"Virtual rebound effects" with emphasis on long-term infrastructure investments, and their interaction with absolute (ordinary) rebound effects

By

Jon Strand

Development Research Group, Environment and Energy Team

The World Bank

Jstrand1@worldbank.org

Introduction

The "rebound effect" in relation to energy consumption in general, and to climate-related emissions more specifically, represents, widely speaking, a manifestation of the insufficient use of price instruments in managing energy consumption and the associated greenhouse gas (GHG) emissions. It is a term usually applied in cases where improvements in energy efficiency, resulting from particular investments or other efforts, drive overall energy consumption per unit of economic activity down. The resulting higher energy efficiency may then lead to a "rebound", by which is usually meant an increase in the activity that gives rise to energy-consumption, as per-unit energy consumption becomes less expensive. Straightforward examples of such "rebound" are when efficiency improvements are manifested via more fuel-efficient cars, or more energy-efficient light bulbs. The resulting higher energy efficiency of using these (cars, or light bulbs) may then lead to more driving, or more use of lighting, which counteracts the initial and potential saving effected by the innovation.

In this note I will argue that the concept of a "rebound" can, fruitfully, be applied more widely, with reference to energy efficiency improvements as in the above examples. I will introduce the notion of a *potential (or virtual) rebound*, where the rebound is defined in comparison to an energy consumption or use alternative where energy use related to infrastructure investments and their utilization would otherwise be reduced, but where inefficiently low energy dictate that it instead remains constant in (too) many states of the world. This effect adds to the standard rebound effect, by which we then mean the actual increase in energy consumption that results from a per-unit reduction in energy price or cost.

The main idea is that the virtual and the absolute rebound effects can be, and often are, mutually reinforcing. By this I mean that, *when the virtual rebound is greater, this can in itself lead to a greater absolute rebound*.

To exemplify, consider an economic system (such as an urban area; or an energy production and delivery system) where a range of long-term investments need to be made, which in aggregate have substantial impacts on the system's short- and long-run energy consumption. Initial investments then need to be made with such implications. These investments are made in anticipation of particular future energy prices that can be either high or low. When future energy prices are high (low) in expectation, the system will adapt by choosing an investment structure that gives rise to relatively low (high) energy intensity ex post. Consider on this basis an actual price path for energy after these basic investments have been made. I will also assume that the system can be "retrofitted" ex post, and that a "retrofit" will occur given that realized energy prices are "high". The "retrofit" implies that an additional (retrofit) investment is made which purges the system of (much of) its energy consumption ex post. Examples could be electrical power plants based on coal, that can later (and only then) be equipped with carbon capture and storage (CCS) technology purging the system of its carbon emissions, when the carbon price turns out to be "very high", but not otherwise. Another example is an urban transport system relying on private vehicles, where the vehicle park initially depends on fossil fuels, but which can however be replaced by vehicles that do not depend on such fuel (electric instead of gas-driven cars; or simply where fossil fuel is replaced by biofuels).

The *"virtual rebound"* can here be thought of as *the (higher) energy consumption that follows from a low ex post energy price, relative to a (lower) energy consumption that would have been the result of system retrofits, that would otherwise have been carried out, under more appropriate, and higher, ex post energy prices*.[1] Consider e g the situation where the ex post true climate cost of carbon emissions are "high", and an energy intensive system ought to be retrofitted. The respective government however keeps energy costs low (by not imposing the necessary carbon taxes), so that these retrofits are not being made. The resulting energy consumption, higher than under a rationally executed retrofit, can then be said to represent a "virtual rebound", relative to the energy consumption reduction that would have resulted when facing higher (and more rational) energy prices.

To again use the example of the U.S. transport system, higher basic fuel costs and/or climate-related carbon emissions costs should, rationally, have led to public transport taking over a larger share of this transport system (through "retrofitting" the system by investing more in e g rail and bus transport). When this is not done, I will be call it a a *"virtual rebound".*

Choosing a high-energy-intensity system (such as a transport system that relies on cars) may also in itself lead to a higher than otherwise absolute rebound (in response to a low ex post energy price), than what would have followed, had a less energy intensive system been chosen initially. This is a type of "*positive rebound synergy"* that can be quite harmful.

To exemplify such a possible synergy, consider as above a transport system relying predominantly on private vehicle transport and with heavy average. "business- as-usual" travel loads (the U.S. system); versus a system based much more on public transport and with lighter travel loads (the systems in Europe or Japan). Consider on this basis an improvement in vehicle efficiency; this is the standard case when normally discussing rebounds. It is very well possible (indeed, likely) that the "standard rebound" will be greater in the more energy intensive system. This could happen because a larger fraction of the

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[1] Another way to define it would be in terms of a "negative retrofit rebound effect": the avoidance of the retrofit activity that would have taken place under higher, and more appropriate, energy prices.

public, naturally or habitually, rely on cars in the private vehicle-intensive system; and it would remain this way also after the energy efficiency improvement has taken place.[2]

Two recent papers, Strand (2010) and Strand, Miller and Siddiqui (2011), can serve to exemplify these principles. The latter is then the key paper. It is here assumed that an infrastructure investment that will later put greater or lower demands to energy must be made at a point of time when energy costs are unknown; these costs are revealed at a later point of time when the investment can also be retrofitted whereby the investment is purged of its fossil energy consumption. There is a particular, initial, energy intensity, and retrofit propensity, that will be (constrained) optimal given that the price path for energy is “correct” (units in the economy are charged energy prices corresponding to the true social costs of energy use including correction for all externalities).

From this starting point, one can investigate how much greater, in expectation, the energy consumption of this system will be, when economic actors, including government units in a given country, are faced with lower than optimal energy prices ex post (e g are not charged true global costs of carbon emissions).

Table 1, based on the analysis in Strand, Miller and Siddiqui (2011), illustrates the “virtual rebound” in such a context. A fully specified mathematical model of ex ante and ex post behavior, in response to optimal and suboptimal energy prices, is here simulated under particular parametric assumptions. The model assumes that both the cost of energy and the cost of carrying out a necessary retrofit to eliminate energy consumption ex post, are both stochastic. Both are modeled as log-normally distributed and independent. The model example also builds on an assumption that expected retrofit cost (per unit of energy consumption) = 3, and that the variance on retrofit cost is throughout the same as the variance on energy cost.

Table 1: “Virtual rebound”: Excessive ex ante expected energy consumption and/or carbon emissions due to “too low” expected energy prices (= 2 in the example), instead of “correct” (higher) expected energy prices ex post. Percentage increment relative to base energy consumption in optimal solution.

“True” expected energy price	Low variance for future energy price	Medium variance for future energy price	High variance for future energy price
2.5	20	18	17
3	58	41	36
4	255	125	98

Source: Adopted from Strand, Miller and Siddiqui (2011), Table 1

The numbers appearing in the table represent energy consumption, in excess of optimal consumption, for given initial infrastructure investment, given that agents are faced with energy prices ex post that are “too low” in expectation. In short, necessary retrofits are not carried out in many cases. This problem is greater when the price difference (between the higher, correct, price, and the lower price actually facing

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[2] In this case, however, other possibilities are also open. Referring to the example, it could be that the

economic actors) is greater. It is also greater when the variances on energy prices (and on retrofit costs) are smaller. High variances on prices imply a higher probability that the realized "correct" price will actually turn out to be lower than the energy price actually imposed (=2 in expectation here). In such cases, nothing is lost when the actual future price is lower than the expected future price. When variances are lower, fewer such cases arise; then there are more cases where a mistake will be made given "wrong" energy pricing.

Overall, we see that the mistake that is made in terms of excessive energy consumption, when ex post energy prices are too low, can be substantial. In some of the numerical examples given (based on actually imposed energy cost being half of optimal levels in expectation), the consumption of fossil energy (and the associated carbon emissions) are more than twice the optimal levels. The intuitive reason is that, in such cases, much or most of the energy consumption would, in the optimal solution, be purged of the system through retrofits; much fewer such retrofits (or none) take place in the market solution when energy prices are much lower.

In Strand (2010), I in addition assume that there is a "standard rebound" (a short-run increase in the activity associates with non-retrofitted infrastructure investment) that gives rise to energy consumption and/or carbon emissions), coming in addition to the "virtual rebound", when energy prices are too low in the ex post state. These effects are not yet explicitly quantified, but it is straightforward to find numerical examples where they can be. This is subject to continued work by the author.

References:

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