heritage Energy Model. See methodology for details.

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the Paris agreement will significantly harm the U.S. economy. Bureaucratically administered mandates, taxes, and special interest subsidies will drive family incomes down by thousands of dollars per year, drive up energy costs, and eliminate hundreds of thousands of jobs. All of these costs would be incurred to achieve only trivial and theoretical impacts on global warming. Policymakers should therefore make every effort possible to prevent implementation of these harmful environmental regulations.

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Appendix: Methodology

The Heritage Energy Model

The analysis in this *Backgrounder* uses the Heritage Energy Model (HEM), a derivative of the National Energy Model System 2015 Full Release (NEMS).[16] NEMS is used by the Energy Information Administration (EIA) in the Department of Energy as well as various nongovernmental organizations for a variety of purposes, including forecasting the effects of energy policy changes on a plethora of leading economic indicators. The methodologies, assumptions, conclusions, and opinions in this *Backgrounder* are entirely the work of statisticians and economists in the Center for Data Analysis (CDA) at The Heritage Foundation, and have not been endorsed by, and do not necessarily reflect the views of, the developers of NEMS.

HEM is based on well-established economic theory as well as historical data, and contains a variety of modules that interact with each other for long-term forecasting. In particular, HEM focuses on the interactions among (1) the supply, conversion, and demand of energy in its various forms; (2) American energy and the overall American economy; (3) the American energy market and the world petroleum market; and (4) current production and consumption decisions as well as expectations about the future.[17] These modules are:

- Macroeconomic Activity Module,[18]
- Transportation Demand Module,
- Residential Demand Module,
- Industrial Demand Module,
- Commercial Demand Module,
- Coal Market Module,
- Electricity Market Module,
- Liquid Fuels Market Module
- Oil and Gas Supply Module,
- Renewable Fuels Module,
- International Energy Activity Module, and
- Natural Gas Transmission and Distribution Module.

With the exception of the Commercial Demand Module, HEM is identical to the EIA's NEMS. The Commercial Demand Module makes projections regarding commercial floor-space data of pertinent commercial buildings.

Overarching the 12 modules is the Integrating Module, which consistently cycles, iteratively executing and allowing these various modules to interact with each other. Unknown variables that are related, such as a component of a particular module, are grouped together, and a pertinent subsystem of equations and inequalities corresponding to each group is solved via a variety of commonly used numerical analytic techniques, using approximate values for the other unknowns. Once a group's values are computed, the next group is solved similarly, and the process iterates. Convergence checks are performed for each price and quantity statistic to determine whether subsequent changes in that particular statistic fall within a given tolerance. After all, when group values for the current cycle are determined, the next cycle begins. For example, at cycle j, a variety of n pertinent statistics represented by the vector

16. U.S. Department of Energy, Energy Information Administration, "The National Energy Modeling System: An Overview," October 2009, http://www.eia.gov/oiaf/aeo/overview/pdf/0581(2009).pdf (accessed April 3, 2013).

17. Ibid., pp. 3–4.

18. HEM's Macroeconomic Activity Module uses the IHS Global Insight model, which is used by government agencies and Fortune 500 organizations to forecast the effects of economic events and policy changes on notable economic indicators. As with NEMS, the methodologies, assumptions, conclusions, and opinions in this report are entirely the work of CDA statisticians and economists, and have not been endorsed by, and do not necessarily reflect the view of, the owners of the IHS Global Insight model.

is obtained.[19] HEM provides a number of diagnostic measures, based on differences between cycles, to indicate whether a stable solution has been achieved.

EIA Simulations and Diagnostics

We used the HEM to analyze the economic effects of the Paris Agreement. Codes were provided to us by the EIA, which recently performed a similar analysis itself.[20]

19. Steven A. Gabriel, Andy S. Kydes, and Peter Whitman, "The National Energy Modeling System: A Large-Scale Energy-Economic Equilibrium Model," *Operations Research*, Vol. 49, No. 1 (January–February 2001), pp. 14–25, http://pubsonline.informs.org/doi/pdf/10.1287/opre.49.1.14.11195 (accessed December 23, 2014).

20. News release, "Analysis of the Impacts of the Clean Power Plan," Energy Information Administration, May 22, 2015, http://www.eia.gov/analysis/requests/powerplants/cleanplan/ (accessed March 25, 2016).

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BACKGROUNDER

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Turning America's Energy Abundance into Energy Dominance

Kevin D. Dayaratna, PhD, and Nicolas D. Loris

Abstract

In June, President Trump delivered remarks at the Department of Energy to promote America's global position as an energy powerhouse. Calling for an era of energy dominance, Trump outlined a number of ways in which domestic producers can capitalize on the country's abundance of domestic resources. Heritage Foundation research projects that opening access and deregulating would generate significant economic gains, helping the Administration achieve its 3 percent growth target. Expanding energy supply would produce a peak employment gain of 1.4 million new jobs and generate $2.4 trillion in gross domestic product from now until 2035, the equivalent of $27,000 per family of four.

Key Points

- President Trump has issued the Energy Independence Executive Order, which directs federal agencies to review, rescind, and potentially replace burdensome regulations that obstruct energy development.
- America is extremely energy rich. Expanding supplies would produce a peak employment gain of 1.4 million new jobs and generate $2.4 trillion in gross domestic product from now until 2035, the equivalent of $27,000 per family of four.
- Working with Congress, the Trump Administration can leave a legacy that fundamentally changes the energy sector for the better. Policy reforms that open access and reduce harmful regulations that do not produce meaningful environmental benefits will make the U.S. dominant in the energy sector.

Despite the success that the U.S. has had as a global energy powerhouse,[1] a number of government-imposed obstacles prevent Americans benefiting from the nation's rich wealth of natural resources. Earlier in 2017, President Trump issued the Energy Independence Executive Order, which directs federal agencies to review, rescind, and potentially replace burdensome regulations that obstruct energy development.[2]

Opening access to the nation's vast energy resources will unleash American ingenuity and talent, lower energy bills for families and businesses, and create hundreds of thousands of jobs for years to come. President Trump and Congress should implement the necessary policy reforms to enable the energy industry to capitalize even further on America's energy abundance.

This paper, in its entirety, can be found at **http://report.heritage.org/bg3258**

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Energy's Importance to Quality of Life and the Economy

Energy is ubiquitous in today's economy. From heating and cooling homes, to powering businesses, schools and hospitals, to moving goods and people across the world, energy is a critical component to quality of life in the U.S. Harnessing the U.S.'s abundant natural resources not only provides families with a reliable source of energy, but also significantly improves public health and well-being by serving as an input for medicines, plastics, fertilizers, cleaners, and much more.[3]

Coal, oil, and natural gas meet more than 80 percent of America's energy needs. In fact, these natural resources have comprised *at least* 80 percent of the nation's energy mix for more than a century.[4] Conventional fuels, often derided by environmental activists as an energy source of the past, could actually meet the U.S.'s and the world's energy demands for centuries to come. Conventional fuels will be essential to meeting future energy needs in the developing world, where more than 1.2 billion people (17 percent of the global population) do not have access to reliable electricity.[5]

America's Energy Abundance

The U.S., in addition to the rest of North America, is extremely energy rich. The Institute for Energy Research estimates that North American oil resources total nearly 1.8 trillion barrels of recoverable oil, over 75 percent of which is contained in the U.S.[6] This oil is more than enough to meet the U.S.'s current energy demands for the next two centuries.[7]

However, these estimates may in fact *underestimate* America's energy wealth, because they fail to keep up with technological advancements discovering new resources. In fact, innovative companies have squashed exaggerated claims of looming resource exhaustion. Allen Gilmer, Co-Founder and Executive Chairman of Drillinginfo, recently called the Permian Basin in west Texas and southeastern New Mexico "a permanent resource."[8] Gilmer remarked:

> The research we've done indicates that we have at least half a trillion barrels in the Permian at reasonable economics, and it could be as high as 2 trillion barrels. That is, as a practical matter, an infinite amount of resource.[9]

Accessing the Abundant Energy: Horizontal Drilling and Hydraulic Fracturing

Oil and natural gas extraction in the U.S. is a fundamentally different process than that found in places like Canada, the Middle East, Venezuela, or offshore operations. In the U.S., companies extract these resources, known as tight oil or shale oil/gas, through a combination of horizontal drilling and hydraulic fracturing.

1. U.S. Department of Energy, Energy Information Administration, "United States Remains the World's Top Producer of Petroleum and Natural Gas Hydrocarbons," June 7, 2017, https://www.eia.gov/todayinenergy/detail.php?id=31532 (accessed October 5, 2017).
2. President Donald J. Trump, "Presidential Executive Order on Promoting Energy Independence and Economic Growth," March 28, 2017, https://www.whitehouse.gov/the-press-office/2017/03/28/presidential-executive-order-promoting-energy-independence-and-economi-1 (accessed October 5, 2017).
3. "Products Made from Oil & Gas (Part 1)," Petroleum Services Association of Canada, 2017, https://oilandgasinfo.ca/patchworks/products-made-from-oil-gas-part-1/ (accessed October 5, 2017).
4. U.S. Department of Energy, Energy Information Administration, "Fossil Fuels Have Made Up at Least 80% of U.S. Fuel Mix Since 1900," July 2, 2015, https://www.eia.gov/todayinenergy/detail.php?id=21912 (accessed October 5, 2017).
5. International Energy Agency, "Uneven Progress on Achieving Access to Sustainable Energy for All," April 3, 2017, https://www.iea.org/newsroom/news/2017/april/uneven-progress-on-achieving-access-to-sustainable-energy-for-all.html (accessed October 5, 2017).
6. The U.S. also contains 14 quadrillion cubic feet of natural gas and 10 trillion short tons of coal.
7. Institute for Energy Research, *North American Energy Inventory*, December 2011, https://www.instituteforenergyresearch.org/wp-content/uploads/2013/01/Energy-Inventory.pdf (accessed October 5, 2017).
8. David Blackman, "Gilmer: We Should View The Permian Basin As A Permanent Resource," *Forbes*, August 17, 2017, https://www.forbes.com/sites/davidblackmon/2017/08/17/gilmer-we-should-view-the-permian-basin-as-a-permanent-resource/#45d0577d56ff (accessed October 5, 2017).
9. Mark J. Perry, "From Peak Oil to Energy Abundance. Energy Expert Now Says the Permian Basin is a Permanent, Near-Infinite Resource," American Enterprise Institute, August 21, 2017, https://www.aei.org/publication/we-should-view-americas-most-prolific-oil-field-the-permian-basin-as-a-permanent-near-infinite-resource/ (accessed October 5, 2017).

- **Horizontal drilling** is an innovative method that assists shale oil and gas extraction. In this approach, energy companies drill down and subsequently outward (horizontally). Horizontal drilling enables producers to significantly expand their search horizons and extract more oil and gas in a quicker and more efficient manner than typical vertical drilling allows. Horizontal drilling also drastically reduces the surface area footprint of the drilling activities, minimizing the visible environmental footprint.

- **Hydraulic fracturing,** often referred to as fracking, enables producers to extract oil and natural gas trapped in rock deposits. Producers drill wells that on average are 7,500 feet below the surface—thousands of feet underneath drinking water aquifers—and inject water, sand, and chemical additives deep in the ground at high pressure to fracture the forms or formations. The fracturing releases trapped oil and gas, which is then pumped to the surface.

Hydraulic fracturing and horizontal drilling are imperative to the safe and efficient extraction of recoverable oil and gas in various parts of the country, generating tremendous economic growth and job creation.[10] However, misinformation from environmental activist organizations has demonized fracking and the fossil fuel industry. Opponents have deemed the process unsafe, arguing that fracking contaminates drinking water.[11] A number of academic studies have discredited this claim, finding no widespread, systemic contamination because of the fracking process.[12] Both the Environmental Protection Agency (in a five-year study) and the U.S. Geological Survey recently found that fracking has not adversely affected drinking water.[13] Environmental organizations also claim that continued reliance on conventional fuels exacerbates catastrophic global warming, despite the fact that natural gas decreases carbon-dioxide (CO_2) emissions.[14] This *Backgrounder* includes simulations of impacts on the climate from increase in oil and natural gas production to assess the legitimacy of claims.

Energy companies have capitalized on the wealth of resources underneath U.S. soil on state and privately owned lands. The energy industry and consumers alike benefit from most of the shale oil and shale gas in the U.S. not being under federal control. However, federal regulations and federal land ownership have rendered vast quantities of recoverable oil and natural gas onshore and offshore either inaccessible or costlier to extract.[15] A burdensome environmental review and permitting process for resource extraction on federal lands, including the climate change regulation of methane emissions, restrict the accessibility of energy resources on federal lands for little to no environmental benefit.

10. Institute for Energy Research, "Bakken Shale Fact Sheet," 2012, http://instituteforenergyresearch.org/wp-content/uploads/2012/08/Bakken-Fact-Sheet.pdf (accessed October 5, 2017), and Diana Furchtgott-Roth, "Government May be Shut Down, But the Energy Industry Is Booming," Manhattan Institute *Commentary*, October 4, 2013, http://www.economics21.org/html/government-may-be-shut-down-energy-industry-booming-608.html (accessed October 5, 2017).
11. Sierra Club, "Increasing Reliance on Natural Gas Displaces the Market for Clean Energy and Harms Human Health and the Environment in Places where Production Occurs," http://content.sierraclub.org/naturalgas/why-move-beyond-natural-gas (accessed October 5, 2017).
12. Brian D. Drollette et al., "Elevated Levels of Diesel Range Organic Compounds in Groundwater Near Marcellus Gas Operations Are Derived from Surface Activities," Proceedings of the National Academy of Science of America, Vol. 112, No. 43, pp. 13184–13189, October 27, 2015, http://www.pnas.org/content/112/43/13184.full.pdf (accessed October 5, 2017), and Energy in Depth, "Compendium of Studies Demonstrating the Safety and Health Benefits of Fracking," http://eidhealth.org/wp-content/uploads/2017/04/Positive-Health-Compendium.pdf (accessed October 5, 2017).
13. U.S. Environmental Protection Agency, *Hydraulic Fracturing for Oil and Gas: Impacts from the Hydraulic Fracturing Water Cycle on Drinking Water Resources in the United States (Final Report)*, 2016, https://cfpub.epa.gov/ncea/hfstudy/recordisplay.cfm?deid=332990 (accessed October 5, 2017), and Peter B. McMahon et al., "Methane and Benzene in Drinking-Water Wells Overlying the Eagle Ford, Fayetteville, and Haynesville Shale Hydrocarbon Production Areas," *Environmental Science & Technology*, Vol. 51, No. 12 (2017), pp. 6727–6734, http://pubs.acs.org/doi/abs/10.1021/acs.est.7b00746?journalCode=esthag (accessed October 5, 2017).
14. Greenpeace, "Fracking," http://www.greenpeace.org/usa/global-warming/issues/fracking/ (accessed October 5, 2017), and U.S. Department of Energy, Energy Information Administration, "U.S. Energy-related Carbon Dioxide Emissions in 2015 Are 12% Below Their 2005 Levels," May 9, 2016, https://www.eia.gov/todayinenergy/detail.php?id=26152 (accessed October 5, 2017).
15. Mark Green, "Expanding Offshore Access Is Key to U.S. Energy Security," EnergyTomorrow, May 1, 2017, http://energytomorrow.org/blog/2017/05/01/expanding-offshore-access-key-to-us-ener (accessed October 5, 2017).

Climate Impact of Increased Oil and Gas Production

To assess the veracity of claims that increased oil and gas production, especially fracking, would lead to exacerbated global warming, we used the Model for the Assessment of Greenhouse Gas Induced Climate Change (MAGICC)—also used by the Intergovernmental Panel on Climate Change—to estimate how temperatures and sea levels would change as a result of increased CO_2 emissions resulting from our policy scenario.[16]

Even under the dubious assumption that a doubling of CO_2 emissions significantly increases warming, our simulations indicate that, by 2100, global temperature would change by no more than 0.003 degrees Celsius and sea levels would rise by no more than 0.02 cm. The MAGICC model simulations, in conjunction with the results from HEM, thus demonstrate that accessing the U.S.'s vast oil and gas supply would have tremendous economic benefits and negligible impact on the climate.

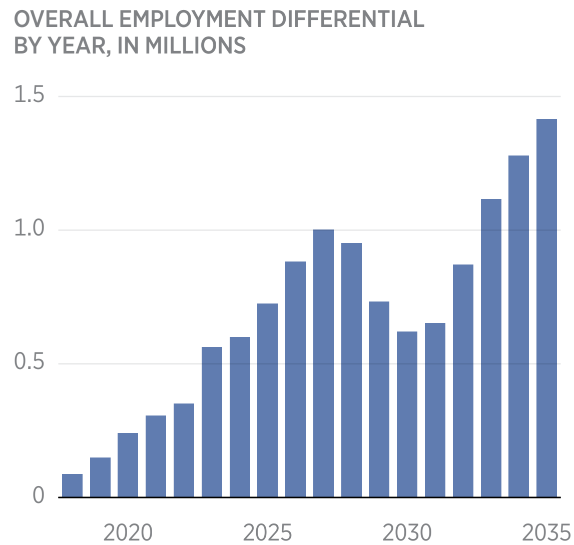
The Economic Impact of Using U.S. Oil and Gas Resources

To quantify the economic impact of capitalizing on our vast oil and gas supply, we used the Heritage Energy Model (HEM). We performed a simulation comparing current policy to a policy assuming that the recoverable shale oil and shale gas are 50 percent higher through greater access, reduced regulations, and improved efficiencies. All of the assumptions are set forth in the Appendix.[17]

The combination of a rational regulatory environment with open access could put a 50 percent increase within reach. Although lower energy prices may tamper new investments, companies are reducing operating costs and improving efficiency to enhance productivity.[18] Vice Chairman of IHS Markit Daniel Yergin remarked, "The industry is in the middle of re-engineering its processes and its technologies to be a $50 industry, not a $100 industry."[19]

CHART 1

How Unleashing America's Energy Abundance Would Affect U.S. Jobs



SOURCE: Heritage Foundation calculations using the Heritage Energy Model. See methodology for details.

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Chart 1 provides the impact, based on the simulation results, of lifting unnecessary regulations and taking advantage of the abundant oil and gas resources our country has to offer.

The prospect of fracking creates employment opportunities for those directly associated with the

16. University Corporation for Atmospheric Research, "MAGICC/SCENGEN," http://www.cgd.ucar.edu/cas/wigley/magicc/ (accessed October 5, 2017).

17. U.S. petroleum production and natural gas production in 2016 were about 50 percent *higher* than the projection the EIA made for them eight years earlier. In fact, our assumptions in this study may even be under-estimates not fully taking into account the potential of ever-improving smart drilling technologies. For a similar analysis using a previous version of NEMS, see Kevin D. Dayaratna, David W. Kreutzer, and Nicolas D. Loris, "Time to Unlock America's Vast Oil and Gas Resources," Heritage Foundation *Backgrounder* No. 3148, September 1, 2016, http://www.heritage.org/environment/report/time-unlock-americas-vast-oil-and-gas-resources.

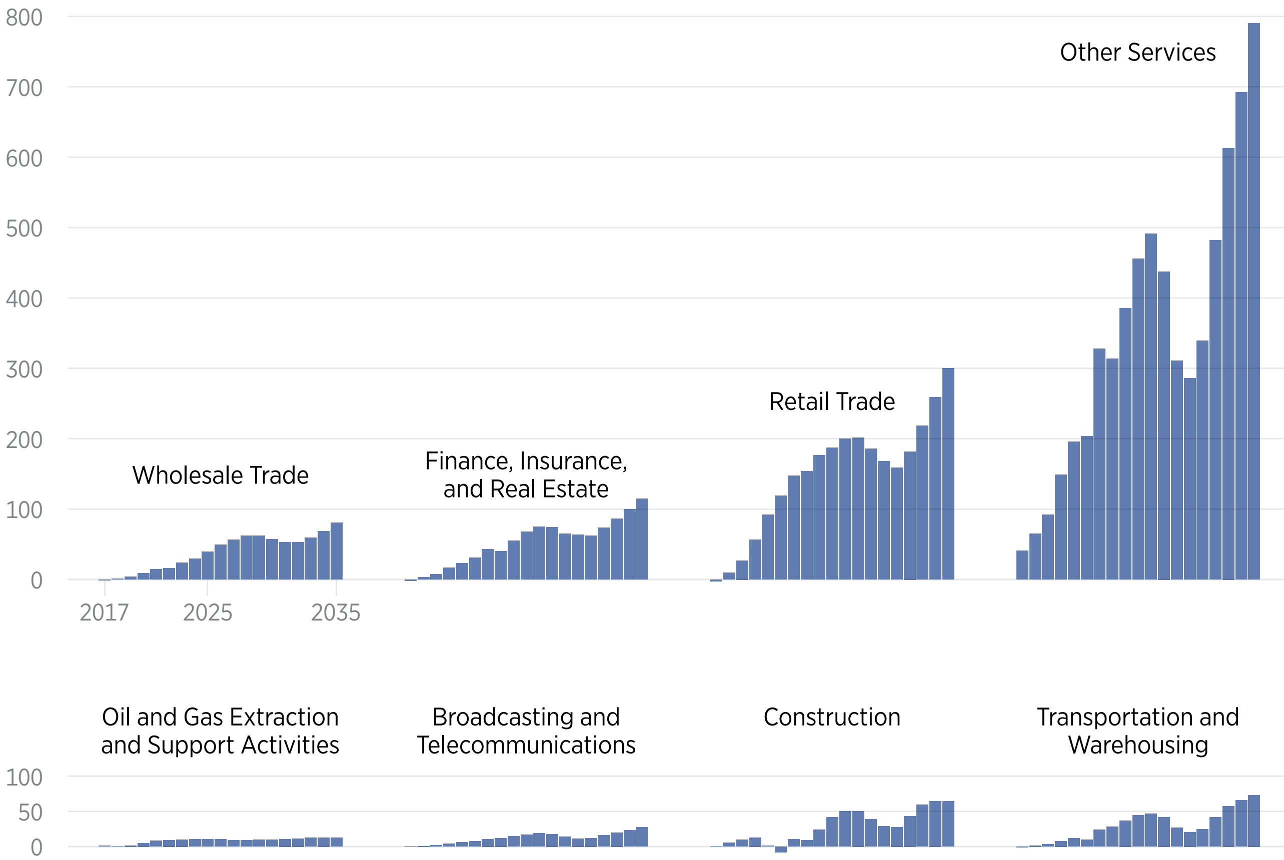
18. Karen Boman, "Cost Reduction, Greater Efficiency Focus of Technology in 2017," Rigzone, January 6, 2017, http://www.rigzone.com/news/oil_gas/a/148019/cost_reduction_greater_efficiency_focus_of_technology_in_2017 (accessed October 5, 2017).

19. Stanley Reed, "Oil Companies at Last See Path to Profits After Painful Spell," *The New York Times*, August 1, 2017, https://www.nytimes.com/2017/08/01/business/energy-environment/oil-prices-bp-exxon.html?mcubz=3 (accessed October 5, 2017).

CHART 2

Unleashing America's Energy Abundance: Job Growth by Sector

EMPLOYMENT DIFFERENTIAL BY YEAR, IN THOUSANDS



SOURCE: Heritage Foundation calculations using the Heritage Energy Model. See methodology for details.

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extraction including data scientists, engineers, and geologists. Moreover, the energy boom provides more employment opportunities for local businesses near extraction sites such as hardware stores, hotels, laundromats, restaurants, and so forth. Chart 1 illustrates a peak employment gain of 1.4 million new jobs and average gains of over 660,000 jobs. These gains occur for a variety of reasons.

Even for businesses not directly or indirectly associated with energy production, cheaper energy lowers the cost of doing business. Nearly every business in the U.S. uses energy as an input cost for its product, whether it is as simple as paying the electricity bill or filling up a vehicle with gasoline or diesel to transport goods. Cheaper energy means companies across the country would incur lower operational costs and therefore have more resources to invest in labor and capital.

Chemical companies are investing heavily in the U.S., citing the affordable and abundant natural gas as their motivation. As of July 2017, the American Chemistry Council reports that the industry is cumulatively investing $185 billion on 310 projects in the U.S.[20] Chart 2 shows some of the industries that would reap tremendous benefits from increased energy production.

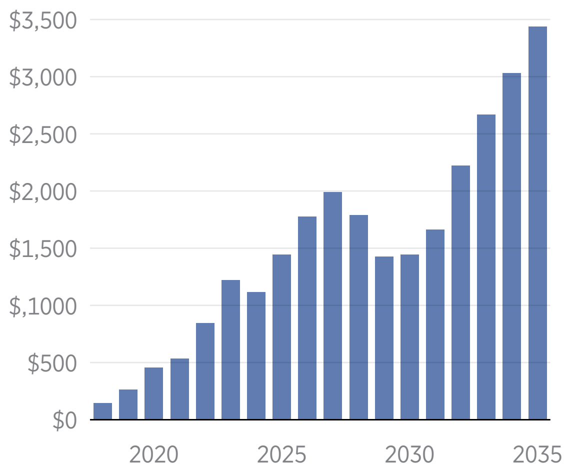
The economic gains at the industry level are impressive, but individuals and households also

20. American Chemistry Council, "U.S. Chemical Investment Linked to Shale Gas: $185 Billion and Counting," July 2017, https://www.americanchemistry.com/Shale_Gas_Fact_Sheet.aspx (accessed October 5, 2017).

CHART 3

Unleashing America's Energy Abundance: Higher Family Incomes

PERSONAL INCOME DIFFERENTIAL BY YEAR FOR A FAMILY OF FOUR, IN INFLATION-ADJUSTED DOLLARS



SOURCE: Heritage Foundation calculations using the Heritage Energy Model. See methodology for details.

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receive remarkable financial benefits. The dramatic increase in oil and natural gas production drives down prices, putting money back in the wallets of Americans. Cheaper energy lowers the cost of living. After accounting for inflation, overall energy expenditures in 2015 were the lowest since 2004, driven in large part because of increased supplies.[21] According to the U.S. Energy Information Administration, "In constant 2015 dollars, average annual household energy expenditures peaked at about $5,300 in 2008. Between 2008 and 2014, average annual household energy expenditures declined by 14.1%."[22]

Increased energy supplies will drive prices down further, generating significant cost savings and overall economic gains to households. As Chart 3 illustrates, the average family of four gains over $27,000 by 2035. In terms of total gross domestic product, these gains translate to an increase of over $2.4 trillion.

Our analysis also computed the changes in annual electricity expenditures for a family of four. Annual electricity expenditures will decline, resulting in a total savings of nearly $1,000 for such a household. These savings are particularly important for low-income families and seniors on fixed incomes where energy costs represent a larger portion of their budget.[23] When low-income households are making difficult decisions regarding health care and access to food, the additional energy savings are essential to a better quality of life.

How to Capitalize on America's Energy Abundance

President Trump's energy independence executive order includes direction to open access to resources on federal lands and review, suspend, revise, or rescind a number of regulations.[24] The simulation results above illustrate the vast gains that would occur if policymakers open access to off-limits areas, streamline the permitting process, and reduce the regulations with no direct, substantial environmental benefits. Working with Congress, the Trump Administration can leave a legacy that fundamentally changes how energy investments are made. To achieve these gains, federal and state policymakers should:

Open Access to Energy Exploration of Federal Waters and Lands. The Administration should open all federal waters and federal lands that are not part of the national park system or congressionally designated areas to exploration and production for all of America's natural resources. Congress should require the Department of the Interior (DOI) to conduct lease sales, rather than develop five-year

21. U.S. Department of Energy, Energy Information Administration, "Total U.S. Energy Expenditures in 2015 Were the Lowest in More than a Decade," August 10, 2017, https://www.eia.gov/todayinenergy/detail.php?id=32432 (accessed October 5, 2017).

22. U.S. Energy Information Administration, "Declining Energy Prices Lower the Cost of Living," May 3, 2016, https://www.eia.gov/todayinenergy/detail.php?id=26072 (accessed October 5, 2017).

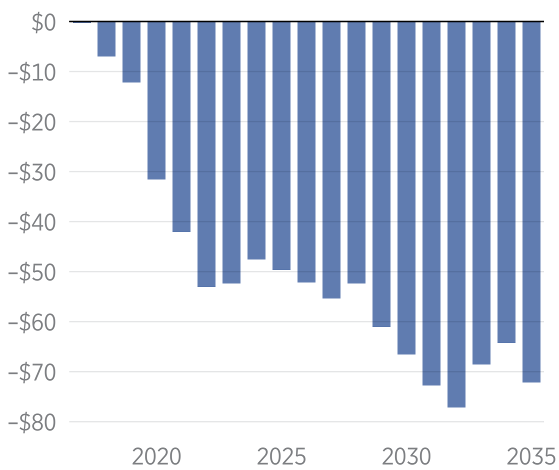
23. Jon Jin, "The Burden of Energy Costs on Low-income Families," Healthify, June 7, 2016, https://www.healthify.us/healthify-insights/the-burden-of-energy-costs-on-low-income-families (accessed October 5, 2017).

24. President Donald J. Trump, "Presidential Executive Order on Promoting Energy Independence and Economic Growth."

CHART 4

Unleashing America's Energy Abundance: Lower Electricity Bills

ELECTRICITY EXPENDITURES DIFFERENTIAL BY YEAR FOR A FAMILY OF FOUR, IN 2016 DOLLARS



SOURCE: Heritage Foundation calculations using the Heritage Energy Model. See methodology for details.

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planning programs, if a commercial interest exists. The lease plans do not reflect dynamic market conditions that affect companies' decisions to explore and develop offshore resources. Congress and the Administration should overhaul the leasing process that ensures access to safely develop energy off America's coasts.

Reverse Federal Regulations on Fracking. Federal regulations duplicate existing state regulation on fracking since companies must obtain state permits for all wells, including federal wells, and must comply with all state regulations. Citizens working with state and local bureaucrats have a significantly better sense about increasing economic growth while protecting their environment. The federal government should rescind all methane regulations for oil and gas activities, which will drive costs higher for no climate benefit.[25]

Allow States to Manage Energy Development. Permitting energy extraction on federally owned land will result in even more oil and gas extraction and create jobs in areas that would otherwise not see such economic growth. The average period for the federal government to process an application for permit to drill (APD) lasts for months (sometimes over a year), whereas states process an APD in days or weeks. The DOI should reduce the APD time frames to that of states.

A better solution requires legislative change, wherein Congress grants authority to state regulators to oversee the environmental review and permitting of energy projects on federal lands within their borders. The Federal Land Freedom Act, which would allow states to regulate energy development, will produce better economic and environmental results.[26] Ultimately, Congress should explore ways to sell federal lands to states and private individuals who are in a better position to reap the benefits from energy production while protecting the environment.

Streamline the National Environmental Policy Act (NEPA) Process. The NEPA requires federal agencies to conduct comprehensive environmental impact assessments for a wide range of projects, including energy extraction on federal lands. A number of factors result in NEPA delays at the federal, state, and local level. At the federal level, some of the major issues include differing interpretations of NEPA requirements, failed interagency coordination, administrative bottlenecks, and outdated requirements that fail to take into account changing conditions. In fact, the Obama Administration recognized that the federal government could expedite permitting without sacrificing environmental protection by effectively relinquishing NEPA requirements for a large number of projects funded by the American Recovery and Reinvestment Act.

25. Nicolas D. Loris, "Methane Regulations Add to the Price Tag of the Administration's Climate Plan," Heritage Foundation *Issue Brief* No. 4341, February 3, 2015, http://www.heritage.org/environment/report/methane-regulations-add-the-price-tag-the-administrations-climate-plan.

26. Nicolas D. Loris, "The Federal Land Freedom Act: Empowering States to Regulate Energy Will Yield Better Economic and Environmental Results," testimony before the Subcommittee on Energy and Mineral Resources, Committee on Natural Resources, U.S. House of Representatives, November 21, 2016, http://www.heritage.org/testimony/the-federal-land-freedom-act-empowering-states-regulate-energy-will-yield-better-economic.

Empowering states to regulate energy production on federal lands would satisfy all NEPA requirements. Without legislative reform, however, the Trump Administration should require agencies to complete environmental assessments as expeditiously as possible. Reforms include:

- **Properly shaping the scope of the project.** Agencies control the substance of a NEPA analysis by shaping the "scope" (i.e., the purpose and need) of the project. As a result, the agencies can effectively control the outcome of the NEPA review through deliberate scoping. Therefore, the utmost constraint should be exercised in scoping to ensure that the NEPA analysis is targeted and relevant, thus helping to reduce legal challenges and shorten the review.

- **Eliminating redundancies.** The multitude of other regulatory requirements makes a full-scale NEPA review redundant. The Council on Environmental Quality (CEQ) should allow agencies to treat existing analyses as functional equivalents for project elements that have been previously reviewed.

- **Ensuring scientific transparency and integrity.** The scientific integrity of the NEPA process suffers from a lack of consistent methodology. The CEQ has left agency officials free to apply any assessment approach of their choosing, but thorough cost-benefit analyses are rare. The CEQ should carefully monitor the scientific validity of information/data used in the review, and reject unsound findings.

- **Establishing a lead agency and restricting the input of other agencies.** Responsibility for the NEPA review should be assigned to a "lead" department. The involvement of other agencies should be strictly limited to issues that fall within their specified jurisdiction or expertise.

Allow Fracking on Private Land. Property rights are a fundamental component of American society. Individuals should have the right to use their property as they see fit and have the freedom to contract with private employees to frack on their own lands if they so desire. Proper enforcement of property rights, in conjunction with appropriate regulations implemented by state and local governments, enable the extraction of potentially valuable resources and the protection of the environment.[27] States should not issue blanket moratoriums on fracking that strip away these rights.

Prohibit Taxes or Regulations Regarding Greenhouse-Gas Emissions. Past Heritage Foundation research has demonstrated that any carbon tax or climate change regulations will reduce energy supply, raise energy costs, and eliminate jobs, but have an insignificant impact on global temperatures.[28] The Environmental Protection Agency and the DOI should rescind these regulations and Congress should clarify that the Clean Air Act was never intended to regulate CO_2 and other greenhouse-gas emissions and prohibit any further climate regulations.

Conclusion

The U.S. has a vast supply of oil and gas running beneath it. Capitalizing on this vast supply will have tremendous economic benefits, creating hundreds of thousands of jobs and making families all across the country more prosperous in the process. Policymakers should pursue policies to unlock these resources.

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27. Nicolas D. Loris, "Free Markets Supply Affordable Energy and a Clean Environment," Heritage Foundation *Backgrounder* No. 2966, http://www.heritage.org/research/reports/2014/10/free-markets-supply-affordable-energy-and-a-clean-environment.

28. Kevin D. Dayaratna, Nicolas D. Loris, and David W. Kreutzer, "Consequences of Paris Protocol: Devastating Economic Costs, Essentially Zero Environmental Benefits," Heritage Foundation *Backgrounder* No. 3080, April 13, 2016, http://www.heritage.org/environment/report/consequences-paris-protocol-devastating-economic-costs-essentially-zero.

Appendix: Methodology

The Heritage Energy Model

The analysis in this *Backgrounder* uses the Heritage Energy Model (HEM), a derivative of the National Energy Model System 2017 Full Release (NEMS).[29] The NEMS is used by the Energy Information Administration (EIA) in the Department of Energy as well as various nongovernmental organizations for a variety of purposes, including forecasting the effects of energy policy changes on a plethora of leading economic indicators.

The methodologies, assumptions, conclusions, and opinions in this *Backgrounder* are entirely the work of statisticians and economists in the Center for Data Analysis (CDA) at The Heritage Foundation, and have not been endorsed by, and do not necessarily reflect the views of, the developers of the NEMS.

The HEM is based on well-established economic theory as well as historical data, and contains a variety of modules that interact with each other for long-term forecasting. In particular, the HEM focuses on the interactions among

1. The supply, conversion, and demand of energy in its various forms;
2. American energy and the overall American economy;
3. The American energy market and the world petroleum market; and
4. Current production and consumption decisions as well as expectations about the future.[30]

These modules are the:

- Macroeconomic Activity Module,[31]
- Transportation Demand Module,
- Residential Demand Module,
- Industrial Demand Module,
- Commercial Demand Module,
- Coal Market Module,
- Electricity Market Module,
- Liquid Fuels Market Module,
- Oil and Gas Supply Module,
- Renewable Fuels Module,
- International Energy Activity Module, and
- Natural Gas Transmission and Distribution Module.

The HEM is identical to the EIA's NEMS with the exception of the Commercial Demand Module. The Commercial Demand Module makes projections regarding commercial floor-space data of pertinent commercial buildings. Other than the HEM not having this module, it is identical to the NEMS.

Overarching the 12 modules is the Integrating Module, which consistently cycles, iteratively executing and allowing these various modules to interact with each other. Unknown variables that are related, such as a component of a particular module, are grouped together, and a pertinent subsystem of equations and inequalities corresponding to each group is solved via a variety of commonly used numerical analytic techniques, using approximate values for the other unknowns. Once a group's values are computed, the next group is solved similarly, and the process iterates. Convergence checks are performed for each price and quantity statistic to determine whether subsequent changes in that par-

29. U.S. Department of Energy, Energy Information Administration, "The National Energy Modeling System: An Overview," October 2009, http://www.eia.gov/oiaf/aeo/overview/pdf/0581(2009).pdf (accessed April 3, 2013).

30. Ibid., pp. 3–4.

31. The HEM's Macroeconomic Activity Module uses the IHS Global Insight model, which is used by government agencies and Fortune 500 organizations to forecast the effects of economic events and policy changes on notable economic indicators. As with the NEMS, the methodologies, assumptions, conclusions, and opinions in this report are entirely the work of CDA statisticians and economists, and have not been endorsed by, and do not necessarily reflect the view of, the owners of the IHS Global Insight model.

ticular statistic fall within a given tolerance. After all group values for the current cycle are determined, the next cycle begins. For example, at a particular cycle, a variety of pertinent statistics, is obtained.[32] The HEM provides a number of diagnostic measures, based on differences between cycles, to indicate whether a stable solution has been achieved.

This report uses the HEM to analyze the impact of making hydraulic fracturing more feasible by increasing the availability of petroleum in North America. In particular, we ran two of the same simulations that the EIA used in "Annual Energy Outlook 2017," in comparing the greater availability of shale oil, shale gas, and its variants in North America with current policy.[33]

32. Steven A. Gabriel, Andy S. Kydes, and Peter Whitman, "The National Energy Modeling System: A Large-Scale Energy-Economic Equilibrium Model," *Operations Research*, Vol. 49, No. 1 (January–February 2001), pp. 14–25, http://pubsonline.informs.org/doi/pdf/10.1287/opre.49.1.14.11195 (accessed December 23, 2014).

33. U.S. Department of Energy, Energy Information Administration, "Annual Energy Outlook 2017," 2017, https://www.eia.gov/outlooks/aeo/data/browser/ (accessed October 5, 2017): "Estimated ultimate recovery per shale gas, tight gas, and tight oil well in the United States, and undiscovered resources in Alaska and the offshore lower 48 states, are 50% higher than in the Reference case. Rates of technological improvement that reduce costs and increase productivity in the United States are also 50% higher than in the Reference case. In addition, tight oil and shale gas resources are added to reflect new plays or the expansion of known plays."