The rebound effect: a tassel in the study of technological change dynamics, by Elena Verdolini[1]

Disclaimer: This outline presents some of the considerations regarding rebound effects that have emerged in recent discussions within the Energy Demand Working Group at Fondazione Eni Enrico Mattei. It highlights some relevant research by FEEM and provides a research plan to be pursued within the next year. As such, it does not constitute an attempt to review the literature on the topics addressed, to which others have contributed significantly.

Researchers at FEEM have heavily focused on assessing the implications of environmental policies in terms of innovation, technology diffusion, energy demand and consequent improvement in environmental performance (GHG emissions). This has been addressed both by means of econometrics analysis as well as studies based on two climate economy models developed at FEEM (a recursive dynamic CGE model – ICES[2] – and an integrated assessment model -WITCH[3]).

Within the 3 years European Research Council project ICARUS (www.icarus-project.org) we study the extent of the drivers and mechanisms of innovation in energy and clean technologies, testing model specifications both through econometric work based on patent data and through expert elicitation of the future, uncertain effectiveness of RD&D. The resulting knowledge on innovation and diffusion mechanisms will be included in next generation integrated assessment models. Within the 3.5 years European Commission funded PURGE project, the Work Package 7 focuses on improving the understanding of how individuals respond to changing prices of consumer durables and to energy prices by modifying their purchasing behaviour as well as changing their use of appliances.

Three lines of research are particularly relevant in this respect. While the first two concern the process of innovation and technological diffusion, the third is specifically looking into the issue of the resulting effectiveness of innovation. All three streams of research are necessary when looking into the issue of rebound effects.

First, FEEM researchers have actively been involved in studying policy-induced innovation dynamics with respect to climate and energy technologies. With respect to econometric analysis, a main indicator of innovation can be found in patent data. Using this proxy it is possible to investigate the role of policy and economic drivers in spurring new ideas and how these then diffuse throughout the international market. As an example Verdolini and Galeotti (2011) use patent data in 12 energy technologies to study demand and supply determinants of innovation for a panel of 17 OECD countries. They show that increased energy prices and the enforcement of environmental policy are associated with higher innovation level. Both the stock of own knowledge and knowledge spillovers significantly contributed to inducing innovation. Lanzi and Ian Sue Wing (2010) investigate directed technical change in the energy sector through a dynamic model in which energy demand is satisfied with production derived from renewable and fossil-fuel energy. They establish a long-run relationship between relative energy prices and relative innovation in the two sectors, which is estimated using a panel of 23 OECD countries over the period

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[2] http://www.feem.it/getpage.aspx?id=138&sez=Research&padre=18&sub=75&idsub=102

[3] http://www.witchmodel.org/

1978-2006. We conclude that increase in the relative price of fossil-fuel energy leads to an increase in the relative amount of innovation in renewable technologies.

Augmenting general equilibrium models with these improved specifications of innovation dynamics with respect to energy and climate technologies is particularly interesting, as on top of the positive knowledge externalities associated with the innovative process, several negative environmental externalities characterize the way currently used to produce energy. Among the many works related to this, in Bosetti et al. (2011) it is analysed whether multiple policy instruments which can deal with the innovation and the climate externalities can bring about gains for efficiency and effectiveness.

A second issue of research is the diffusion of energy and climate-friendly technologies, both in terms of technology availability and in terms of deployment.

Although fast-developing countries such as China, Brazil and India are rapidly approaching the top innovators, innovation in energy technologies is concentrated in a few developed countries, which account for the majority of R&D spending worldwide. Conversely, in future years the increase in energy production will be mainly concentrated in developing countries. Reducing global CO_2 emissions will therefore not only require that developed countries adopt and diffuse low carbon technologies at home, but also that they promote the use of GHG-reducing technologies abroad (IEA 2010). Bosetti and Verdolini (2011) draw from recent contributions in the trade literature to model the incentives of heterogeneous innovating firms to transfer a blueprint/technology abroad. They test this model using data on patenting in efficiency-improving fossil fuel electricity production technologies in a sample of 40 countries. Particular attention is devoted to the role of environmental policy and Intellectual Property Right protection in determining the likelihood that foreign firms will enter a given market for technology.

Assessing the speed at which innovation translates in increased energy efficiency of production and/or in reduction in GHG emissions per unit of output is thus a crucial tassel in this line of research. Verdolini, Johnston and Haščič (2010) focus on the electricity sector and present a preliminary analysis of efficiency trends in the production of electricity from fossil fuels (FFs) across OECD countries. Notwithstanding the significant increase in the stock of innovation in efficiency-improving technologies, the overall efficiency of the power sector has increased very slowly in the past 25 years. This suggests the necessity to support the deployment of the (relatively) abundant technological know-how to overcome long-lived capital stock dynamics and sunk costs. Within this line of research, we are extending the study of energy intensity to other sectors with the aim of assessing how technological availability of low carbon technologies has impacted economic competitiveness and pressure on the environment. Answering these questions is crucial to substantiate the claim that eco-innovation can lead to improved productivity and improved environmental quality, namely sustainable development.

The third relevant line of research stems from the consideration that the availability of energy efficient and low carbon technologies does not necessarily translate in a reduction of emissions as there are rebound effects. Indeed, the natural prosecution of this line of work is to focus on how increased availability of efficient technologies, their transfer across national borders and the improvements in energy intensity translate in changes in total energy demand and CO_2 emissions. Increases in energy efficiency have historically been coupled with increases in energy consumption. As efficiency in the use of energy increases, the relative cost of energy with respect to other inputs falls. This change in relative prices induces substitution or behavioural shifts in the firms and consumers. Part of the potential saving from efficiency improvements are taken back in the form of higher demand for energy services (Herring 2006, Gillingham et al. 2009 among others). The magnitude of the rebound, or take-back, effect has important implications for on net effect on GHGs emissions stemming from the efficiency improvements.

A number of contributions argue that simple engineering calculations resulting from improved efficiency will overestimate the potential emission reductions resulting from these changes. On the one hand, GHGs per unit of consumption will be lower. On the other hand, the total number of units consumed might increase, and therefore the overall level of GHGs emissions might increase as well. Greening et al. (2000), Herring and Sorrell (2008) and Jenkins et al. (2011) provide reviews of the recent literature on the rebound effect highlighting the contributions with respect to assessing the direct, indirect and economy-wide rebound effects.

FEEM researchers are currently focusing their effort in two research topics:

i) *economy-wide rebound effect* analyzed through the computational general equilibrium ICES model and

ii) *empirical estimates of the rebound effect for consumers and the manufacturing sector in the EU*.

While the definition of these lines of research is at a preliminary stage, it was deemed of great importance to take part in the *Energy Efficiency Policies and the Rebound Effect* in order to present our intents, gain from the experience of other research groups working in this field, and obtaining fruitful insights.

With respect to *economy-wide rebound effect*, the implications feedback effects that may arise in the implementation of climate policies are investigated using the recursive dynamic CGE model (ICES) developed at FEEM. A crucial point in this respect is the way in which technical change (TC) is modelled, since this will affect the final estimates. In particular, while an exogenous path for technical change may provide a reasonable generalization of the way technology evolves in the future, it lacks the ability to simulate a behaviour induced by changes in prices due to certain policies or even changes in demand. Given that one of the main elements of a rebound effect is precisely the response to changes in demand and prices, considering an endogenous technical change specification constitutes an effective tool to advance in this kind of research and offer more reliable findings. For this purpose, a specification of biased endogenous TC based on a stock of knowledge that cumulates through investments in R&D has been developed. At present we have extended the global trade database (GTAP) on which the model is based upon in order to include these stocks of knowledge and we have modified the ICES model structure in order to account for this TC formulation. Estimation of the rebound effect is currently under way.

The second area of focus is the *empirical estimation of rebound effect for both consumers and industry*. Estimates with respect to consumers have been presented for the USA and for some European countries. Most analysis focusing on end-use energy services such as home heating and cooling, transportation and home appliances provide estimates in the range of 10-30% (see Greening et al. 2000 and Jenkins et al. 2011). However, most of these studies suffer from a series of shortcomings due to both limitations of data availability and the ability to successfully control for a number of "quality" changes that would affect estimates of the rebound effect. In addition, due to the micro focus of these studies, a number of countries and sector are yet not covered by the available empirical research.

Conversely, as pointed out by a number of review papers, the issue of rebound effect in the manufacturing sectors has been largely left unstudied and evidence in this respect is limited and characterized by a series of limitation, such as the focus on single firms and on short-run rebound estimates (Jenkins et al. 2011). Schipper and Grubb (2000) for example provide a descriptive analysis of energy use, intensity and activity trends in 13 IEA countries. This analysis does not ultimately assess the magnitude of rebound effects but only provides indirect evidence that actual rebound levels were less than 100%.

An exception in this respect is the recent contribution by Saunders (2011) which proposed a novel methodology to assess the rebound effect. Focusing on 30 producing sectors in the USA economy, he provides estimates of the rebound effect due to substitution in the range of 10 to 90%, with most sectors clustering around 20-50%. In addition, he estimates the rebound associated with increased demand for products, which in turn results from lower prices due to increased efficiency in the use of energy. Long-run output effects are generally in the range of 0-15%, with estimates in energy intensive sectors being as high as 20-30%. The substitution and output effects sum to a weighted average total direct rebound effect in the range of 20-60%, with higher estimates characterizing the more energy intensive sectors (as high as 120% for electric utilities).

The effort of FEEM's researchers is spent in two different directions. First, within the EUFP7 PURGE project (http://www.feem.it/getpage.aspx?id=3833&sez=Research&padre=18&sub=70&idsub=86&pj=Ongoing) the issues of rebound effects both at the consumer and at the industry level are investigated for both selected EU countries (Czech Republic, UK and Spain) and China. The project involves (1) collecting data on existing energy efficiency incentives (2) develop, test and administer surveys about energy efficiency decisions both in the residential, commercial and industrial energy consumers as well as the construction sector (3) model the data collected from the survey and (4) analyze energy use data to cast light on the issue of direct rebound effect. This will allow to collect novel microeconomic data that will allow to provide novel econometric evidence and fill some gaps in the literature. We also plan to complement this data source with additional surveys carried out at the European level. Furthermore, insights from behavioural economics could supplement the analysis, by providing a direct test of the demand response to policy in an experimental setting. A new experimental lab is being set up by the University of Venice in collaboration with FEEM, and could be used to perform such experiments.

Second, with respect to the production sectors, we plan to build on the work by Schipper and Grubb (2000) and Saunders (2011). With respect to Schipper and Grubb analysis, we are planning to include more countries (possibly some fast developing economies) and 10 years of additional data. While such an analysis will not provide an estimate for the rebound effect, it will inform on a number of trends across developed and developing countries. This preliminary phase will also serve as an exploration and data collection phase. Particular attention in this respect will be paid not only to the economy as a whole, but also at strategic energy intensive sectors such as electric utilities.

Third, given the novelty and strengths associated with Saunders' (2011) analysis and the fact that the author has given access to the modules used to perform his analysis, we would like to extend his results to EU countries. We have started a data collection analysis to assess whether an appropriate database can be built for the major EU countries. Extending Saunders to EU countries will provide two important insights. First, it will validate the performance of Saunders' methodology also with respect to EU countries. Second, it will provide comparable estimates for the rebound effect in countries other than the USA. This analysis has also important repercussions at the policy level since the European Commission has listed energy efficiency as a top priority of its energy roadmap.

In addition to the abovementioned work, we would like to address a number of questions that are likely to be very significant especially with respect to econometric analysis of the rebound effect:

1. The discussion of rebound effects and the resulting CO2 emission dynamics is in our opinion strictly linked with the issue of directed technical change and the substitution between clean and dirty energy sources. While the issue of capital and energy substitutability has been widely addressed (albeit providing a wide range of results), the substitutability between clean and dirty energy input and its consequences for the relevance of rebound effect dynamics appears to us as not yet widely discussed.
2. If energy efficiency programs and goals are accompanied by other types of environmental/energy policy aimed at supporting renewable energy source, the impact of rebound effect on CO2 emissions is likely to differ significantly. Promoting renewable source or establishing a price on carbon will lead to a change in the composition of the energy mix. Renewable sources will provide a higher share of TPES but will not increase the CO2 emissions associated with energy production. As a result, the link between increase in energy use and increase in carbon emissions might not be as tight.
3. In addition to considering domestic rebound dynamics, the problem should be addressed at the international level. Energy-using products are often traded at the international level, and rebound effect dynamics are likely to arise even as a result of changes in the price of imported energy services, goods and production technologies.

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