Why CO_2-pricing must be central to any successful climate change policy

The limits of energy efficiency

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Many commentators and policymakers seem to believe that energy efficiency alone can address much of the CO_2 problem – and that it can do so at very low cost (or even negative cost), at least compared to a 'do nothing case'.[i] In fact, however, any successful policy toward mitigation of CO_2 emissions must centre on CO_2 pricing. Energy efficiency can only be a contributory factor and, in some circumstances, can even have a negative long-term impact if the centrality of CO_2 pricing is not recognised.

Since the optimism that sprang from the Kyoto protocol in 1998, it has proven remarkably difficult to put in place a credible plan to effectively tackle the problem of growing and accumulating CO_2 emissions in the atmosphere. Agreements at the UN Climate Conferences in Copenhagen in 2009, and in Durban in 2011, have put in place roadmaps and plans for action in the future. However, they failed to put in place the critical mechanisms needed to put a price on CO_2 emissions globally. As a result, the world has not moved much further forward than where it was 14 years ago.

Most observers agree that a robust cap-and-trade policy on CO_2 emissions would provide the incentives needed for credible long-term investment in CO_2 abatement technologies.[ii] In spite of the compelling logic behind this, however, CO_2 pricing remains a contentious and politically difficult policy measure. A much more popular route towards CO_2 emission reductions is energy efficiency.[iii]

This paper looks at the issue of energy efficiency and examines some of the established beliefs about its benefits and impacts. It highlights some important missing nuances in the logic linking efficiency improvements with reductions in CO_2 emissions. I argue that in the absence of a credible price on CO_2 emissions, the effectiveness of energy efficiency measures is greatly reduced. In fact, in some cases they may even make the problem of CO_2 emissions worse in the long term.

It is important to match policy goals with appropriate policy measures. Policies to improve energy efficiency can deliver many benefits in the form of better living standards, increased productivity, and improved energy security. These reasons alone make energy efficiency policies worth pursuing. However, as a means of reducing CO_2 emissions over the long term, they may not be sufficient. This may strike many as an uncomfortable finding, but without a full understanding of the long-term dynamics of energy efficiency improvements, policy design may end up less effective than originally intended.

Nevertheless, if a credible price on CO_2 emissions **is** eventually established, energy efficiency measures can still be made into a powerful 'lever' with which to drive through the transformation to a low CO_2 energy system.

An old debate

The effectiveness of energy efficiency measures has been debated at least since the Industrial Revolution. In 1846 the British economist Stanley Jevons observed that improvements in energy efficiency, while aimed at reducing the demand for energy, also make the use of that energy cheaper (per unit of output), leading to an offsetting 'rebound' in demand.[iv] Since then, this so-called "Jevons Paradox" has become something of an *idée fixe*: a lot of effort has gone into quantifying this 'rebound effect' under various conditions, but the basic idea behind the paradox is little changed.

So what does this mean for the relationship between energy efficiency and CO_2 emissions? Given the dominance of hydrocarbons in the energy mix, two important factors are typically ignored or misunderstood.

First of all, CO_2 emissions are the consequence of something simple, but quite profound, namely that burning fossil fuels efficiently enables large numbers of people to affordably consume "energy services"—be it heating, lighting, miles transported or physical goods. This leads essentially to Jevons' insight: the more efficient the conversion between each unit of input energy and each unit of energy service, the more "useful" each unit of source energy becomes.

Secondly (and something which obviously post-dates the questions that Jevons addressed), the logic of combating climate change implies the need to not only reduce the eventual *rate* at which CO_2 is emitted into the atmosphere, but to limit *the total amount* of CO_2 that is allowed to accumulate in the atmosphere before the transition to a low CO_2 energy system is complete. More importantly, the battle against climate change means bringing forward the point at which this transition is complete.

These points may initially sound like details but they have major implications for the effectiveness and efficacy of energy efficiency policies. Specifically, innovations that improve the efficiency with which fossil fuel is converted into energy service, but which don't do the same for non-fossil fuels,[1] make fossil fuels fundamentally more affordable compared to non-fossil fuels, even though they reduce the rate of consumption in the short term.

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[1] Note that in the context of this paper, non-fossil energy includes not only nuclear energy and renewables, but also energy generated from fossil fuels where CO_2 emissions are subject to capture and sequestration (CCS).

Consider the example of a driver who initially uses a 30 mpg (miles per gallon) car to drive 300 miles per week when gasoline costs $4/gallon. If at some point in the future, that same driver acquires a car that achieves 60 mpg, he can carry on driving the same distance per week even if the price of gasoline were to rise to $8/gallon (all other things being equal).

At first sight, the improvement in efficiency seems a good thing: after all, there has been an immediate improvement in the driver's living standards, as driving is now cheaper than it was before. So how might there be a problem? The greater affordability of fossil fuels caused by such improvements in energy efficiency serves to increase the future supply of fossil fuels - again a matter that Jevons brought up. The increased efficiency of the car effectively has made it profitable to produce oil with higher extraction costs without causing the driver to drive fewer miles. In the short term, the increase in productivity, net income and wealth, which is brought about by higher efficiency, contributes an additional boost to energy affordability (this 'income effect' will not be considered further in this paper, however).

In the long run, then, the initial halving in the rate of consumption from replacing a 30mpg car with a 60mpg car does not represent a **reduction** in CO_2 emissions: instead of **avoided** emissions, it may represent only a **postponement**, **plus a long-term addition** to the stock of economically extractable resources.

There are some important uncertainties and caveats. After all, there is still value in postponing emissions, as it effectively 'buys time' in which further innovations may come up with cheaper ways of dealing with CO_2 emissions. However, postponed emissions are not the same as avoided emissions, especially if the long-term scope for even greater total emissions has been increased.

More versus less carbon

The key to understanding the impact of energy efficiency on CO_2 emissions lies in the long-term competition between the costs of using fossil fuels on the one hand, and of using non-fossil fuels (the latter of which, in this paper, includes fossil-based fuels using CCS technology) on the other. Based on the terminology introduced by Harrod, Hicks and Solow in the macroeconomics literature, energy efficiency improvements can be classified into two types:[v],[vi],[vii],[viii]

- **Carbon-augmenting:** increases in energy efficiency that make the use of (unabated) fossil fuels more affordable, but have no such impact on the affordability of non-fossil fuels (all other things assumed equal). As set out above, they allow a higher cost of fossil fuel production without changing the unit price of energy service for the end-consumer. Such measures include more efficient internal combustion engines, more efficient aircraft engines, high efficiency coal-fired power stations, and high efficiency gas-fired domestic boilers.

- **Carbon-neutral:** increases in energy efficiency that make the use of both fossil fuels **and** non-fossil fuels more affordable, and therefore do not affect the relative prices of either energy source from an end-user point-of view (all other things assumed equal). These measures include low-loss power grids, building insulation, lighter vehicle chassis and energy-efficient lighting.

A simple diagram (Fig. 1) illustrates this difference, using a stylised model of the cost of using fossil fuels (i.e., oil, gas, and coal combined) compared with the cost of using non-fossil fuels. The model assumes a single energy-consuming sector, which can use either fossil fuel or non-fossil fuel as an input. Efficiency improvements can be applied to either the production or consumption of fossil-fuel derived energy only (carbon-augmenting), or to the production or consumption of both forms of energy at once (carbon-neutral). While the structure of the model is very simple, it still provides some useful basic insights. A more sophisticated model is required to go any further than these insights, however.[ix]

The red line (fossil fuels) slopes upwards as more of the carbon resource base is consumed, reflecting the idea that over time, the lowest-cost fossil fuels are consumed first and replaced by higher cost fossil fuels.[x] The blue line represents some future level of the steady-state cost of non-fossil fuels—that is, the cost of the next unit of non-fossil energy at a point in the future when non-fossil energy (including CCS) covers the majority of demand for energy. The blue line is flat because this cost is, to all intents and purposes, independent of the carbon resource base.[2] The intersection of the solid blue and the red lines represents the point at which consuming fossil fuels becomes more expensive than consuming non-fossil fuels, labelled as point A ($P^{non\text{-}fossil}$, UC_1). This model therefore considers the cost of energy as a function of the **stock** of carbon in the ground, rather than the **flow** of carbon coming out of the ground.

As already noted this model is a simplification of reality, and may not hold under a number of circumstances. For example:

- if production of biofuels can be expanded to meet most, if not all, energy demand (at an acceptable cost) in the long term, then the distinction between the red and the blue lines largely disappears, especially in areas where there is no alternative to liquid fuels. Biofuels currently account for only around 4% of total commercial energy, so we are some way away from such a situation. In the meantime, biofuels are still a useful additional tool with which to reduce the CO_2 intensity of the energy system.

- if technology can be developed to remove CO_2 from the air, or as in the case with CCS, prevent it from being emitted in the first place.

- if the cost of producing renewable energy declines so quickly that the transition to a low CO_2 energy system takes place of its own accord and at low cost. In such a case, the blue line drops quickly below the red line. While this outcome cannot be discounted, the

[2] Strictly speaking, the blue line represents the cost of a "flow" of energy, superimposed against the "stock" of carbon in the ground. Some linkage between the cost of fossil fuels and the capital cost of renewables is inevitable, but continuing technical innovation seems to be bringing down the unit cost of renewables independently of the price of fossil fuels. This long-term cost is therefore best understood as a notional flat line, whose level may be higher or lower at any particular point in the resource base.

time needed to roll-out new/renewable energy technologies at scale should not be underestimated.[xi]

Unless such “null-cases" hold, the model provides a useful description of the competition between fossil and non-fossil resources at some unknown point in the future when the transition to a low CO_2 energy system is underway. The unknowable times and quantities involved might make it harder to understand this model when compared with the current “rebound” model of energy efficiency with its short-term dynamics, measurable quantities and identifiable timeframe. However, it is more suitable for understanding some of the long term effects of changes in energy efficiency on the CO_2 problem.

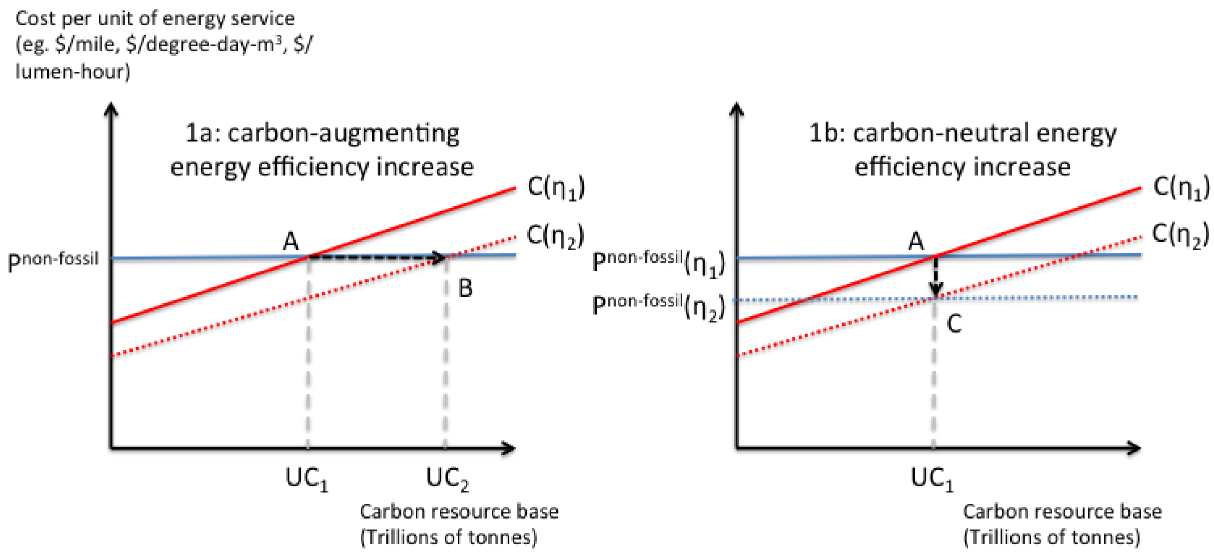

Fig 1: effect of efficiency measures on ultimate extracted carbon resource (UC)

The left-hand chart of figure 1 shows the effect of a carbon-augmenting energy efficiency increase *in the absence of a CO_2 price* (more about this later): here, the red line $C(\eta_1)$ moves down to $C(\eta_2)$, as the increase in carbon-augmenting efficiency from η_1 to η_2 leads to a lower cost per unit of energy service from fossil fuels. The crossover point between the cost of using fossil and non-fossil fuels occurs further on in the carbon resource base, point B ($P^{non\text{-}fossil}$, UC_2). This implies that, all other things equal, a greater amount of carbon can be extracted before it becomes more expensive to use fossil fuels rather than non-fossil fuels—leading to a higher level of final cumulative CO_2 emissions.

By contrast, the right-hand chart shows the effect of a carbon-neutral energy efficiency increase: in this case, the carbon-neutral increase in efficiency causes both the red line **and** the blue line to move downwards by the same proportion, again, all other things equal. Point A ($P^{non\text{-}fossil}(\eta_1)$, UC_1) moves vertically down to point C ($P^{non\text{-}fossil}(\eta_2)$, UC_1), but the point along the carbon resource base at which fossil fuels become more expensive than non-fossil fuels remains unchanged at UC_1.

As with any simple model, other things may be going on which have the potential to change this result. The most apparent of these concerns the cost of non-fossil energy. If the long-term reduction in energy demand from an increase in efficiency is not completely absorbed by rebound effects, then time-wise, it takes longer before a given amount of the carbon resource base has been consumed. Within that extra time (i.e., 'postponement'), it is possible that the cost of non-fossil energy drops, resulting in a lowering of the blue line and a reduction in the amount of carbon that can be affordably extracted (moving points B and C to the left). That said, an equivalent point can be made for the red line also. These points are, of course, difficult to represent graphically.

However, it is still highly uncertain as to whether such a cost-reduction effect can be relied on in the long-term, especially if the installed capacity of non-fossil energy is approaching the same level as total energy demand. A much more sophisticated model would be required to examine the interaction of these effects in greater detail.

These caveats notwithstanding, the difference between carbon-augmenting and carbon-neutral energy efficiency improvements is striking: in the absence of an offsetting CO_2 price, polices which encourage the former risk leading to ever greater amounts of fossil fuels becoming economically extractable, even if the short-term effect leads to a reduction in the **rate** of CO_2 emissions. This uncomfortable finding, as alluded to in the introduction, is therefore at odds with the generally accepted understanding.

Carbon-augmenting efficiency measures do improve energy security as they effectively add to the economically affordable supply of energy in the long term, and in some cases can reduce import-dependency to the same effect. Energy efficiency improvements can also make sense as a means of increasing economic efficiency/competitiveness.

Policies to encourage carbon-neutral energy efficiency, while potentially having no impact on the amount of carbon that can be economically extracted, at very least increase the likelihood that a constrained non-fossil resource base can meet the demand for energy **service** that is currently derived from fossil fuels. This means that they can therefore be seen as a useful tool in the transition to a low CO_2 energy system over the long term.

Looked at on a historic basis, energy efficiency improvements underlie many of the huge improvements in living standards seen in the last two centuries in the industrialised world. Thus intuitively, as well as logically, improving energy efficiency *feels* like the right thing to do, and in many respects, *is* the right thing to do. However, the potential long-term impact of, in particular, carbon-augmenting efficiency improvements could give rise to unintended consequences.

However, the real lack of effectiveness of efficiency improvements at addressing the CO_2 problem (compared to their potential) only becomes fully apparent when considering the interaction of efficiency improvements and a CO_2 price.

The importance of CO_2 pricing

CO_2 pricing (or taxation) is the key to unlocking the full potential of energy efficiency to reduce CO_2 emissions. As shown above, in the absence of an offsetting price on CO_2 emissions, measures to encourage (specifically carbon-augmenting) energy efficiency can lead to higher ultimate/potential emissions. However, where an offsetting CO_2 price is applied, this can be avoided.

Of course, a CO_2 price can take several forms, from the price of traded CO_2 emission permits, to a tax on CO_2 emissions, to portfolio standards whereby an obligation is placed on energy producers to source a given percentage of their energy from non-fossil sources. In this latter case, while no explicit CO_2 price would be imposed, the requirement to produce (currently more expensive) non-fossil energy for each unit of fossil energy produced would impose a plethora of 'shadow' CO_2 prices on producers.

Applied at an appropriate level, a CO_2 price can counteract the increase in relative affordability caused by the increase in carbon-augmenting efficiency, leaving the 'affordable' carbon resource base no larger than it was originally (looking at figure 1a – if such a tax were applied then the dotted red line would move back to its original position and point B back to point A).

This shows where all energy efficiency measures can be useful in the context of a cap on future CO_2 emissions: provided that a real and credible price is applied to CO_2 emissions, then within a given cap on CO_2 emissions, efficiency measures effectively allow a greater total amount of 'energy service' to be provided. Alternatively, income from CO_2 pricing could be diverted to the construction of low- and zero-CO_2 energy sources (including CCS). The higher the level of efficiency, the higher the CO_2 price that could be sustained, and the greater the amount of zero-CO_2 energy that could be constructed, per unit of CO_2 emitted.

However, the line of causation here is important: where there is an increase in carbon-augmenting efficiency, it is the price placed on CO_2 emissions that leads to the offsetting reduction in economically extractable fossil fuels. In other words, **it is the CO_2 price, which does most of the work to avoid emissions, and not the efficiency increase.** Unless such a price on CO_2 emissions is established, carbon-augmenting energy efficiency increases should not be viewed as an "alternative" or equivalent means of reducing CO_2 emissions.

As an intuitive analogy, a CO_2 price links efficiency improvements (driven essentially by human ingenuity) to effective action to address the CO_2 problem, just as the clutch in a car enables the transmission of energy from the engine to its wheels. Without a clutch, the driver's effectiveness at making the car move is obviously limited!

Absent a CO_2 pricing system of some kind, the imposition of carbon-augmenting efficiency measures in some respects resembles "pushing on a rope" – in other words, it acts in the opposite direction to where the constraint is needed. In the longer term, CO_2 pricing, in whatever form it may take, is arguably the **only** low-risk policy tool to reduce CO_2 emissions in the long-term.

Towards CCS and away from coal

The arguments against energy efficiency measures in the absence of CO_2 pricing do not amount to a counsel of despair. On the contrary, long-term investment in CCS, nuclear and renewable technology, coupled with coal-to-gas switching in the short-to-medium term, have the potential to provide a real and durable contribution to reducing emissions even before a CO_2 pricing system is put in place. Given the limits on growth that CCS, nuclear and renewable technologies face right now, coal-to-gas switching has taken on added importance. Moreover, due to the costs involved in developing CCS technology (to a point at which it can fulfil its potential to avoid CO_2 emissions), it too needs further policy-driven support:

- **Coal-to-gas switching** is highly likely to be one of the first things incentivised by a credible CO_2 pricing system. Given that this involves machinery and infrastructure with a long economic life (for instance, power stations, steelworks and cement plants), it therefore makes sense to promote choices away from coal and towards gas as a low-cost means of reducing the rate of CO_2 emissions even before a CO_2 pricing system is put in place. Because of each unit of energy from gas involves the emission of less CO_2 than the equivalent energy from coal, such a switch extends the time window available in which to affect the transition to a low-CO_2 energy system (this 'extra time' is arguably a similar effect to that which could be expected from an increase in energy efficiency, but there is an important difference in the risks that these policies entail, as discussed below).

- **CCS** enables fossil fuel to be extracted from the ground, useful energy derived from it, and the carbon in the fossil fuel returned underground in the form of CO_2. Although this technology needs support to make it work economically, it allows emissions into the atmosphere to be permanently avoided. Given the well-documented lag between the design and roll-out of early demonstration plants and their eventual roll-out at scale, there is an urgent need to push on with the development of this technology.

The difference between these measures and carbon-augmenting efficiency measures is significant. In order to be fully effective, carbon-augmenting efficiency measures require an extensive CO_2 pricing system to be (firmly) in place—otherwise there is a risk that they make the transition to a low CO_2 energy system more difficult. Because they do not enhance the efficiency of existing energy-conversion and energy-consuming technologies[3], policies to encourage CCS and coal-to-gas switching **now** have the potential to facilitate an earlier and easier transition to a low CO_2 energy system in a way that does not risk adding to the CO_2 problem in the longer term. Moreover, steady growth in nuclear and renewable technology has the potential to contribute at large scale in the longer-term, while action is needed now.

[3] CCS results in a lower "well-to-wheels" or "well-to-wire" efficiency, due to the energy required to capture and inject CO_2 into the ground.

Conclusions

The history of mankind's harnessing of fossil energy since the Industrial Revolution has been one of rising energy efficiency, rising productivity, rising incomes, rising affordability of fossil fuels and a rising rate of fossil fuel extraction. Even in the early days of industrialisation, Jevons was arguing that this was no coincidence. If we fail to understand properly the link between energy efficiency and fossil fuel extraction, we are missing opportunities to put in place effective and appropriate policies. Not only are we failing to fully leverage the potential of energy efficiency measures to address the CO_2 problem but in doing so, we are also running the risk of counterproductive side-effects in the long-term.

In the short term, more effective and less risky options than energy efficiency measures are available in the form of CCS and coal-to-gas switching. It is time to recognise that the effectiveness of energy efficiency measures (particularly in their carbon-augmenting form) will be greatly constrained **until a CO_2 pricing system is in place**. Before this comes about, it is imperative to pursue more realistic, yet cost-effective alternatives.

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[i] IPCC (1996), "Technologies, Policies and Measures for Mitigating Climate Change" (http://www.ipcc.ch/pdf/technical-papers/paper-I-en.pdf); EPA (2010), "EPA and NHTSA Finalize Historic National Program to Reduce Greenhouse Gases and Improve Fuel Economy for Cars and Trucks"; Lovins and Lovins (1997), "Climate: Making Sense and Making Money", Rocky Mountain Institute; UNEP/CD4CDM (2005), "Baseline Methodologies for Clean Development Mechanism Projects" (http://cd4cdm.org/Publications/UNEP_CDM%20Baseline%20Meth%20Guidebook.pdf).
[ii] See blogs.shell.com/climatechange/2012/05/debate/; and INSEAD Knowledge "Shell CEO van der Veer: Carbon Dioxide Regulation Necessary to Make the Markets Work" (http://knowledge.insead.edu/EBSShellCarbonDioxideRegulation080303.cfm?vid=31).
[iii] McKinsey & Co (2011), "Resource Revolution: Meeting the World's Energy, Materials, Food and Water Needs"; European Commission (2011), "Energy Roadmap".
[iv] Jevons (1885), "The Coal Question: An Enquiry Concerning the Progress of the Nation, and the Probable Exhaustion of our Coal Mines".
[v] Harrod (1939), "An Essay in Dynamic Theory". Economic Journal 49, 14-33.
[vi] Hicks (1932), "The Theory of Wages".
[vii] Solow (1956), "A Contribution to the Theory of Economic Growth". Quarterly Journal of Economics, 70, 65-94.
[viii] The idea of carbon-augmenting technology changes has been used in the RICE-99 and DICE-99 models of CO2 policy effectiveness. See Boyer and Nordhaus (2000), "Warming the World", MIT press.
[ix] Over-reliance on simplified or "reduced-form" models is clearly something to be avoided. A sophisticated assessment of the pitfalls of relying on (reduced-form) Marginal Abatement Curves can be read in Morris, Paltsev and Reilly (2008), "Marginal Abatement Costs and Marginal Welfare Costs for Greenhouse Gas Emissions Reductions: Results from the EPPA Model", MIT Joint Program on the Science and Policy of Climate Change.
[x] A similar, but more complex resource cost assumption was developed in Pindyck (1978), "The Optimal Exploration and Production of Nonrenewable Resources". Journal of Political Economy, 86(5), 841-861.
[xi] Kramer and Haigh (2009), "No Quick Switch to Low-carbon Energy", Nature 462, 568-569.