Ecological Efficiency, Disproportionality and Methodological Precision: on the Importance of Linking Methods to Theory

Dana R. Fisher, *Columbia University*
William R. Freudenburg, *University of California-Santa Barbara*

York and Rosa (Y&R) raise a series of essentially methodological concerns about our recent article (Fisher and Freudenburg 2004), but they say relatively little about the theoretical questions we consider central to any disagreement about work on the environmental state. We begin this response by briefly summarizing the key theoretical issues before turning to the more specific methodological issues that (also) separate their recent work from our own.

For the past several years, perhaps the central debate in environmental sociology has involved sharp disagreement about the political and economic feasibility of environmental protection. On the one hand, some scholars expect what Schnaiberg and Gould call an "enduring conflict" between environmental protection and economic vitality (1994; see also Catton 1980; Dunlap 1993, Schnaiberg 1980). We see the work by Y&R as consistent with work within this perspective. On the other hand, a number of scholars have argued, in the words of Giddens (1998:19), that environmental protection has become "a source of economic growth rather than its opposite." (See Spaargaren and Mol 1992. For an important recent compilation of the differing views, see Mol and Buttel 2002.)

Rather than lining up with one side or another in this ongoing debate, the two of us have taken an agnostic position: given that proponents of both sets of views have been able to identify *specific examples* that are reasonably consistent with their perspectives, we see the need for approaches that can permit a more systematic and fine-grained assessment of the available evidence (e.g., Fisher and Freudenburg 2001). In particular, we have sought to identify the kinds of variables that permit the debate to move beyond black/white, either/or positions, and instead to focus on the *degree* to which economic growth in developed nations may or may not be "decoupling" from ever-increasing environmental damage. Two variables, in our view, have shown particular promise. One has to do with *ecological* efficiency (as opposed to the more traditional "economic efficiency") of production processes; the other has to do with the degree of disproportionality between economic and environmental impacts at the level of economic sectors, industries or even specific facilities. Ultimately, we believe, resolution of the underlying theoretical question is likely to depend on a combination of broad-scale, cross-national comparisons along with more detailed analyses that focus on specific industries or facilities. Some of our other recent work provides apples-to-apples comparisons of efficiencies and disproportionalities *within* a given nation, finding levels that were frankly surprising to us – with some facilities producing an emissions-to-jobs ratio more than a thousand times worse than the national average. (See especially Freudenburg in press.) The key finding of our recent piece (2004), however, had to do with overall or national-level differences in ecological efficiency, particularly among the industrialized nations of the Organization for Economic Cooperation and Development (OECD), which are the ones that have the greatest impacts on the global environment.

The Substantive Issue

At several points in their critique, Y&R characterize our paper as having stated that "GDP has no effect on CO_2 (carbon dioxide) emissions." That characterization is overstated in a way that links directly to the question of ecological efficiency. We clearly report the existence of what appears to be a moderately strong zero-order correlation between GDP and CO_2 (roughly .65), but we do not stop there. Instead, we go on to note that the correlations "drop to insignificance once other variables are controlled" – much as happens in recent economic assessments that correct the shortcomings of earlier models (Krause et al. 2002, 2003). By far the most important of those "other variables" are our simple measures of ecological efficiency.

At several points in their critique, Y&R argue that variables other than ecological efficiency – such as total primary energy supply (TPES) or "ecological footprint" measures – are the ones that should make it "difficult" for remaining independent variables "to have a significant independent effect on CO_2 emissions." In fact, what emerges from our analysis is that neither the TPES nor the "ecological footprint" measures come close to statistical significance in any of our equations, *after controls are imposed for ecological efficiency*. Instead of exerting powerful effects, as Y&R expect, these two variables join the GDP measure in dropping out of the analysis through the process of backward elimination. Contrary to the Y&R expectations, the measures that make it "difficult" for other variables to have statistically significant coefficients are our two measures of ecological efficiency. Intriguingly, one of those efficiency variables is operationalized in a way that Y&R might criticize as raising at least the potential for multicollinearity, while the other could scarcely have been operationalized more differently.

Y&R do ultimately refer to the issue of ecological efficiency in the fourth specific point of their critique. Although we see this issue as being central to the most important arena of theoretical disagreement in environmental sociology today, they argue that our finding about the significance of ecological efficiency "misses the point" because of their assertion that increased efficiency "contributes to the expansion" of production and hence emissions. They support their claim by referring to what Clark and Foster (2001) have termed "the Jevons Paradox," named after the 1865 observation by Jevons that greater efficiency in the use of coal led to more coal consumption. For the record, we share their view that the key environmental measure, in the end, is the *total* environmental impact created by a society or an industry – not just the impact per unit of production — and we join Y&R in recommending the thoughtful article by Clark and Foster. We add, however, that today's literature in industrial ecology, or for that matter in neoclassical economics, tends to see the patterns of coal consumption during the early industrial revolution as being significantly less paradoxical.

In fact, it is characteristic of the early stages of development in a technology to find dramatic increases in *ecological* as well as *economic* efficiencies – leading to rapidly falling prices and hence to dramatically increased demand. Those who are old enough to remember price declines of the early calculators, or for that matter, personal computers, should be reasonably familiar with this pattern. A similar tendency is also visible in present-day energy technologies. More than a century after Jevons, however, today's increases in physical or ecological efficiency of the coal industry are quite modest. Instead, the truly significant increases in both ecological and economic efficiency are being seen in newer industries that also happen to have far less damaging ecological consequences, namely wind power and photovoltaic or solar electricity. As noted by Brown (2004), wind-powered electricity had an

average cost of 38 cents per kilowatt hour in 1982, but a cost only one-tenth that high – roughly 4 cents per kilowatt hour in 2003. Partly as a result, the world's installed wind-generating capacity has seen phenomenal growth, from a total of 210 megawatts in 1983 to 2990 megawatts in 1993 and to 39,294 megawatts in 2003. Despite recent setbacks for non-carbon-based electricity generation in the American *political* arena (for a full discussion, see Fisher 2004), recent years have actually seen *increasing* growth in the demand for wind and solar electricity generation, in percentage as well as absolute terms, with global demand for wind-powered electricity growing at a rate of more than 25 percent a year, every year from 1994 through 2003 (Brown 2004). By contrast, despite intense efforts by political leaders in the United States (and other coal-rich nations such as China) to increase coal production/consumption, world coal demand rose only from 4,417 to 5,262 million tons from 1983 through 2003 (U.S. Energy Information Administration 2004). These are large numbers, but they translate into a growth rate of less than 1 percent per year. Rather than "missing the point," ecological (and to some degree, economic) efficiencies are *central* in their importance. To repeat our earlier observation, such efficiencies, along with the issue of disproportionalities, may well be the two variables that have most to offer in resolving the key theoretical debates in environmental sociology today.

The Methods – and the Invitation

The remaining differences between Y&R's views and ours are largely methodological in nature, although that phrase may include an apparent difference in preferred methods for resolving empirical disagreements. We first saw the York et al. (2003) article after all but the final version of our paper had been completed. To a greater extent than we initially appreciated, their article reaches conclusions that are virtually the opposite of our own. York et al. essentially conclude that only socioeconomic scale plays an important role in influencing a nation's "Ecological Footprint," while we conclude that national economic output drops to insignificance once controls are imposed for ecological efficiency. Ultimately, the issue may best be resolved by more fine-grained analyses, at the levels of the economic sector, the industry, and even the specific facilities that specialize in closely comparable industries, but there is also clearly a need for further analysis at the level of the nation-state, examining methodological and other factors that might help to explain the differences in the findings of our two studies.

This need became clear when one of us (Freudenburg) assigned both articles for a seminar in fall 2004. After reading and discussing the articles with his students, Freudenburg sent Drs. York and Fisher an e-mail, suggesting that the three of us, potentially along with Drs. Rosa and Dietz, work together on a subsequent analysis that might identify the factors leading to the differing findings. As the invitation was spelled out in that initial e-mail:

> "There are about a half-dozen possibilities for explaining the differences in findings, all pretty straightforwardly methodological, and the obvious thing to do would be to look at all of them to see which one(s) offer the best fit(s) to the data. The ones I can remember off the top of my head at the moment include:

1) Dana-Bill use 29 OECD [Organization for Economic Cooperation and Development] countries; Richard et al. use pretty much the whole world;

2) Dana-Bill focus on CO_2, Richard et al. focus on ecological footprints;

3) Dana-Bill control for national ecological efficiency with two simple variables (one each for industrial and consumer waste), while Richard et al. don't;

4) Dana-Bill use linear regression with backward elimination, while Richard et al. use quite a few logs and quadratic logarithmic transformations…"

The e-mail ended with a brief discussion of the potential challenges of obtaining all the relevant data for all nations, and with an offer of a "reverse beer bet," namely that if one "side" could be shown to be "at least 51 percent correct," that winning side would need to buy a first round of beer for the other.

The first two of the possibilities identified in the informal e-mail note provide the focus for much of the Y&R critique. They express a number of concerns about our decision to focus on the industrialized countries of the OECD (point 1 above) and to focus on the largest single constituent of the "greenhouse gases" that contribute to global warming, namely carbon dioxide or CO_2 (point 2 above). A complementary set of concerns, of course, could be raised by the decision to include all the nations in the world when testing theories that are specified as applying only to "late" or "advanced" capitalistic countries, as well as by the Y&R decision to measure environmental impacts in terms of the ecological footprint variable, which has been criticized for ignoring the role of trade (Ayres 2000). Although Y&R seem to conclude that the proper response is to be cautious in interpreting *one* set of results, our view continues to be that the sensible resolution would involve an initial caution about *both* sets of results, using the classic techniques of triangulation, before reaching any firm conclusions about which approach (or approaches) might offer the most plausible conclusions overall.

Much of the remainder of the Y&R critique relates to points 3 and 4 in the e-mailed invitation, although the remaining connections are less straightforward. Point 3, having to do with the importance of efficiency, is perhaps the central substantive difference between their view and ours. They argue that efficiency measures "miss the point." As has been previously stated, however, we believe that questions about *overall* environmental impacts are best answered empirically, and that ecological efficiency and disproportionality may well *be* the point. The Y&R views on point 4 require more detailed discussion, since they center largely on whether one variable might be "included" in another – an issue better known in the statistical literature as a debate over ratio variables – and on the potential for multicollinearity.

We turn first to the debate over ratio variables, which dates back more than a century, to the time when Pearson (1897), in an argument that is largely in agreement with the view that is expressed by Y&R, warned that ratio variables with a common denominator might provide spurious measures. Pearson's concerns about ratio variables, however, were not necessarily shared by other early statisticians. Yule (1910), for example, would respond that such measures would not be spurious if the theory being tested actually called for the variables being measured by the ratios in question. Over the years, Pearson's concerns about "common denominators" have been extended to virtually any situation where variables might share a common component – as will almost always be the case for cross-national comparisons such as these – but most of the relevant conclusions have tended instead to favor Yule. In the 1970s, for example, Fuguitt and Lieberson (1973: 141) expressed a view that "spurious correlation is not an issue in correlating ratios or differences having common terms, provided that one's interest is exclusively in the composite variables rather than in the components," as was the case in our paper. In 1980, Long came to a conclusion that is

demonstrated by our own findings (1980: 38): "The use of ratio variables with common components in theory building...does not constrain or make more likely one sign or direction of association over another." Instead, as Kritzer found (1990: 248), another decade later, "The issue of how to measure variables is one of theoretically determined specification, not one of worrying about statistical artifacts like the correlation among ratios formed from independent random variables."

Kritzer's conclusion resonates particularly well with our findings. Y&R argue, for example, that "one effect" of including Total Primary Energy Supply per capita (TPES) "is that it is difficult for other independent variables to have a significant independent effect on CO_2 emissions." A closer look at our findings, however, suggests that it may actually have proved "difficult" for the TPES measure itself to have an effect, because none of the *Betas* for TPES in the nine models in our Table 3 rise as high as .2, and none come close to statistical significance ($p > .4$ in all equations).

All of which brings us to the issue of multicollinearity. Y&R criticize our brief mention of Tolerance statistics and then go on to note, accurately, that "The problem with multicollinearity, of course, is that it can make the coefficient estimates in regression models highly unstable." It is precisely for this reason that we went well beyond the mechanical examination of Tolerance statistics and instead followed (and reported) the results from "the practice recommended by statistical textbooks such as Hamilton (1990:581-82)," namely "simplifying a regression by dropping nonsignificant variables," in a process sometimes called *backward elimination*. Because we dropped what statistical textbooks sometimes call "redundant" or nonsignificant variables in the most conservative and transparent way possible – one at a time, with all remaining coefficients being recalculated each time – that same table allows *Social Forces* readers to see for themselves the actual relevance of the Y&R concern about "highly unstable" coefficient estimates. As we reported in the paragraph that introduced the results in the original article: out of 44 coefficients reported in the second through the final (ninth) models of Table 3, there is not a single case where the direction (sign) of a variable reverses, and there is only one case where the coefficient shifts by as much as .10 – the change from .656 to .547 for Motor Vehicle Travel per capita between the third and fourth models. If we include all nine equations, including the fully saturated model where the potential for multicollinearity would be expected to be most severe, there would be 59 such coefficients, and again there is a striking lack of variation. It is important to note here that there is one error in a non-significant coefficient that might have contributed to the Y&R concerns about multicollinearity. In the saturated model, the standardized and unstandardized coefficients for the Ecological Footprint measure are erroneously printed in the published version of the article (but not in the prepublication word-processing file that we sent directly to Dr. York) as .540 and .699, respectively (although the significance level is accurately reported in both locations, as $p = .533$). The published version accidentally includes the coefficients from the previous row in the table for Motor Vehicle Travel per capita; the actual *Beta* for the Ecological Footprint measure should have been printed as -.165, which is precisely the same value as in the next model (an erratum is presently forthcoming). In short, out of 59 coefficients, there is still only one case where the value shifts by as much as .10 – a far better indicator than Tolerance statistics or calculations of Variance Inflation Factors, in our view, of the utter absence of "highly unstable" coefficient estimates.

The Closing Invitation

The critique by Y&R raises a number of other issues as well – for example, the regret that we

use the conservative approach of eliminating variables that are statistically insignificant plus the concern that our decision to use only the industrialized nations of the OECD might truncate the variability in our income measures. We chose the conservative approach, however, precisely because we wanted to follow the common advice in statistical textbooks about the need to be alert for any potential multicollinearity and about the desirability of eliminating redundant variables. As Y&R themselves note, the OECD nations display considerable variability in incomes, with per capita income ranging from $5,243 in Mexico to $38,689 in Luxembourg.[1] They argue that not just the use, but the *production* of automobiles may constitute "a major source of $CO_{2,}$," while we take note of the fact that Japan is the world's second-largest *producer* of automobiles,[2] with per capita levels of motor vehicle travel less that one-fifth as high as those in the United States. They cite the important work of Frey (2003) and Roberts and Grimes (1997) on the "distancing" problem or the potential for rich nations to "export" their most dangerous industries to poor countries having weak environmental regulations, but we note that CO_2 emissions are scarcely in the same category of toxicity as those involved in shipbreaking or in open-air burning of computer wastes to recover small quantities of heavy metals. In an analysis of roughly 3,000 U.S. counties over a decade, Howell et al. (2003) found that counties' air pollution emissions were much more strongly correlated with prosperity than were toxic emissions.

The broader point, however, remains. Two recent articles in major sociological journals have reached sharply differing conclusions about the degree of "decoupling" that has or has not taken place between economic activity and environmental degradation. The difference in conclusions is central to what may well be the most important debate in environmental sociology today. There is every reason to believe that a relatively straightforward examination of a handful of possible explanations, in the respected tradition of triangulation, will be able to demonstrate whether the differences are due to the inclusion of ecological efficiency measures, the exclusion of non-OECD nations, the choice of one dependent variable vs. another, or some other combination of factors. Our belief is that, in the best traditions of scientific advancement, the situation is one that calls for an even-handed examination of *all* potential explanations. Accordingly, we repeat our invitation not just to Drs. York and Rosa, but also to other colleagues who are interested in the truth, to join us in searching for answers. We are still willing to buy the first round of drinks.

[1] Data adapted from www.nationmaster.com/graph-T/eco_gro_nat_inc_cap&int=-1 (Accessed February 28, 2005).
[2] Based on estimates from the International Organization of Motor Vehicle Manufacturers (OICA) at www.oica.net/htdocs/Main.htm (Accessed February 28, 2005).

References

Ayres, Robert U. 2000. "Commentary on the Utility of the Ecological Footprint Concept." *Ecological Economics* 32: 347-49.

Brown, Lester R. 2004. "The Short Path to Oil Independence: Gas-Electric Hybrids and Wind Power Offer Winning Combination." Eco-Economy Update 2004-12 (Oct. 13), Earth Policy Institute. (available on-line at http://www.earth-policy.org/Updates/Update43.htm).

Catton, William R., Jr. 1980. *Overshoot: The Ecological Basis of Revolutionary Change*. University of Illinois Press.

Clark, Brett, and John Bellamy Foster. 2001. "William Stanley Jevons and *the Coal Question:* An Introduction to Jevons's 'Of the Economy of Fuel.' " *Organization & Environment* 14 (1):93-98.

Dunlap, Riley E. 1993. "From Environmental to Ecological Problems." Pp. 707-738. *Social Problems*. Craig Calhoun and George Ritzer, editors. McGraw Hill.

Ehrlich, Paul R., and John P. Holdren. 1972. "Impact of Population Growth." Pp. 365-77. *Population. Resources and the Environment*. Washington, D.C.: US. Government Printing Office.

Fisher, Dana. 2004. *National governance and the global climate change regime*. Rowman & Littlefield Publishers.

Fisher, Dana, and William R. Freudenburg. 2001. "Ecological Modernization and Its Critics: Assessing the Past and Looking toward the Future." *Society and Natural Resources* 14 (#8, Sept.): 701-09.

Fisher, Dana, and William R. Freudenburg. 2004. "Postindustrialization and Environmental Quality: An Empirical Analysis of the Environmental State." *Social Forces* 83 (#1, Sept.): 157-88.

Freudenburg, William R., and Peter Nowak. 2000. "Disproportionality and Disciplinary Blinders: Understanding the Tail that Wags the Dog." Paper presented at 8th International Symposium on Society and Resource Management, Bellingham, WA, June.

Freudenburg, William R. Forthcoming. "Privileged Access, Privileged Accounts: Toward a Socially Structured Theory of Resources and Discourses." *Social Forces* (forthcoming).

Frey, R. Scott. 2003. "The Transfer of Core-Based Hazardous Production Processes to the Export Processing Zones of the Periphery: The Maquiladora Centers of Northern Mexico." *Journal of World-Systems Research* 9:317-354.

Fuguitt, Glenn V., and Stanley Lieberson. 1974. "The Correlation of Relations or Difference Scores Having Common Terms." *Sociological Methodology 1973-1974.* H. Costner,

editor. Jossey-Bass.

Giddens, Anthony. 1998. *The Third Way*. Polity Press.

Hamilton, Lawrence C. 1990. *Modern Data Analysis: A First Course in Applied Statistics*. Pacific Brooks/Cole.

Howell, Frank, William R. Freudenburg and Gregory Works. 2003. "Development, Inequality and Environmental Quality: An Analysis of Competing Hypotheses Using Local Areas in the U.S." Paper presented at Annual Meeting, Rural Sociological Society, August.

Krause, Florentin, Stephen J. DeCanio, J. Andrew Hoerner and Baul Baer. 2002. "Cutting Carbon Emissions at a Profit (Part I): Opportunities for the United States." *Contemporary Economic Policy* 20 (4, Oct.): 339-65.

Krause, Florentin, Stephen J. DeCanio, J. Andrew Hoerner and Baul Baer. 2003. "Cutting Carbon Emissions at a Profit (Part II): Impacts on U.S. Competitiveness and Jobs." *Contemporary Economic Policy* 21 (1, Jan.): 90-105.

Kritzer, Herbert M. 1990. "Substance and Method in the Use of Ratio Variables, or the Spurious Nature of the Spurious Correlation?" *Journal of Politics* 52:243-54.

Long, Susan B. 1980 "The Continuing Debate over the Use of Ratio Variables: Facts and Fiction." In *Sociological Methodology 1980*, Karl Schuessler, editor. Jossey-Bass.

Mol, Arthur P.J., and Frederick H. Buttel, editors. 2002. *The Environmental State Under Pressure: Research in Social Problems and Public Policy, Vol. 10.* Boston: JAI.

Nowak, Peter J., and Perry E. Cabot. 2004. "The Human Dimension of Resource Management Programs." *Journal of Soil and Water Conservation* 59 (#6, Nov/Dec): 123A-135A.

O'Connor, James R. 1988. "Capitalism, Nature, Socialism: A Theoretical Introduction." *Capitalism, Nature, Socialism* 1 (1, Fall):11–38.

Pearson, Karl. 1897. "On a Form of Spurious Correlation which may Arise when Indices are used in the Measurement of Organs." *Proceedings of the Royal Society of London* 60: 489-97.

Roberts, J. Timmons, and Peter E. Grimes. 1997. "Carbon Intensity and Economic Development: A Brief Exploration of the Environmental Kuznets Curve." *World Development* 25:191-198.

Rosa, Eugene A., Richard York and Thomas Dietz. 2004. "Reflections on the STIRPAT Research Program." *Environment, Technology and Society*. Summer:1-2.

Schnaiberg, Allan. 1980. *The Environment: From Surplus to Scarcity*. Oxford University Press.

Schnaiberg, Allan, and Kenneth Alan Gould. 1994. *Environment and society: the enduring*

conflict. St. Martin's Press.

Spaargaren, Gert, and Arthur P.J. Mol. 1992. "Sociology, Environment, and Modernity: Ecological Modernization as a Theory of Social Change." *Society and Natural Resources* 5:323-344.

U.S. Energy Information Administration. 2004. *International Energy Annual 2002*. U.S. Energy Information Administration (available on web at http://www.eia.doe.gov/emeu/iea/table14.html).

York, Richard, Eugene A. Rosa and Thomas Dietz. 2003. "Footprints on the Earth: The Environmental Consequences of Modernity." *American Sociological Review* 68 (#2, April): 279-300.

Yule, G. Udny. 1918. "On the Interpretation of Correlations between Indices or Ratios." *Journal of the Royal Statistical Society* 73: 644-47.

Direct all correspondence to: Dana R. Fisher, Department of Sociology, Columbia University, 324M Fayerweather Hall, 1180 Amsterdam Ave., MC 2551, New York, NY 10027. E-mail: drf2004@columbia.edu.