The Great Negawatts Debate

An Exchange of Views

No advocate has had a greater influence on the changing orientation of U.S. utilities toward energy efficiency — even the terms we use to talk about it — than Amory Lovins. Lovins' projections for the savings to be mined through energy efficiency have always challenged what many in the industry saw as practicable. His vision of the equivalency and even superiority of energy efficiency to conventional power supply has in large measure prevailed, though his projections of the savings potentially available and their cost have often been criticized as too aggressive. However, as he argues here, quoting a colleague, "Whatever exists is possible."

Paul Joskow and Donald Marron have published an acclaimed criticism of the performance of utility demand-side management programs, taking data directly from utilities that implemented the programs examined. Joskow argues compellingly here that technical potential studies such as those Lovins has conducted tell little about what savings will actually be achieved in the field or what they will cost. He also finds that Lovins' accounting and analytical methods leave something to be desired, and takes heart that the industry may be turning toward more market-driven approaches of achieving efficiency.

This debate began in other venues, as readers may know, but we are pleased to continue it here. Readers, beyond being educated and entertained, may be surprised to find in Lovins' and Joskow's pointed criticisms of each others' work a surprising scope of agreement. For everyone who cares about the business of energy efficiency, we consider these articles required reading.

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Apples, Oranges, and Horned Toads:

Is the Joskow & Marron Critique of Electric Efficiency Costs Valid?

Amory B. Lovins

Paul Joskow and Donald Marron (J&M), in "What Does a Negawatt Really Cost? Further Thoughts and Evidence" (*TEJ*, July '93, at 14-26), repeat their earlier contentions that Rocky Mountain Institute (RMI) and others have seriously understated the costs of potential electric end-use efficiency. Despite rejoinders,[1] J&M's thesis is still being disseminated and often uncritically adopted.[2] This article therefore seeks to explain more fully where J&M's interpretations diverge from RMI's published analyses,[3] why, and what substantial common ground both groups hold.

J&M's central assertion is that the costs of saved electricity reported by their "sample" of ten utilities exceeded those found in RMI's technical-potential (TP) analyses by a factor averaging nearly six-fold, for three reasons:

(1) "[B]ecause utilities report at least some administrative costs ... that are ... ignored in [RMI's] ... TP analyses";

(2) "[B]ecause some utility programs have measured savings that fall significantly below *ex ante*

projections of the kind that are incorporated in TP studies"; and

(3) "[B]ecause [RMI's] estimates of costs and performance are excessively optimistic, relying on uncertain technologies with uncertain costs and limited commercial market experience."

This paper will suggest that the apparent discrepancy between RMI's TP analyses and J&M's limited field data (FD) is due not to those three factors, all of which are wrong or irrelevant or both, but rather to five other causes:

(1) TP and FD numbers generally describe things so different that they cannot be compared at all;

(2) The average and high, though not the low, costs in J&M's FD substantially exceed nationally representative levels;

(3) J&M improperly base their conclusions on average and high-end data from reported ranges so extremely wide, both within and between their ten utilities, as to be practically meaningless;

(4) J&M's FD (like most utility programs) reflect technical content inferior to the optimized packages of technologies shown in RMI's TP analyses, so J&M's programs can be expected to save less electricity and to cost more per kWh saved;

(5) Important, acknowledged, but apparently unanalyzed differences in accounting conventions between J&M's FD and RMI's TP analyses can by themselves cause most or all of the reported discrepancy.

The normally unambiguous term "field data" is applied here to J&M's stated program costs in an unusually elastic sense. Although J&M's *Science* article emphasizes "[t]he actual history of costs and energy savings of these utility conservation programs," and most of J&M's readers probably suppose that all their FD were actually measured in utility programs already carried out, some unspecified part of their "data" turns out instead to be utilities' future *expectations*.[4]

J&M's most basic error is to suppose that data about one thing, if measured and if valid, can be used to judge the correctness of something completely different.

I. Fundamental Fallacies in the J&M Analysis

A. What Do the Discrepancies Imply?

J&M's most basic error is to suppose that data about one thing, if measured and if valid, can be used to judge the correctness of something completely different. Thus they suppose that if some utilities save electricity in particular programs at higher costs than TP supply curves show, then those curves — RMI's, the Electric Power Research Institute's (EPRI), the Department of Energy's — must be wrong and an unsound guide to policy. That's like concluding, from a few wildcatters' drilling success in one area during one short period, that the U.S. Geological Survey's estimates of the supply curve of ultimately recoverable national oil resources, based on all available evidence about economic geology, are overstated and should be ignored.

B. Unrepresentative Costs

Much of the particular drilling experience J&M have examined also happens, like the unlucky wildcatters', to be a lot costlier than many of their peers'. J&M quote this criticism from my *Science* letter, then object that I "offer no examples of the more representative utility programs that [I had] in mind." Such an example occurs two sentences later: Their 1.5–6.7¢/kWh FD mean costs for various utilities' commercial and industrial programs are *four to six times* the apparently corresponding medians reported by Steve Nadel's *Lessons Learned*,[5] which reviewed more than 200 programs at 58 utilities through 1988. Although J&M didn't cite which costs they drew from which activities in which years at which utilities, making it impossible for readers to scrutinize their numbers (and hard for me to guess which is which, even though I've consulted for all but one of those utilities), they need look no further than *Lessons Learned* for quite thorough quantitative evidence that their high costs are unrepresentative.[6] The comparison is all the stronger because J&M represent their ten utilities as among the best efficiency practitioners,[7] while *Lessons Learned*, far from being a winner's circle of the most cost-effective modern programs, is an undiscriminatingly inclusive grab-bag of pre-1989 programs with highly variable quality. J&M's sole response is to call charges of unrepresentativeness "simply unfair." Yes, but in the opposite direction: The average costs that they claim represent some of the best programs are in fact many times costlier than old run-of-the-mill programs, let alone today's actual best.

J&M's *Energy Journal* paper does acknowledge qualitatively that their ten utilities' commercial and industrial (C&I) program costs are "higher and more variable" than those of Nadel's 237 programs at 38 utilities; yet in *The Electricity Journal* in July 1993, J&M claim "no credible evidence" that their sample shows unusually high costs overall. Since they reject as a benchmark the most comprehensive data set available, what sort of evidence *would* they consider credible?

Their costs seem unusually high even at the highest level of aggregation. For example, EPRI estimates that nearly all U.S. utilities' DSM programs through mid-1993 cost an average of ~2.1¢/kWh, about equal to most utilities' short-run marginal cost of generation. But ~2.1¢/kWh is near the low end of J&M's ten-utility range of 1.9–6.9, averaging ~3.4, ¢/kWh for diverse kinds of programs.[8] The ~2.1¢/kWh U.S. average cost is especially encouraging because so many utility programs' costs have been raised by undue emphasis (chiefly for social or political reasons) on relatively costly residential shell upgrades, including low-income weatherization,[9] rather than on the bigger and cheaper C&I opportunities, which Nadel's and many others' data confirm usually cost less than 1¢/kWh.

Rather than taking some cheap programs as models to emulate, J&M took the costly ones as grounds for impugning all of them.

C. Huge Scatter

Lurking in J&M's unpublished calculational details is a third major fallacy: inferring a general truth from points near one end of an unanalyzably wide range. They state that the average reported costs they describe for residential programs:

> ...[R]anged from 3.5 cents to 22.1 cents per kWh, while for commercial/industrial programs, the range was 1.5 cents to 6.7 cents. Costs reported for individual program *components* (e.g., lighting, motors, etc.) varied from a fraction [0.3] of a cent to $1.81 per kWh saved for residential programs and from a fraction [0.2] of a cent to 18 cents per kWh saved for commercial/industrial programs.

Thus *some* utilities' savings for quite a few end-uses in all sectors *did* cost about the same as, or even less than, the hardware costs shown in RMI's TP supply curve. (Those costs ranged from zero to ~3¢/kWh; some were negative because they were more than offset by saved maintenance costs, about which more below.) That correspondence is especially encouraging because, as I'll suggest below, J&M's model programs appear to have been generally inferior in technical content to the carefully optimized packages shown in RMI's TP curve. But rather than taking some cheap programs as models to emulate, J&M took the costly ones as grounds for impugning all of them.

D. What's a 'Program'?

This may not be immediately obvious, because J&M never define or characterize a "utility program." They appear to have simply aggregated a range and an average (whether simple or savings- or use-weighted is unclear) for the costs of whatever efficiency activities their ten utilities happened to be carrying on or expecting to carry on in two broad sectors — residential and commercial/industrial. Whether those diverse activities were remotely comparable in purpose, nature, scope, technical content, degree of savings, initial status of the stocks being improved, climate, and other conditions appears not to have troubled J&M: Presumably, wrapping a water heater is equivalent to superinsulating a house, changing a light bulb is comparable to retrofitting all energy systems in a large building, and all interactions between measures or programs, however large, can be safely ignored. Not surprisingly, so varied were each utility's efforts within those sectoral "programs" that the various utilities' *ranges* of costs had an unweighted mean of 29-fold for residential and six-fold for commercial/industrial programs. For example, the unspecified residential efforts of Utility 7 (unnamed and with statistics unstated, like all the rest) showed a 172-fold cost range of 0.4–68.8¢/kWh — which somehow neatly reduced to an "average" cost of 4.8¢/kWh!

To an empirical scientist, such huge ranges, with their wide standard deviations and sensitivity to outlying values, suggest numerical goulash. Yet J&M, undaunted, had no difficulty in boiling down the scatter to "weighted average" "program costs" ranging from 1.9 to 6.9¢/kWh, and using these in turn for comparisons with RMI's TP costs. Perhaps they know what such numbers mean, but I daresay the reader doesn't, and can't compare them with TP costs for specific technologies and end-uses. This remains true even for what J&M call "sub-programs": those are described only by such vague labels as "efficient motors," "lighting," "water heaters,"[10] and "new construction."[11]

The huge evaluation literature, most of which rather carefully defines the nature and content of the programs being evaluated, does agree with J&M on one important point: There is a wide range of empirical costs even for utility programs with broadly similar technical content and otherwise comparable conditions. The reasons for this range are mostly understood. They include differences in (among other things) definitions, accounting conventions and practices, delivery skill, quality control, and measurement and evaluation techniques. Perhaps most important and hardest to measure is that utilities and their regulatory commissions are in the midst of profound cultural and technological change. Like each individual within them, they all have diverse slopes in their learning curves.

To an empirical scientist, such huge ranges, with their wide standard deviations and sensitivity to outlying values, suggest numerical goulash.

E. Loose Logic

All those differences aside, J&M's logical train derails at the first switch. RMI infers from the lower values within a big range of empirical costs that *savings can be cheap if done well;* as Ken Boulding put it, whatever exists is possible. J&M instead infer from points near that range's high end that all savings, or at least average savings, *must be expensive.* The former conclusion is scientific; the latter is ideological and illogical.

Moreover, since costs are so divergent and nobody has perfect information, what matters most is *process* — whether feedback mechanisms make utilities emulate good programs, and stop or fix bad ones. That's what evaluation, utility management, customer response, and regulation do pretty well — and will go on doing unless their thousands of practitioners become disheartened by J&M's implication that they don't exist or don't matter.

In short, J&M's approach to cost comparisons is akin to stopping the first ten assorted road vehicles one sees, ranging from motor-scooters to 18-wheelers; asking their drivers how many miles per gallon they typically get under whatever driving conditions they happen to experience; adducing a dozen hypothetical reasons why those values are probably overstated; and then inferring from the average of the ten (emphasizing the worst ones) that efficient passenger cars don't exist and are impossible, so anyone who denies those propositions is drastically overstating the potential for efficient cars. As practitioners who have engineered and built many highly efficient cars (so to speak) with empirically known cost and performance, my colleagues and I naturally find this odd. Indeed, for reasons explained next, we think our approach is better grounded in empiricism than is J&M's mixture of goulash averages and opaque estimates of future costs.

II. Do J&M's High Program Costs Rebut RMI's Supply Curve?

J&M state, and apparently some unnamed correspondents have also told them, that "the Lovins/ RMI numbers ... drastically understate the true costs of energy conservation programs" and that our "estimates of costs and performance are excessively optimistic." Both these statements are false. Both appear to reflect not having read the work being criticized[12] or understood the many published descriptions of its methodology,[13] which is summarized in the box on page 36.

RMI's cited TP supply curve says *nothing whatever* about the costs of utility programs. It does not, as J&M appear to believe, "[embody] projections" about actual program costs; rather, it represents a *technical*-cost target that excellent programs can approach rather closely and might even surpass. It says that a fine athlete on a good track can run a mile in between four and five minutes, not that any ten passers-by can do so on the first try. The failure of the latter experiment says nothing about the validity of the former claim; nor should it discourage anyone from training for track events. Thus, while TP costs are a benchmark to which utilities' actual programs can and should aspire, comparisons between the two are valid only if commensurable. Let's address that challenge next.

One cannot compare apples with oranges simply by calling them all fruit. In this case, the task is more like comparing apples and oranges with horned toads.

A. Commensurability

The TP analyses that J&M are criticizing assessed the cost *not* of utility programs but of *specific, optimized packages* of technologies, meant to maximize savings within certain cost constraints. Utilities that implement those specific packages with proper design and quality control will and do experience essentially the same technical costs and savings that RMI found — almost tautologically, because RMI's costs and savings are *measured* not just in the laboratory but also in actual field experience. However, utilities that do something different may observe different costs and savings, plus transaction costs specific to their program designs. In fact, nearly all utilities do something different, largely because they have trouble learning as fast as their technical opportunities are changing.

J&M are aware of differences in technical content between utility programs, and cite them in note 6 of their July '93 *TEJ* article as "another source of significant differences in program costs...even for relatively homogeneous sub-programs (e.g. lighting or motors)." Yet they do not seem to realize that the same difference is even more important when comparing the FD costs of diverse utility programs with national-average TP analyses. **Table 1** shows the major differences in such comparisons.

Because of these many and profound differences in what is being compared, the costs of programs with different technical content can neither confirm nor rebut RMI's supply-curve conclusions.[14] The two kinds of costs are simply incommensurable: One cannot compare apples with oranges simply by calling them all fruit. In this case, the task is (in Jim Harding's phrase) more like comparing apples and oranges with horned toads. J&M prefer an even higher level of abstraction than "fruit" — one whereby different ways of saving electricity, in different quantities, from different starting-points, in different end-uses, in different applications and sectors, in different utility territories and climates, with different user cultures and behaviors, and reported in different ways, can all be compared in cost, as if electric efficiency were a homogeneous commodity rather than an extremely highly differentiated service. To understand the next layer of fallacy in this approach, it is helpful to discuss a specific example of technologies and accounting conventions.

III. Example: Commercial Lighting Retrofits

Utilities' field programs and hence FD are probably closest to RMI's technological prescriptions, and hence to RMI's findings of TP, in high-quality commercial lighting retrofits. These are among the most mature, widely used, and lucrative utility programs. J&M specify no technical content, initial conditions, quality of design or execution, or levels of savings for their "sub-programs" in commercial/industrial lighting, which are probably a mixture of new and retrofit measures. Whatever they are, their reported costs[15] (actual or projected, in 1991 $) are 10.0, 7.1, 5.5, 4.5, 3.7, 2.3, 2.2, 2.2, 1.8, 1.5, 1.4, 1.4, and 0.8¢/kWh, for a median of 2.2¢/kWh, an un-

Table 1: Major Differences Between RMI's TP and J&M's FD Analyses

What's included in costs by...	RMI's TP analysis or...	J&M's FD analysis
Internal costs paid by...	society, no matter how allocated	utility, or utility plus customers
expressed as...	average for the supply-curve increment described (which excludes the costliest available measures)	usually marginal for the particular increments of savings achieved by each of very diverse particular programs
For...	some design plus all purchase, installation, and maintenance	*incentives for* purchase and use (plus customer costs in some cases)
Of...	carefully optimized, savings-maximizing packages of ~1,000 of the best electricity-saving technologies available in 1989	suboptimized, usually obsolete, and fragmented single measures (or very limited subpackages)
In...	all U.S. end-uses and sectors, reflecting the national range of conditions, starting with 1986 frozen efficiency	some end-uses and sectors in particular regions with various climates, other conditions, and initial efficiency levels
For use...	wherever they fit, assuming 100% capture of the practical retrofit opportunity, regardless of how long it takes	in limited "time-slices" of actual installations (which were unspecified mixtures of new and retrofit)
Including...	calculated net effect on lifetime maintenance costs and on the need for and sizing of mechanical systems	in general, no cost effects on maintenance or mechanical systems
Excluding...	all transaction costs of delivery, free riders, and free drivers (since those are all program, not *technical*, properties)	some free riders and some transaction costs of delivery, varying by utility and program; all free drivers
Assessing...	all effects on performance that are well measured and documented	in general, only the most obvious, direct, first-order effects
Organized by...	ten end-uses across all sectors	major sector & broad program category
Based on...	the most detailed *measured* data available in ~1989 (even better now)	unspecified mixtures of field measurements and utilities' future projections
Documented to...	5,000 specific sourcenotes in thousands of pages of technological analyses drawing heavily on field experience, with methodology and assumptions fully published	unpublished authors' calculations based on cited reports of ten utilities, not specifying which data are from which utility, nor the technical content of any programs, packages, or measures

weighted mean of 3.4¢/kWh, and a standard deviation of 2.7¢/kWh given normal distribution. However, the distribution is clearly skewed and there is more scatter near the top than near the bottom of this range: The lowest eight of these 13 values[16] appear more clustered, and average only 1.45¢/kWh, suggesting the dangers of dealing in simple averages drawn from such wide ranges.

In contrast, RMI's TP analysis of commercial lighting retrofits is highly technology- and application-specific. When re-aggregated, the results are of two main kinds:

• Some 36% of the ~120 installed GW that RMI found could be saved by thorough and thoughtful 1986 lighting retrofits in the U.S.[17] came from replacing incandescent lamps, usually with appropriate compact fluorescents. This retrofit generally has a strongly negative Cost of Saved Energy (CSE)[18] because of the large savings in maintenance cost when lamp life increases from about 4 to 13 times.[19] RMI found that the weighted-average TP saving of this procedure in the various applications was ~78% at a CSE averaging -4.1¢/kWh. That is, the present-valued saved maintenance costs exceeded the gross capital cost of the retrofit by an average of 4.1¢ for each kWh saved.

• A further half of the lighting saving was from retrofitting existing tubular-fluorescent systems. RMI's detailed 1988 analysis of an archetypical 4-lamp 2x4′ troffer showed a CSE of +0.6¢/kWh from retrofitting an optimized five-technology package.[20] We then showed that this case conservatively represented other major cases — modern three-lamp parabolic fixtures, eight-foot strips, etc.

Combined with some additional improvements and with minor terms such as improvements in high-intensity discharge lamps and exit signs, RMI's total potential lighting saving was ~92% of lighting energy (*vs.* LBL's ~80–90%[21]), or ~120 installed GW including net heating, ventilation,

and air-conditioning (HVAC) interactions. Scoping the uncertainties, this is about 16–27% of all U.S. electricity consumed in 1986. Its average CSE was about minus 1.4¢/kWh or less, with unchanged illuminance and improved esthetics and visual performance. This CSE resulted from the savings-weighted average of the positive cost of the tubular-fluorescent retrofits with the negative cost of the incandescent-to-compact-fluorescent conversions, plus various minor terms. Demonstrating all this in satisfactory detail from empirical data up to 1988, much never previously assembled or synthesized, took 348 dense pages documented to 594 sourcenotes. Apparently J&M haven't read it.[22]

Our confidence in these approximate findings was strong because the CSE results rested both on *ex ante* engineering calculations from measured component or subsystem cost and performance data[23] *and* on *ex post* confirmatory observations and evaluations for most of those technical systems when actually installed and tested, often in large numbers. Now further confirmation is available from experienced practitioners who routinely achieve virtually identical results. But it is important to understand how those results are expressed, because in this case, for example, J&M are tacitly using different accounting conventions that would *at least triple* RMI's Cost of Saved Energy *even if the technical content and results were identical.*

A. Accounting Conventions Are Crucial

To see this, let's pick the simplest example: RMI's fluorescent troffer retrofit package, saving about 91% of lighting energy directly used. This further saves net HVAC energy. In the U.S. commercial sector, this HVAC "bonus" was found to average a further ~35% of the direct lighting savings. RMI demonstrated that the CSE was 0.6¢/kWh, taking explicit credit both for net HVAC effects and for saved maintenance costs. The maintenance credit

Methodological Overview of RMI's Technical-Potential Supply Curve

• Rocky Mountain Institute's published TP supply curve for electric efficiency shows the *measured* installed technical cost and the *measured* performance of approximately 1,000 kinds of commercially available technologies. They are 1989 best-of-breed, carefully integrated into optimal packages, and fully installed wherever they would logically and technically fit into the 1986 U.S. stock of buildings and equipment (*i.e.*, only "eligible" installations are included), however long that takes (*i.e.*, the dynamics of actual installation are not part of this kind of analysis, but are handled separately as part of program design).

• The quantities of electricity saved are measured at the retail meter, and are corrected for interactions in a usage-weighted average U.S. climate. Since there were virtually no whole-building or whole-system retrofits to measure in 1989 (they remain rare today), the interactions are usually calculated from measured data, not measured directly.

• "Costs" are *societal* internal Costs of Saved Energy (CSE) and are therefore "net" — *i.e.*, they adjust capital cost for any change in present-valued maintenance costs. Thus if saved maintenance cost exceeds initial capital cost, CSE becomes negative. Capital costs are also appropriately adjusted for any changes in the sizing of or need for associated equipment. For example, the CSE of a superwindow retrofit is adjusted for any HVAC equipment that it downsizes or eliminates. This too may make CSE negative.

• Costs are total or marginal, depending in a commonsensical way on how a given device would be installed in practice to saturate the eligible opportunities over several decades. Installation is assumed to be timed and phased in a way consistent with sound program management—*e.g.*, correlated with normal turnover of HVAC equipment in appropriate cases.[1]

• The analyzed costs vary widely — often by an order of magnitude — between different measures and applications in a given end-use. To simplify the presentation, however, the 1989 summary supply curve cited by J&M aggregated costs into a single savings-weighted average for each of ten major end-uses, each including all sectors and U.S. climates. These end-uses were: lighting, its net HVAC effects, drivepower, space cooling and refrigeration, water heating, electronics, space heating (preliminary data), residential process heat, and two minor terms — industrial process heat and electrolysis, neither analyzed in detail.

• How the total net costs are actually split between the customer, utility, and other parties is program-specific, not a technological property, and thus is not shown.

• Costs are technical and hence explicitly *exclude* (not, as J&M state, "ignore") the transaction costs of delivery (marketing, administration, evaluation, etc.). Such costs would be inappropriate to include in a *technical*-potential analysis because they are program-dependent: Infinitely many program designs can be used to realize a given technical potential. RMI therefore analyzed these transaction costs separately. However, their omission from the TP analysis should not be material, since transaction costs are empirically known to be very small in mature programs.[2]

• Certain specialized soft costs, such as power-quality engineering for inverter drives, are included, but general design costs are not, since in a reasonably mature market these are essentially the same as for inefficient technologies. This approximates the experience of the best designers today.

• The TP supply-curve analysis excludes lifestyle changes (the assumed technologies require none), degradation of service quality (which in fact usually improves, though no economic credit is taken for this potentially dominant benefit[3]), indirect and external costs and benefits,[4] load management, fuel-switching, further technological progress, and some technical options that exceeded long-run marginal cost or were not yet reliably evaluated.

• The supply curve is not adjusted for either free riders or free drivers, not only because these are program-specific rather than technical variables, but also because those whom J&M rightly consider "probably the most experienced group in this area" describe so many fundamental problems in measuring these purported effects that they must be considered essentially unmeasurable.[5] Moreover, many practitioners suspect that if free riders and drivers *could* be reliably measured, they'd often turn out to be of roughly equal size, more or less offsetting each other. Contrary to J&M's assumption, *maximizing* both is often a sound program design strategy.[6]

Endnotes

1. It is possible that J&M may use a very different convention that I believe is incorrect. Their *Energy Journal* article (*see* article note 4, *infra*) berates nine of their ten utilities for not counting "the remaining life of existing appliances" and for not penalizing utility programs for the costs of scrapping existing equipment. But if the equipment is to be replaced anyway at the end of its life, scrappage costs are unavoidable; if it is to be replaced prematurely because the capital and operating costs of the new unit undercut the running costs of the old unit, then that decision should be cheerfully made without regard to the old unit's sunk cost. (Curiously, J&M make essentially the opposite argument in suggesting that programs are improperly assuming engineering lifetimes longer than economic lifetimes when the latter are driven by considerations other than saving energy costs.) There is room for debate about whether to use a midlife convention or some other rule for calculating the *timing* and hence the discounted present value of retrofits, but hardly about whether to substitute amortization (an accounting concept) for sunk cost (the correct economic concept). Black & Pierce's similar claim (*see* note 2, article, at 1381) that utilities should count "the economic loss from replacing existing equipment before the end of its useful life" seems misguided.

2. *See, e.g., Negawatts for Arkansas*, note 11, *infra*, at 105-106, which analyzed the 1984 transaction costs reported by Southern California Edison Co. to the California PUC. Directly allocated overheads (outreach, research, evaluation, technical and regulatory support), levelized over an assumed 20-year average measure life, cost 0.0051¢/kWh in the business and 0.039¢/kWh in the residential sectors — respectively 3.5% and 2.0% of direct program costs, which in turn were a fraction of total measured costs. Additional overheads (administration, public awareness and education, advertising, measurement, and evaluation) cost 0.026¢/kWh, but may have been largely or wholly offset by uncounted avoidance of similar costs to support the displaced supply-side resources. J&M's latest *Science* letter, note 22, *infra*, objects that this is a single example, but fails to acknowledge that the "more recent data for multiple utilities" on which J&M relied instead were misquoted from their cited source (see note 15, *infra*) and inconsistent with J&M's own data.

3. It is not unusual for a lighting or HVAC retrofit to yield labor-productivity benefits worth an order of magnitude more to the building operator than the entire electricity bill. RMI's Green Development Services will present examples at the ACEEE 1994 Summer Study later this year.

4. For example, promptly replacing old PCB-containing ballasts incurs no extra disposal cost (other than in time value) because they would have to be properly disposed of anyway; but it can avoid huge hazardous-waste cleanup costs by removing the ballasts before their ultimate failure makes them leak. Similarly, promptly retrofitting CFC-containing refrigeration equipment can avoid the higher cost of recharging them later, and reducing the number of lamps by reflectorizing a tubular-fluorescent fixture can reduce long-term disposal or recycling cost commitments. RMI's analysis takes no credit for such avoided costs.

5. *See* E. HIRST & J. REED, EDS., HANDBOOK OF EVALUATION OF UTILITY DSM PROGRAMS (ORNL/CON-336, 1991). All too often, efforts to measure free riders consist in essence of asking participants after the fact whether they are smart or stupid — with predictable results. It is remarkable, too, how seldom those supposedly inevitable free-rider savings are included in utilities' demand forecasts. J&M's note 21 in the July '93 *Electricity Journal* states: "In general, we are skeptical of the 'free driver' argument, although it is obviously an empirical issue." Precisely the same, however, should be true of free riders, which J&M strongly and asymmetrically emphasize. In my view, both issues deserve much *less* attention than they have received.

6. Maximizing free *riders* can be an effective temporary lever for market transformation (*see* T. Flanigan & A. Fleming, *BC Hydro Flips a Market*, PUBL. UTILS. FORT., Aug. 1, 1993, at 20-22, 34) that makes free ridership "irrelevant" (*see* Hirst & Reed, *supra* note 5 at 133). The Northwest's Super Good Cents program did exactly that to transform the residential building market. So did that region's manufactured housing program. Maximizing free *drivers* through word-of-mouth outreach, emulation, and market development can save more energy at lower cost. However, traditional control-group evaluation *penalizes* rather than rewarding the program for such success. As I remarked in ELECTRIC POTENTIAL, Mar./Apr. 1986, at 3-13 (and quoted in my Jan. 12, 1992 letter to Prof. Joskow, note 1, *infra*), reducing "participants' gross savings by however much a 'control group' of nonparticipants saved in the same period ... tacitly assumes that nonparticipants aren't influenced at all by the participants' successful example. That assumption is probably wrong: indeed, a goal of good utility program design is to make it as wrong as possible."

alone cut the present-valued net cost of the retrofit in half. That's because the reflector eliminated half the lamps, the 4-lamp ballasts then eliminated three-fourths of the ballasts, and over the nominal 20-year ballast life, most of the relamping and reballasting otherwise required was eliminated. The present value of those equipment and labor savings equalled half the initial cost of the total retrofit package. But using different accounting conventions changes this expressed cost dramatically:

- 0.6¢/kWh counting both the HVAC bonus and the saved maintenance costs;
- 1.2¢/kWh counting only the HVAC bonus;
- 1.6¢/kWh counting neither;
- 2.0¢/kWh counting neither, and expressed in J&M's 1991 $ (using the GNP implicit price deflator, not J&M's CPI, but still using RMI's 5%/y real discount rate — *i.e.*, using approximately J&M's apparent accounting conventions);
- 3¢/kWh in 1991 $, using early-1980s generic typical ballast savings rather than those measured for the specific ballast we suggested, and counting only the two "intrinsic" electricity-saving mechanisms of the ballast/control system rather than all ten that RMI documented in 1988 or all of the 18 or so now known.[24]

The costs and savings are exactly the same in all five cases, but they're expressed in different terms that change the apparent cost by up to fivefold or more. Yet to my knowledge only one U.S. utility normally counts the HVAC bonus, and none routinely count the saved maintenance cost — not even the Bonneville Power Administration, which thought it did. Moreover, most utilities understate actual savings in the manner described in the fifth bullet, so even when good ballast and control systems are specified, they don't get credit for all the electricity they can actually save.

Moreover, probably no utility fluorescent lighting retrofit program yet uses the optimized technology package RMI analyzed, let alone the critical prior steps of improving task quality, source/task/eye geometry, and lighting design.[25] Most programs also dilute their cost-effectiveness by including clearly obsolete or cream-skimming technologies, or inferior versions of supposedly modern ones.[26] Thus, although utility subprograms that deliver the specific kinds of hardware RMI described do observe costs essentially identical to those RMI found, they are usually embedded in larger lighting-retrofit programs whose inferior components raise total costs and reduce total savings.

Most programs also dilute their cost-effectiveness by including clearly obsolete or cream-skimming technologies, or inferior versions of supposedly modern ones.

Lighting retrofits as a whole combine fluorescent, incandescent, and (relatively minor) retrofits. Differences of convention, like whether saved maintenance costs are credited against capital costs, are even more important for the incandescent than for the fluorescent retrofits. In 1986 $, the EPRI/RMI *Scientific American* article whose supply curves J&M think their FD rebut showed average all-sectors lighting-retrofit costs around +1¢/kWh if saved maintenance costs weren't counted, or -1.4¢/kWh if they were. That article's text could hardly be clearer:

> Together the lighting innovations that are commercially available can potentially save one seventh to one fifth [the EPRI-low-to-RMI-mean range] of all the electricity now used in the U.S. These innovations would cost about one cent per kilowatt-hour to install. The reduced maintenance costs, Rocky Mountain Institute calculates, would save the user an additional 2.4 cents per kilowatt-hour saved.

Just this 2.4¢/kWh methodological difference — whether saved maintenance costs are counted as RMI does or ignored as utilities do — *is big enough to explain virtually all the TP-vs.-FD discrepancy that J&M describe.* In the commercial sector, that difference more than doubles. Yet, while acknowledging the "central role"[27] of saved maintenance costs in

RMI's conclusions, J&M ignore their own omission of this major benefit as an alternative explanation to their facile conclusion that RMI has "drastically understated the real costs."[28]

B. Surprisingly Close Agreement Anyway

For all these reasons, FD should normally show smaller and costlier savings than RMI's TP analysis. Instead, most of J&M's C&I lighting programs showed *cheaper* savings than RMI's: Eight of J&M's 13 programs averaged about one-fourth cheaper than RMI's commercial fluorescent-troffer retrofit when expressed in the same accounting terms, and J&M's median for all 13 C&I lighting programs, 2.2¢/kWh, was slightly cheaper than the ~2.5¢/kWh[29] cost of all RMI's commercial lighting retrofits. Then again, J&M's programs probably saved less, too.

How about other utilities' observed program costs for commercial lighting retrofits? Agreement with RMI's TP costs would be surprising *a priori* because of the many differences in focus, technical content, and analytic thoroughness. Coincidentally, however, the agreement is again pretty close. In Nadel's *Lessons Learned* database, 13 full-scale utility lighting rebate programs that reported total utility direct-plus-indirect costs averaged 1.3¢/kW,[30] or 2.6 times below J&M's mean. Of course, Nadel's 1.3¢/kWh is only the utility's contribution, not the total resource cost to society.

However, that total resource cost *was* paid by three direct-installation programs, reported to cost an average of 1.9¢/kWh on the same conventions[31] — close to J&M's mean and, with due allowance for the different measure lives and discount rates, to RMI's 1.6¢/kWh (1986 $) for fluorescents only or 2.1¢/kWh (1986 $) for all commercial lighting. Six newer programs analyzed by The Results Center are in the same range.[32]

All these costs thus seem broadly consistent not only with RMI's *but also with most of J&M's* when reported on a comparable basis (no HVAC interactions, no credit for saved maintenance cost, similar dollars and discount rates). However, though superficially comforting, any such numerical consistency is coincidental, because RMI's analysis used a better package of technologies that went further up the supply curve, and more thoroughly characterized the system's actual technical performance. The utility programs, in general, both spent less and saved less — both because they used less-optimized technological packages and because they failed to take credit for some of the more subtle, though perfectly real and measurable, benefits. It is therefore coincidental that their costs per saved kWh worked out about the same. Only if the technologies were identical and the savings identically analyzed would the comparison be valid. In my experience advising dozens of utilities, such fair comparisons do yield very close agreement. So they should, since they're describing the same thing: RMI's TP analysis is based on the same field costs and warranted performance of equipment that utilities are experiencing, and indeed RMI often got those data from them.[33] The rest is arithmetic.

In nearly all states, utilities are still penalized, or at least not rewarded, if they do succeed in maximizing savings.

C. What *Do* the Costs Imply?

To J&M's claim that it is proper to compare TP and FD costs as a basis for judging the TP costs' validity, because "[t]he actual performance of programs that have been developed in response to [TP] ... projections is the best basis for determining whether current policies are delivering the promised benefits," I would respond by noting that:

- When expressed in the same terms, TP costs and representative FD costs are generally in quite good agreement;
- This congruence is coincidental, however, because at least RMI's TP costs represent better packages that would save more energy;

- Optimizing most actual utility programs' technological content would raise their savings, often severalfold, at the same or lower cost per kWh;
- Yet, even before such optimization, efficiency is so cheap that most programs are already highly cost-effective;
- It would be surprising if most utilities *had* bothered to optimize their programs for maximum savings, since in nearly all states they are still penalized (via ratemaking that couples profits to sales volumes and flows through all savings to customers), or at least not rewarded, if they do succeed in maximizing savings. Utilities that spend money on DSM but save little energy are simply following the incentives that most states, pending regulatory reform, still give them.

It is no secret to my clients and audiences since the 1970s that most utilities' efficiency programs in most sectors and end-uses, though cost effective, are in fact suboptimized. They're pretty good, but could be better. They choose poorer technologies, or combine them less artfully, than the packages we analyzed; or they deliver them with poorer quality control or in less streamlined fashion than best practice; or they incur excessive transaction costs; or they use a well-known collection of thoroughly avoidable ways to overpredict actual savings.[34] (Most people don't run four- or even five-minute miles either — though that's no reason not to coach runners.)

In particular, programs designed with the widely used spreadsheet-based, measure-by-measure software typically yield savings severalfold smaller and costlier than skilled designs that carefully integrate technologies into optimized packages. Efficiency supply curves in buildings are often not even monotonic: Cost-effective total savings can be bigger if certain *non*-cost-effective measures are included than if they are omitted, because their inclusion can eliminate costly mechanical systems and thus cut total cost.[35]

Practitioners have been striving for a couple of decades to correct these suboptimizations—to help utilities' talented and dedicated staffs learn as fast as technology and design understanding improve. Gratifying progress is starting to be made through the efforts of specialized centers on demand-side technologies (*e.g.*, for lighting, at Rensselaer, Seattle, and E SOURCE). It does not appear, however, that J&M understand either the problem or the solution in this rapid technological and integrative-design evolution.

IV. Technological Optimism, or Rigorous Empiricism?

That brings me to J&M's assertion that RMI's TP "estimates of costs and performance are excessively optimistic" because they relied on "uncertain technologies with uncertain costs and limited commercial market experience." Again, had J&M read RMI's detailed analyses, they would know this to be untrue. I challenge them to cite a single instance of such technologies underlying RMI's TP analysis — let alone the comprehensive range of examples necessary to support their sweeping assertion.[36]

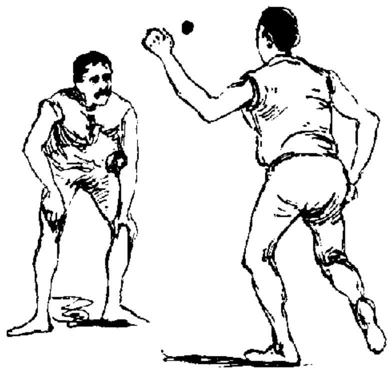
While no cost or performance measurements can be exact, the RMI team carefully handled the inevitable uncertainties by using such standard techniques as scoping and conservatisms. The technologies RMI assumed for its supply curve were in no sense experimental or speculative; they were all on the market with standard specifications and warranties (except for a very few, of trivial if any total effect, that were then in the process of entering the market after field tests). Though the technologies RMI assessed were not yet in *general* use—if they were, there would have been no point doing the analysis—they had a base of field experience ample to support the conclusions drawn. RMI's analytic results were later borne out and improved upon. In my opinion, all ten blocks of RMI's ~1989 supply curve, if reevaluated today, would show even bigger and cheaper savings.[37]

V. Concluding Remarks

J&M's article in *The Electricity Journal* softens some of their least defensible earlier conclusions and adds some useful new contributions.[38] It acknowledges for the first time in notes 21 and 24 that control groups can shift and hence make technically successful programs look economically unsuccessful. (Unfortunately, J&M never draw the obvious conclusion that this method of evaluation is seriously flawed,[39] but instead interpret my specific criticisms of its misuse generically, incorrectly stating that "Lovins rejects the use of control groups and appropriate supporting statistical analysis to verify energy savings."[40])

J&M also describe a worthwhile, though quantitatively premature,[41] example of what happens when good evaluation is not matched by corresponding updates in programmatic content to keep ahead of the diffusion of improved practices from innovative to fairly commonplace. And they add welcome support to long-standing and widespread efforts to propagate to all programs the careful design, evaluation, and feedback now practiced only by the best.[42]

However, it is hard to interpret J&M's papers on the costs of saving electricity as merely a call for better evaluation and more adaptive program improvements. Rather, J&M fundamentally disagree that utilities should acquire efficiency "resources" even when least-cost. J&M believe this approach "is the source of a lot of sloppy thinking (and wasteful expenditures), ... leads to higher rates[43] and pervasive cross-subsidies,[44] ... will simply be unsustainable [as] competition evolves in



the electric power industry,"[45] and substitutes "central planning" for consumer sovereignty.

That view could be very easily confused with the tired dogma that marginal-cost pricing (perhaps including externalities) provides customers with good enough information about the societal benefits of saving electricity: that "when presented with the information necessary" about private costs and benefits, customers guided by Adam Smith's invisible hand are "generally in the best position to evaluate" whether to invest in efficiency, so utilities' interventions to ensure "best buys first" should be more or less stringently restricted rather than generously rewarded.

I share J&M's fondness for free markets as efficient allocators, advocate regulatory methods that emulate efficient market outcomes, and oppose regulatory micromanagement of utility programs and utility micromanagement of customers' choices. I agree emphatically that "we want least-cost outcomes, not nice computer printouts produced by integrated least-cost planning software." To that end, I have invented many of the methods now in use for shifting implementation from engineered program delivery to market-making — *e.g.*, by making saved electricity into a fungible commodity subject to competitive bidding, arbitrage, secondary markets, derivative instruments, etc. In these senses I am in sympathy with J&M's principles.

However, I have also studied and experienced market failures[46] in this sphere for far too long to share J&M's optimism that "a decentralized customer service and customer resource perspective" will automatically yield societally efficient allocation and utilization of resources. To the extent economic theory supposes that market failures in buying negawatts must be immaterial, economic theory is wrong — as everyone knows who actually tries to sell negawatts for a living.

In the real world inhabited by practitioners, very few customers have the information, opportunity, societally efficient discount rate, time, and dedication to buy efficiency whenever it's cheaper than supply. J&M's own limited information about the technologies they're discussing is Exhibit One on the reality of market failures. Those who best appreciate this reality are in general not central planners but market-oriented pragmatists. I invite J&M to join their ranks. I hope J&M will come to share my view that utilities can simultaneously think of efficiency as a valuable resource *and* enable their customers to acquire it by a variety of carefully targeted interventions that rely chiefly on markets, seek to harness their dynamism and flexibility, and creatively overcome observed market failures.

It would also advance the state of the art if J&M would deal clearly, substantively, and in detail with the serious criticisms of their work first provided to them privately, then reluctantly published, over the past two years. Instead, they continue to reiterate[47] misleading descriptions of what they did and blanket assurances that criticisms are "unfounded." Such unwillingness to acknowledge and correct real problems in their work suggests an unhealthy preference for *ex cathedra* pronouncements over self-exposure to the rigors of the scientific method, and threatens to obscure or tarnish their other useful contributions.

While displaying little familiarity with major recent progress in program design, evaluation, and regulatory reform, J&M do usefully confirm those developments' importance. And they raise a key underlying issue. If, as they claim, FD *did in fact* show that utilities' efficiency programs are generically far costlier than RMI and others had said — in comparisons free of all the artifacts and distortions described above — what would that mean? Would it mean RMI and others

were simply wrong and had grossly understated efficiency's actual cost, so major utility investments in efficiency have been based on false premises?

Many practitioners more familiar than J&M with the TP estimates they're criticizing, including RMI's, would suggest a different interpretation: that very few utility programs yet harness the modern technologies, and especially the optimized *combinations* of technologies, that are available, attractive, and highly cost-effective; that inculcating and operationalizing a thorough understanding of these new opportunities is hard and needs far greater effort; that far-reaching reforms are needed in design and real-estate practice and incentives; and that success in these efforts will yield great rewards for both utilities and customers. These are certainly among the central lessons of my own extensive utility consulting practice over the past couple of decades.

Such practitioners realize that well-designed programs are yielding field data consistent with the TP estimates of very big, cheap savings, but that many programs' content remains far from that goal. This gap impels them to improve the programs, even as J&M's view of costs impels them to question all programs' justification. But either way, J&M's latest restatement of their basic recommendation[48] remains valid: "We did not say that conservation programs should be 'deemphasized'; rather, programs and their evaluation should be improved so that they really help to remove market barriers and to facilitate wise energy choices by customers." On that conclusion, if not the way of getting there, we can all agree.[49] ■

Endnotes

1. Letter from A.B. Lovins to P.L. Joskow (Jan. 12, 1992) (RMI Publication #U93-2, 1993) — privately provided to J&M nearly a year before they published controversial results largely ignoring that critique; A.B. Lovins, *Inexpensive Ways to Save Electricity*, TECH. REV., Aug./Sept. 1993, at

7, 79; and A.B. Lovins, *The Cost of Energy Efficiency*, 261 SCIENCE 969-70 (Aug. 20, 1993), whose similar May 2, 1993 draft J&M cite.

2. *E.g.*, by B.S. Black & R.J. Pierce, Jr., *The Choice Between Markets and Central Planning in Regulating the U.S. Electricity Industry*, 93 COLUM. L. REV. 1339–1441 (Oct. 1993), a tendentious compendium of all the usual errors in this genre plus a few new ones.

3. The supply curve J&M criticize relies explicitly on RMI's detailed analyses, contained in what are now six Technology Atlases: THE STATE OF THE ART: LIGHTING (1988), : DRIVEPOWER (1989), : APPLIANCES (1990), : WATER HEATING (1991), : SPACE COOLING AND AIR HANDLING (1992), and SPACE HEATING TECHNOLOGY ATLAS (1993), plus supplements. The first four of those six volumes were prepared by a research team under my direction, and published by Rocky Mountain Institute's in-house technical information service, COMPETITEK. From May 1, 1992, when the fifth volume was also virtually complete, that service has been operated by an independent RMI subsidiary, which in September 1992 changed its name to E SOURCE. That service (located at 1033 Walnut St., Boulder CO 80302-5114, 303/440-8500, fax -8502) now publishes all six volumes, successor editions, dozens of bimonthly updates, and other supplements.

4. Paul Joskow and Donald Marron, *What Does a Negawatt Really Cost? Evidence from Utility Conservation Programs*, 13 ENERGY J. 41-74 (1992). Their complete text explains at 72:

> The data provided to us by utilities is [*sic*] an uneven mix of historical experience, projections adjusted for the utility's historical experience, and simple projections made by the utility based on engineering data and experience of other utilities. As a result, the numbers that we are able to compute are a mix of actual utility experience and the projections of what utilities think the conservation programs will cost and achieve.

J&M do not state the proportions of that mix, nor distinguish in their reported figures between historic data and future anticipations. Thus, readers who think of their work as based on historical measurements — perhaps because J&M claim to have subjected RMI's analyses to "rigorous empirical examination in real, representative settings" — may be disappointed. *See*, Paul Joskow and Donald Marron, *What Does Utility-Subsidized Energy Efficiency Really Cost?*, 260 SCIENCE 281, 370 (Apr. 16, 1993).

5. S. NADEL, LESSONS LEARNED (Rep. 90-8, N.Y. State Energy Res. and Devel. Auth., with N.Y. State Energy Office and Niagara Mohawk Power

Corp., American Council for an Energy-Efficient Economy, April 1990. J&M's *Energy Journal* article, *id.*, briefly cites this important reference, but fails to draw the proper lessons from its conclusions.

6. My Jan. 12, 1992 review of J&M's draft article, after some utility-specific examples, noted that *Lessons Learned* had found, with a variety of evaluation and reporting conventions, "in 1988 $ at a 6%/y real discount rate, 15 lighting programs and six of eight general industrial programs costing the utility 1¢/kWh or less (three of the industrial programs cost the utility less than 0.5¢/kWh), and SCE's industrial hardware rebates costing the utility 0.2¢/kWh. *Median* utility cost per saved kWh was at or below 1¢ for audits, lighting information and rebates, industrial programs generally (0.8¢), motor rebates (0.55¢), new-construction rebates, and multiple-end-use rebates (0.9¢) and loans (0.8¢)." Every one of these figures, representing major components of most C&I programs, *is below the low end* of J&M's 1.5–6.7¢/kWh range for C&I programs as a whole. The same is true for what J&M call "program components." J&M's seven "efficient motors" program costs ranged from 1.8 to 31 times Nadel's median; their median was 3.5 times his. Their 11 commercial and industrial new-construction program costs ranged from two to 18 times Nadel's median. And so on. J&M further assert that full accounting for costs and accurate measurement of savings would "systematically" increase the costs they report by an unknown factor that might average around two, making their costs even *more* unpreresentative. Of course, any well-evaluated program, of which there are now many, already accounts for the effects that J&M believe have been omitted.

7. Without acknowledging or replying to the numerical evidence already provided to them (see previous note), J&M assert that:

- "Several of [their ten] utilities ... have had conservation programs in place, especially for residential customers, for nearly a decade (e.g., Long Island Lighting)" — as if this ensured low cost; some utilities are well known to have poor learning curves and old but still persistently inefficient programs, such as the Bonneville weatherization program that J&M themselves cite.

- "Others are often pointed to as conservation leaders in the utility industry" — partly true for some (not others), but no guarantee that the particular programs selected are either exemplary or cheap.

- "[M]ore than half ... have programs ... identified by Flanigan and Weintraub as being among the most successful in North America" — true, but having such programs may not indicate exemplary quality overall, and those authors' organization, The Results Center, defined "successful" using a very broad set of criteria, among which low cost is only one, and not a particularly important one at that.

8. C.W. Gellings, presentation to Energy Committee, Aspen Institute for Humanistic Studies (July 10, 1993) and July 16, 1993 personal communication. Gellings used the cost and savings data that utilities reported to the Energy Information Administration (data that vary widely in quality and conventions but are more valid when aggregated nationwide than taken singly); increased all those costs by 15% to allow for any underreporting of administrative costs; used EPRI data to extend backwards before 1989, when the formal reporting began; and reduced totals to back out load-management costs (which dominate most programs). He then both discounted future savings and adjusted them for gradual "decay" over appropriate lifetimes. The results appear conservative.

9. C. Blumstein and J. Harris, *The Cost of Energy Efficiency,* 261 SCIENCE 970 (Aug. 20, 1993). J&M say their low-income programs aren't significantly costlier than general-market programs, and five of their 13 residential programs (none defined) did show low-income programs to be cheaper than the rest, but it isn't clear whether this is because they also stayed lower on the supply curve and hence saved less.

10. This looks simple, but is perhaps the most complex system of all: The residential hot-water retrofit packages analyzed by RMI typically include close to 20 distinct measures, all intricately interactive.

11. Remarkably, J&M's *Energy Journal* article, *supra* note 4, nonetheless manages to conclude that for C&I savings, "The RMI numbers are too low by a factor of two to ten." That's especially clairvoyant because, as they admit, their cited source states *no* "RMI numbers" corresponding to J&M's program or sub-program categories, so they guessed. As noted in the inset on page 36, the RMI supply curve being criticized by J&M aggregates ~1,000 technologies into ten end-use categories, all but two of which are aggregated across all sectors. My Jan. 12, 1992 critique (*supra* note 1), noting this, recommended that J&M use for comparison the sectoral supply-curve summaries in RMI's 1988 study *Negawatts for Arkansas.* They didn't. My critique also stated, consistent with the Arkansas study's findings, that "superinsulating existing residen-

tial shells is expensive—probably ~4–8¢/kWh without, or much less (perhaps down to zero or less) with, credit for downsizing mechanicals on their replacement." J&M's convention of omitting such credits can therefore cause large discrepancies. They report costs of 1.6–160.6¢/kWh for residential "new construction," but no data for shell improvements alone, new or retrofit, and no HVAC sizing credits.

12. J&M cite only my 1990 joint survey article with EPRI, A.P. Fickett, C.W. Gellings, & A.B. Lovins, *Efficient Use of Electricity,* 262 SCI. AM. 64-74 (Sept. 1990), in a semipopular magazine that edits out all technical details, "and references therein." Those references include three of mine: an even less detailed 1989 survey paper, plus the first two (the only ones then published at full length) of the six Technology Atlases cited in note 3, *supra*: 2,509 dense pages of encyclopedic primers documented to 5,135 sourcenotes, later extensively supplemented. These proprietary sources are used by several hundred utilities, governments, industries, and related organizations in about three dozen countries, and are undisputed to this day by anyone who has read them. Joskow and Marron, as far as I know, have not (their institution is not among the 20+ subscribing universities). Nor do they appear to have taken account of any of RMI's or my other detailed technical publications, *e.g.*, those cited in my Jan. 12, 1992 critique of their draft paper (note 1, *supra*).

13. *E.g.*, A.B. & L.H. Lovins, *Least-Cost Climatic Stabilization,* 16 ANN. REV. EN. ENVT. 433-531 (1991), which J&M's *Science* article (note 4, *supra*) cites as its note 5.

14. This is equally true of the amount or percentage of electricity saved. J&M's article in this journal states that "the experience of utilities with careful measurement programs indicates that the magnitude of energy savings achievable through utility programs is substantially smaller than indicated by the TP studies." This cannot be due simply to differences in market fraction captured, since TP studies explicitly assume 100% capture of technically eligible applications (that's what "technical potential" means). (As a reality check, capture fractions around 70–90+% have lately been achieved in particular efficiency micromarkets.) J&M must therefore be saying that utilities *have tried to capture the TP* identified in TP studies like RMI's, but have failed to do so. They give no examples, and I am not aware of any. Essentially all utility program designers would agree that they fall far short of the technological comprehensiveness and integrated design that underlie RMI's TP analyses. On the contrary, the only such effort of which I am aware, PG&E's Advanced Customer Technology Test for Maximum Energy Efficiency (ACT^2), is in fact achieving cost-effective savings comparable to or larger than those shown in RMI's TP analyses, *i.e.*, around three-fourths. To my knowledge, no utility has tried to deploy technology packages similar to those shown in RMI's TP analyses and has *then* failed to achieve a similar or larger percentage saving; but of course inferior packages do save much less.

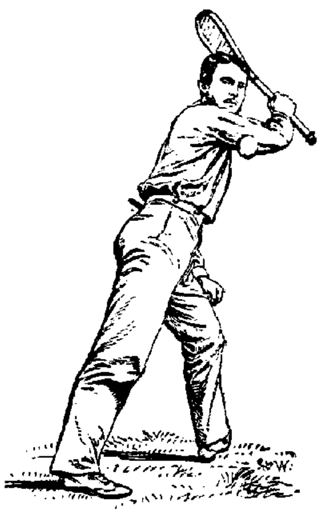
15. Most of these figures apparently do not include all administrative costs. However, based on seven utilities' highly aggregated estimates of those costs for C&I programs, with a ninefold range of 5-48% and a mean of 24%, J&M's *Energy Journal* article somehow concludes that "a 30% administrative cost fraction appears to be at the low end of a reasonable range for the C&I programs." They also cite a 20–30% range from LINDA BERRY, THE ADMINISTRATIVE COSTS OF ENERGY CONSERVATION PROGRAMS (ORNL/CON-294, 1989). However, Berry's paper does not say that: It does cite ~25–35% administrative costs for "commercial audit plus incentive programs aimed at a variety of end uses," but it also finds 13% for "commercial rebate programs, such as Wisconsin Electric's Smart Money program," and recommends "a lower value [10% to 15%] ... for commercial lighting programs or for rebate[-]only programs which do not offer audits."

16. Nine utilities (the tenth produced no C&I lighting data) yielded 13 data points because two had multiple time periods and one of those had two distinct sub-programs.

17. Including net effects on space-heating and -cooling energy (HVAC interactions). A.B. Lovins & R. Sardinsky, *The State of the Art: Lighting*, COMPETITEK/RMI (1988) (available from E SOURCE); the second edition is due in spring 1994. Of course, in 1986, compact fluorescents had only been on the U.S. market for five years and there were only a few dozen kinds, compared with more than 700 today.

18. Calculated in 1986 U.S. dollars levelized at 5%/y real, using the standard Lawrence Berkeley Laboratory format: $CSE = Ci/S[1-(1+i)^{-n}]$, where C = capital cost net of any present-valued net effect on maintenance or other associated costs, i = annual real discount rate expressed as a decimal (in RMI's convention, 0.05), S = kWh/y saved including HVAC interactions, and n = lifetime in years.

19. In their *Energy Journal* article, *supra* note 4, J&M doubt this, commenting: "If this is true, it indicates that



consumers and firms are wasting more than just electricity in their lighting design. Alternatively, it may be taken as a signal of the great optimism implicit in the RMI estimates." Relative lamp lives, however, are not an untestable RMI assumption but an observable and commercially warranted fact. Only scholars with a peculiar aversion to facts would prefer speculating about lamp lives to consulting any standard lighting equipment catalog. *See also* note 36, *infra*.

20. Namely, a well-designed imaging specular reflector, two tristimulus-phosphor (but not yet T8) lamps, a very efficient four-lamp tandem-wired continuous-dimming electronic ballast, dimming controls, and occupancy sensor. Much of this analysis, which was corrected for thermal effects, is summarized by an illustration and caption in the *Scientific American* EPRI/RMI article (note 12, *supra*) from which J&M obtained RMI's TP supply curve, and more fully described in J&M's citation in note 13, *supra*. Both cite the complete source (note 17, *supra*).

21. M.A. PIETTE, F. KRAUSE, & R. VERDERBER, TECHNOLOGY ASSESSMENT: ENERGY-EFFICIENT COMMERCIAL LIGHTING (LBL-27032, Lawrence Berkeley Laboratory, 1989). The difference is due to some specific measures that RMI included and LBL didn't; the differences in the main technologies that both studies included are unimportant.

22. Their latest letter, at 262 SCIENCE 319-21 (Oct. 15, 1993), adds that RMI's "results are based on many assumptions about the generality of usage conditions, marketing, installation, monitoring costs, and the potential market for each device and not, as Lovins would have it, only on empirical data." This further suggests their unfamiliarity with the work they're citing. Had they read it, they would know that "marketing," "monitoring costs," and "the potential market for each device" are bounded out by the basic principles of RMI's TP analysis (see inset box on p. 36), and that "usage conditions" and "installation" were surveyed in a previously unprecedented compilation of *empirical* data.

23. Not just RMI's. For example, Dr. D.G. Goldstein (Natural Resources Defense Council, San Francisco) evaluated a variety of new and retrofit commercial-lighting packages under slightly different accounting conventions (10% HVAC bonus, 1990 $, 3%/y real discount rate, saved maintenance costs included), using a highly transparent spreadsheet methodology expressed in standard Illuminating Engineering Society format. He chose packages of technologies somewhat less refined than RMI's, used highly

conservative assumptions, and did not fully count benefits, but reached broadly similar conclusions. For example, the most nearly comparable retrofit package, expressed in his terms, saved 76% of initial lighting energy in a standard 4F40 fixture, while delivering the same design illuminance with better quality, at an average cost of 0.9¢/kWh. (Just using our 35% HVAC bonus would reduce this to 0.65¢/kWh — within 10% of our 0.6¢/kWh when expressed using the same dollars and discount rate.) For ten classes of commercial lighting improvements, the potential California savings to 2009 totalled 22 TWh/y at an average cost of 0.7¢/kWh, with subpackage costs ranging from 0.8 to +1.9¢/kWh. *See* D.G. Goldstein, R. Mowris, B. Davis, & K. Dolan, Initiating Least-Cost Energy Planning in California: Preliminary Methodology and Analysis (Feb. 1990)(NRDC/Sierra Club submission to California Energy Commission Docket #88-ER-8, 21).

24. Two intrinsic savings (reduced ballast losses and higher lamp efficacy at high frequency); elimination of some duplicate circuitry in 4-lamp ballasts; daylight dimming; occupancy sensors; scheduling controllers; automatic compensation for lumen depreciation (typically saving ~14%); task-tuning (12–20%); and two savings from reduced design margins (due to reduced sensitivity to abnormal supply voltage and to lampwall temperature) totalling 12½%. Those last four effects are almost never included in utilities' program design or measurement. Eight additional kinds of savings were not yet well documented in 1988, and three were then scarcely known, so RMI took no credit for them.

25. Some of the most modern programs come close, but even those that properly emphasize a bundle of good reflectors, T8 lamps, electronic ballasts, and occupancy controls seldom include the dimming controls too — often the biggest single saving opportunity. Photocell-controlled continuous-dimming ballasts not only save ~50% or more in daylit areas, which are often about half of commercial floorspace; as mentioned in the previous note, they also save a further ~14% of the energy over a group relamping cycle by automatically compensating for the gradual deterioration of lamp output with age and dirt, and a further ~12–20% by permitting "task-tuning" — modulating illuminance across the space to match the spatial pattern of visual tasks. These latter two mechanisms typically justify the dimming controls even in non-daylit core zones.

26. The former include "energy-saving" 34-W four-foot fluorescent lamps,

current limiters, and "high-efficiency" electromagnetic ballasts; the latter include compact fluorescents that don't fit the fixtures, yield unattractive color or dim light, start only with delay and flicker, etc.

27. *See* J&M's *Energy. J.* article, *supra* note 4, at n. 21.

28. While the effect of saved maintenance or associated-equipment costs is most important for lighting technologies, the subject of our example here, it is also very important for motor systems, mechanical systems, domestic hot-water systems, reductions in buildings' heating and cooling loads, and many other technologies. Thus, while the lighting example is unusually clear, it is not exceptional.

29. Without HVAC bonus or saved maintenance costs, and in 1991 $ (but still using RMI's 5%/y real discount rate), fluorescent retrofits cost ~2.0¢/kWh and incandescent ones average 3.2¢/kWh, implying an energy-weighted-average commercial lighting retrofit cost of ~2.5¢/kWh. Including other minor types would only slightly change this cost.

30. In mixed current dollars, mainly mid-1980s, levelized at 6%/y real, with varying accounting conventions. These are all such programs for which CSEs are shown in Table 3-1 of Nadel's *Lessons Learned*, *supra* note 5, except for one outlier program that cost 5.7 times as much as the next most costly. The programs differed in many accounting conventions, including their handling of free riders and free drivers, so the results are quite approximate.

31. And using only a 5-y average measure life, *vs.* an average 9.6 y for the previous 13 programs.

32. J. WELLINGHOFF & T. FLANIGAN, COMMERCIAL LIGHTING PROGRAMS: THE KEYS TO DSM SUCCESS (IRT Environment, Basalt, Colo., 1993); IRT uses 1990 $ and a 5%/y real discount rate. The six programs generally ran through 1991. NYPA paid 1.2¢/kWh (and society as a whole paid ~3.1¢/kWh) for lighting efficiency, almost all retrofitted. SMUD paid 2.2¢/kWh for a simple fluorescent-fixture retrofit pilot program that was not yet mature. Four general business-sector efficiency programs that were ~80% lighting, but mixed in with other kinds of measures, averaged 1.4¢/kWh (PG&E 0.7, SCE 1.2, WEPCo 1.2, and ConEd 2.6). All these costs except WEPCo's reportedly included actual administrative costs. The cheapest program, EPA's Green Lights program, based on admittedly approximate self-reported savings averaging 51%, incurred an information-only cost of 0.46¢/kWh through summer 1992, but its expected future retrofit savings — whose promotional and information costs have already been paid by EPA — would cut this to only 0.0035¢/kWh. J&M consider this a model, since customers get only information and must arrange to pay the equipment costs themselves. Gratifyingly, PG&E's latest evaluation shows 98% realization of forecast nonresidential lighting savings during 1990-92. *See* PACIFIC GAS & ELECTRIC CO., EVALUATION OF THE CIA RETROFIT REBATE PROGRAM: FINAL REPORT (CIA-93-X01, Sept. 1993) (Customer Energy Efficiency Policy and Evaluation Section, PG&E, San Francisco).

33. Of course, RMI's analyses are not restricted to supply curves of technical potential: The Institute has separately analyzed actually observed utility program costs, as well as the familiar measurement and evaluation issues they raise, in other publications, some of book length, that J&M do not cite.

34. These are nicely catalogued. *See* S.M. Nadel and K.M. Keating, *Engineering Estimates vs. Impact Evaluation Results: How Do They Compare and Why?*, PROCS. 1991 INTL. EN. PROG. EVALN. CONF. (Chicago) 24-33. They show that specific errors in analysis, installation, or evaluation often yield substantial overpredictions of actual savings *in three specific types* of programs (residential retrofits, small-customer lighting, and showerheads), but that proper procedures yield excellent agreement between predicted and actual savings in *all* kinds of programs. Astonishingly, J&M, in their *Science* article, *supra* note 4 at ref. 7, and in their later letter at 262 SCIENCE at 320 (1993), cite this classic paper only as supporting their assertion that utility programs generally underachieve predicted savings — not for its authors' contrary conclusion that such discrepancies, even in the limited classes of programs where they are normally observed, *are readily avoidable* (*see* note 2 of my response in *Science*, note 1 *supra*).

Nadel has confirmed in a 1993 personal communication to me that J&M's interpretation turns the paper on its head, but J&M continue to insist in their *Science* letter that it "did not lead to an opposite conclusion from [their own]." J&M's bizarre interpretation, like Black & Pierce's blanket statement, *supra* note 2, at 1381, that "Engineering estimates are notoriously inaccurate," represents a typical failure of theoretical economists to understand the nature of engineering calculations. *Properly done* engineering calculations will quite accurately predict their *properly executed* outcome, since the connection is determined by physical law and the intervening causalities are largely controllable and de-

terministic (the only significant exception, which can be measured but not prevented, is behavioral variation). It is definitely not true, in contrast, that properly done *economic* forecasts will prove fairly accurate.

35. This was true, for example, of a new tract house just completed in Davis, California (E SOURCE *Tech Memo* TM-93-5, Nov. 1993, 4 pp.). Despite a design drybulb temperature of 105°F and extreme of ~113°F, the house needed no heating or cooling system, had a mature-market construction cost ~$1,800 *below* normal, and is expected to save ~80% of the space and water heating, space cooling, refrigeration, and lighting energy permitted by the nation's strictest energy code (1993 California Title 24, which is already supposed to include everything societally worthwhile). Cooling savings were 100%, or 92% counting fan energy. Another part of PG&E's ACT^2 experiment, the pilot retrofit of 1,900 m^2 of the company's research office in San Ramon, probably achieved, pending further summer 1994 monitoring, office-retrofit air-conditioning energy savings in the vicinity of the design expectation of 97%, with increased comfort. These findings are consistent with RMI's *The State of the Art: Space Cooling and Air Handling* (1992), which described potential air-conditioning savings around 80–90+% with generally attractive economics. In contrast, J&M suppose potential national savings in heating and cooling to be "modest": 262 SCIENCE, *supra* note 34, at 320.

36. To my knowledge, the only specific example of RMI's supposed technological optimism cited anywhere by J&M is the negative CSEs that RMI reported for many retrofits of incandescent to compact fluorescent lamps. My Jan. 12, 1992 letter to Professor Joskow suggested that:

> ... [R]ather than grousing about 'the great optimism inherent in the Lovins estimates,' you simply try the calculation. Please construct a spreadsheet showing two cashflows: one for, say, a 10,000-h, 18-W compact fluorescent lamp and the other for an equivalent stream of [13] 750-h, 75-W incandescent lamps. Parameterize duty factor from zero to one. Parameterize lamp and installation-labor costs, counting labor at, say, $0 to $1/change (we assume zero residential — not even a shadow cost — and the standard but often conservative $1 commercial). You'll find that whether you assume wholesale or retail lamp prices (the same for both kinds, of course), if you use a utility discount rate (we use 5%/y real) to reflect societal priorities, it's hard to avoid a negative CSE with duty factors above 3–10%, especially if, as we generally do in the commercial sector, you count the HVAC bonus (~35% in energy terms). Your CSEs will typically be around -1½ to +1¢/kWh at duty factors down to ~0.3; at 0.1, around -1 to +1.7¢/kWh.

Next, to get -5 to -20¢/kWh (typically about -8¢/kWh), analyze *modular* compact fluorescents — almost always the best choice, especially in the commercial sector. You'll then be replacing 750-1,000-h incandescent lamps [or ~2,000–2,500-h floods] with one ballast/adapter/optical accessory (*e.g.*, a reflector envelope or globe) initially, plus one initial $3 PL lamp or $6 quad lamp lasting 10,000 h, followed by a succession of similar lamps also lasting 10,000 h and fitting into the same assembly. The ballast/adapter typically lasts at least 50,000 h. We've published such parameterizations extensively for the past five years or so. So far, nobody's told us what's wrong with the arithmetic. Of course, if you take no O&M credit, you'll get a different answer, but that's because you used a different convention about what's a benefit, not because I'm 'optimistic.'

Unless J&M would like to adduce some other example not yet described, or say why they disagree with this one, I can only conclude that they failed to perform the suggested analysis.

37. For example, the space-cooling and electronics assessments have turned out to be especially conservative (*see : Space Cooling and Air Handling* (1992) and *The State of the Art: Appliances* (1991), respectively, cited in note 3 *supra*). The second edition of *The State of the Art: Drivepower* (E SOURCE's *Drivepower Technology Atlas,* Aug. 1993) similarly found even more favorable economics for retrofitting oversized motors, since the first edition did not take credit for correcting such motors' decreased slip, hence increased energy waste, when operating cube-law machines such as pumps and fans. Moreover, whereas the first edition had to make do with limited cost and efficiency data, the second edition conservatively calculated CSE size-by-size from the Motor Master database, which includes every NEMA motor on the U.S. market.

38. These are often hidden within discussions of such familiar issues as free riders, measurement and evaluation, transaction costs, etc. — all described as if they were important new discoveries, rather than subjects of exhaustive professional debate for the past decade or two.

39. In some cases, like Hood River (*see* E. HIRST, THE HOOD RIVER CONSERVATION PROJECT: COOPERATION AND COMMUNITY CONSERVATION, FINAL REPORT 41–42 (DOE/BP-11287-18, 1987), the control group is too labile to be considered reliable. When its consumption is strongly affected by price and income movements, as was BPA's in the 1980s (hence J&M's *Electricity Journal* article at note 24, which shows larger net than gross savings), the purpose of the analysis determines whether it is wiser to use J&M's retrospective (planning) view or a prospective (resource)

view. The latter better reflects DSM's "insurance" value — its tendency to yield greater system benefits when they are most needed (*see* Hirst & Reed, note 5 in inset on p. 37, *supra*).

Failure to match the evaluation technique to the task yields artifactual results. For example, if a new-construction residential program is measured house-by-house to save 5% more than predicted compared with normal construction, the ascribed savings shouldn't be halved just because a stricter building code, promoted by the same utility, meanwhile made nonparticipating houses more efficient too. Yet Nadel and Keating, note 34, *supra*, describe exactly such a case, and more like it. It is wrong to state that the program's houses saved only half as much as expected; rather, the correct summary would be that the houses saved 5% more than predicted, but meanwhile the change in building code moved the goalposts, so that in the future, about half the saving can be achieved by code compliance at no program cost, possibly raising the cost of getting the other half through a modified incentive program. Much the same issue applies to J&M's emphasis on "deterioration in measured program savings over time." Barring very sloppy quality control or maintenance (which do sometimes occur if managers, installers, regulators, customers, and intervenors are all asleep), such deterioration in physical terms should range from small to negligible. Rather, what is meant is presumably that *non*participants will meanwhile save too — often in imitation of the good example set by the participants (note 6 in inset on p. 37, *supra*) — thus decreasing the *net* savings ascribed to the program.

40. J&M's *Science* letter, *supra* note 34, at 320. I have never expressed or held such a view, and consider proper evaluation vital.

41. Such as advanced glazings, or the improved programmatic details developed by careful evaluation feedback in, *e.g.*, Michigan's residential weatherization (M. KUSHLER & P. WITTE, AN EVALUATION OF THE FUEL SAVINGS RESULTS OF A NEW WEATHERIZATION MEASURES PRIORITY SYSTEM (Michigan PSC, Lansing, 1988)). That said, however, it is premature to draw conclusions from seemingly anomalous Bonneville data for a single year (1989) without understanding apparent shifts in the control group, let alone to infer technical deterioration that is probably not significantly present. *See* E. Hirst & M.A. Brown, personal communications, Aug. 13 & 16, 1993. In fact, a review later found that the original 1989 evaluation results on which J&M relied were largely artifactual and not borne out by a larger sample (T. Eckman, personal communication from Northwest Power Planning Council staff member, Sept. 29, 1993). Real program costs were also one-third lower in 1991 than in 1989, returning to historic trends. *See* R. MOE *ET AL.*, EVALUATION OF BONNEVILLE'S 1991 LONG-TERM RESIDENTIAL WEATHERIZATION PROGRAM (Synergic Resources Corp., SRC-7827-R4, Oct. 30 1993). But encouragingly, BPA was spurred by those early 1989 evaluation results to undertake a major reassessment of the program, which is well known to use badly outdated *ex ante* estimates. *See* M.A. BROWN & D.L. WHITE, EVALUATION OF BONNEVILLE'S 1988 AND 1989 RESIDENTIAL WEATHERIZATION PROGRAM: A NEW STUDY OF PROGRAM DYNAMICS (ORNL/CON-323, Dec. 1992). It is better to fix such obvious design defects than to impugn the intelligence of the utility or, as Black & Pierce do (note 2 *supra*, at 1383), the integrity of the evaluators.

42. However, J&M continue to posit exhaustion of the cheapest efficiency opportunities without asking whether, as many practitioners suspect, those remaining are getting bigger and cheaper, because better technologies and integration plus more streamlined delivery methods are outpacing the "depletion." J&M must believe potential savings are small indeed if they think utilities' claimed savings (0.9% of national usage through 1991, according to E. HIRST, ELECTRIC-UTILITY DSM-PROGRAM COSTS AND EFFECTS: 1991 TO 2001 (ORNL/CON-364, May 1993, at v) have already depleted the potential enough to overcome any learning curve and raise costs materially. U.S. utilities disagree: In aggregate, they are projecting a *70% improvement* in DSM cost effectiveness during 1991–2001 (*id.*, pp. 20–21).

43. As my January 12, 1992 review (note 1, *supra*) notes, this "confuses rates with bills, actual rates with rates (and bills) if a costlier resource had been acquired instead, and theoretical microeconomic [rates] ... assessed one program at a time with actual rate effects under the combined influence of all programs, growth in service demand, depreciation, and other real-world factors. (Among other things, equal-opportunity access can provide distributional equity, and rates need not rise unless savings are so fast as to overwhelm the combined effects of generating-plant depreciation, growth in service demand, [any wholesale export opportunities,] and use of saved operating costs to pay — even prepay — fixed costs".) J&M's goal of "the smallest possible impact on overall rate levels" may be valid politically, but has no sound basis in neoclassical economics: Any objective function

based on rates rather than bills ensures societal misallocation.

44. This could be a concern with poor program and rate design, but if so, it is their fault, not that of least-cost investment theory. It is fashionable for large industrial customers to say they've already done all cost-effective savings and don't want to pay for others'. But in practice, (i) I have never found such an opportunities-exhausted customer, (ii) in virtually every case it is easy to show such skeptics that they've barely scratched the surface of cost-effective electrical savings, (iii) most of them vigorously seek rebates if offered them, (iv) it is common for different representatives of the same industrial customer to call in one forum for less utility DSM investment and in another for more; (v) only half of the Niagara Mohawk industrial customers recently offered a limited "opt-out" from DSM participation actually elected it (the rest preferred to keep utilities' DSM support); and (vi) least-cost DSM investments yield system benefits in which there are no nonparticipants.

45. On the contrary, I believe, with most utility executives who have thought seriously about it, that least-cost investments in efficient use of electricity are the best business strategy *whether or not* retail wheeling occurs. The clear lesson of deregulation in natural gas, airlines, and telecommunications is that a wholesale-like price-based commodity play fails at the retail level, which is quintessentially a service business and must bundle with the commodity a variety of non-price attributes that customers also value. The more competition levels wholesale prices, the more end-use efficiency will become a vital service differentiator.

46. See *e.g.* A.B. LOVINS, ENERGY-EFFICIENT BUILDINGS: INSTITUTIONAL BARRIERS AND OPPORTUNITIES (E SOURCE, 1992), for a detailed account of the almost perfectly perverse incentives seen by ~25 actors in the building process. That analysis casts serious doubt on J&M's assertion in the *Energy Journal*, note 4, *supra*, at 53, that "C&I customers are *less* likely to face significant market imperfections than are residential customers."

47. Most recently, but no more edifyingly, in *The Cost of Energy Efficiency*, note 22, *supra*.

48. *Id.* at 320.

49. Helpful comments on earlier drafts of this paper were kindly provided by many reviewers — including Ralph Cavanagh, Dan Kirshner, Bob Marritz, and Anita Wolff — none of whom is responsible for the result.