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ECONOMY-WIDE REBOUND EFFECTS FROM AN INCREASE IN EFFICIENCY IN THE USE OF ENERGY: THE ITALIAN CASE

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Economy-wide rebound effects from an increase in efficiency in the use of energy: the Italian case

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Abstract

The International Energy Agency (IEA, 2009) suggests the importance of efficiency improvement to reduce energy use and, within the European Union, one of the targets for member states is to reduce energy consumption by 20% through increased energy efficiency (European Commission, 2009). Energy efficiency improvement has the unquestionable benefits to reduce the price of energy services. However, it is still under debate the extent to which, improvement in the productivity of energy, is effective in terms of reducing the consumption of energy and thus the associated negative externalities (e.g., carbon dioxide emissions, CO2). Thus, policy makers are particularly interested to determine the size of the energy rebound effect. In this paper, we attempt to quantify the magnitude of the general equilibrium rebound effects from an increase in energy efficiency in the industrial use of energy in Italy. To this end, we use a large-scale numerical dynamic general equilibrium model calibrated using the Italian Social Accounting Matrix for the year 2010.

Keywords: rebound effect, energy efficiency, CGE model.
Jel classification: C68, D57, D58, Q43, Q48.

1. Introduction

By 2030 energy efficiency gains will reduce global energy consumption to approximately 30% below where it would otherwise be (Intergovernmental Panel on Climate Change of the United Nations, IPCC, 2007). The International Energy Agency (IEA, 2009) details the importance of efficiency improvement to reduce energy use and, within the European Union, one of the targets for member states is to reduce energy consumption by 20% through increased energy efficiency (European Commission, 2009).

The importance of energy efficiency policies is made clear by the European Economic and Social Committee (EESC), which states that "the increase in energy demand despite energy efficiency policies and measures will be one of the biggest challenges facing EU energy policy". However, the relation between increased energy efficiency and reduced energy consumption has been questioned due to the rebound effect.

From a simple engineering perspective, a given increase in energy efficiency would generate a reduction of energy consumption by the same amount. However from an economic perspective, an increase in efficiency will also reduce the price of energy in efficiency units with consequent substitution and income effects. Thus in the energy economic literature it is now widely accepted that the response to the introduction of new technologies aimed to save energy consumption is likely to be partially (or totally) offset by the demand response to a reduction in the effective price of energy services (or by the reduction of the price of energy in efficiency units). This is what is known as the rebound effect, initially identified[1] by Jevons (1865) and subsequently by Khazzoom (1980).

The improvement in energy efficiency stimulates demand for energy in production and/or consumption by reducing the price of effective energy services for each physical unit of energy used. The price reduction leads to different but related macroeconomic effects (such as positive substitution, output, competitiveness, etc.) that act to offset the decreases in energy consumption derived from the pure sufficiency effect.

According to Greening et al. (2000) and Barker et al. (2007), the rebound effect can be further classified as direct, indirect and wide general equilibrium rebound effects. Direct rebound effects are generally associated with substitution effects while indirect rebound effects are related to income/output effects. The economy-wide rebound effects correspond to new technologies that create new production possibilities and increased economic growth. In this paper we focus primarily on the economy-wide or general equilibrium rebound effects[2].

It is clear that the rebound effect appears to be general rather than partial equilibrium in nature and its magnitude depends on the price response of direct and indirect energy demands. For this reason, computable general equilibrium models (CGE) have been used to analyse the economy-wide impact of energy efficiency improvements. In addition, since an efficiency improvement leads to a change in the production structure of the economy, any analysis of the impact will be incomplete without a thorough analysis of the supply-side effects.

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[1] See also, Jevons,1865; Khazzoom, 1980; Brookes, 1990; Saunders,1992, 2000; Schipper, 2000

[2] "Economy-wide rebound effects represent the net effect of a number of mechanisms that are individually complex and mutually interdependent" Sorrel (2007).

Economy-wide rebound effects have been extensively analysed for energy efficiency improvements that occur within production especially using computable general equilibrium (CGE) modelling frameworks (see Dimitropoulos, 2007, for a review). However, to the best of our knowledge there are no studies that attempt to measure the economy-wide impacts of increased energy efficiency for the Italian economy.

Thus, we investigate and quantify the general equilibrium rebound effects using an inter-temporal, dynamic, multi-sectoral general equilibrium model developed for the Italian economy where dynamics arise from consumption and investment decision of forward looking economic agents; households and firms respectively. The model allows for labour market imperfections through a bargaining real wage equation (Blanchflower and Oswald, 1994). Furthermore, the decisions of savings are separated from investment decision following the skeletal neoclassical growth model of Abel and Blanchard (1983). We consider four energy sectors in the model: coal, oil, gas and electricity. Thus, we can analyse total energy rebound and energy rebound related to different type of energy source.

The remainder of the paper is structured as follows. Section 2 reviews the relevant works on rebound effect analysed in a general equilibrium context and in Section 3 the model developed for Italy is described. In Section 4 we present and discuss the results of the simulations. In Section 5, a sensitivity analysis of the size of the rebound effect under different production function specification is carried out. Finally, we summarize the main conclusion and possible directions for future research in Section 6.

2. Review of evidence for rebound effect.

By and large we can identify seven general equilibrium effects following an improvement in efficiency in the use of energy: i) an engineering or pure efficiency effect; ii) a substitution effect; iii) an output/competitiveness effect (positive supply-side effect); iv) a compositional effect and v) an income effect on households (UKERC[3], 2007). Recent works (Allan et al., 2007 and Turner, 2009) identify two more, supply-side, effects: a negative multiplier effect (energy demand falls) and, finally, a disinvestment effect.

The two supply side effects play an important role in determining the magnitude of the rebound in the short and long-run. Saunders (2007) argues that long run rebound has to be greater than that in the short run because fixed supply in the short-run constrains the rebound in this period. However Turner (2009) show that the long run rebound can be lower than the short run.

Turner (2009) points out that in the in the work of Saunders the fixed capital rental rate prevent negative multiplier effects in the energy sector to arise. According to Turner (2009) with endogenous capital rental rate disinvestment effects may occur in the long run putting downward pressure on the rebound in this period. Thus, potential disinvestment effects might cause short-run rebound to be greater than the long run although the presence of economic growth.

The rebound effects estimated using numerical dynamic general equilibrium models vary widely in the literature. The reason for this rests on the structure of the KLEM

[3] United Kingdom Economic Research Centre.

production function, the price elasticity of energy demand in production, wage settings and treatment of capital market.

For instance in Semboja (1994), a study applied to Kenya, electricity, other fuels, capital and labour are combined together in a composite that in turns substitutes with material inputs. The productions functions used are Cobb-Douglas and Leontief. As for the capital market, investment demand is treated as a fixed proportion of aggregate investment, allocated to the expansion of capital stock by sector. In the paper there is no discussion of labour market features. Disturbances take the form of an improvement in energy production efficiency (an increase in TFP in the energy sector) and an improvement in efficiency in the use of energy, which lead to an estimated rebound effect greater than 100% (backfire effects).

Glomsrød and Taoyuan (2005) study the rebound effect in China. Value added is the result of energy, capital and labour combine together using a Cobb-Douglas function. Total investments are savings driven and their sectoral allocation is based on sectoral share of total capital in the base year. Labour market is modelled with exogenous real wage with fixed labour supply. The energy efficiency improvement enters in the model by comparing business-as-usual dynamic scenario and a case where costless investments generate increased investments and productivity in coal sector, lowering price and increasing supply of cleaned coal. As with Semboja's work, the rebound in this case is more than 100% as well. A characteristic of this work is that the paper examines also the case in which the use of coal is subject to emission tax.

Vikstrom (2004) analyses rebound in Sweden adopting a nested CES production function approach where capital and energy combine together at the lower nest and then, this composite is combined with labour. The values range used for the elasticity of substitution is from 0.07 to 0.87. Accumulation of capital is not explicitly treated in this model. Savings are allocated to investments and their sectoral composition is allocated in line with a benchmark data set. Labour supply is fixed. The disturbance is a single simulation with 15% increase in efficiency of use of energy of non-energy sectors and 12% increase in efficiency of use of energy in energy sectors. Rebound values range from 50% to 60%.

Grepperud and Rasmussen (2004) in their analysis of the rebound effect for the Norwegian economy use a nested CES production function as in Vikstrom (2004). The elasticity of substitution between energy and capital differ between sectors. The model is shocked by doubling annual average growth rates of energy productivity at the sectoral level. In particular, the model considers six sectors, four where the electricity efficiency doubles and two where the oil efficiency doubles. With regard to rebound estimates, Oil sectors generally show small rebound, while rebound and backfire effects are found in electricity efficiency improving sectors.

In his study for Japan, Washida (2004) used a multi-level CES function in which value added is obtained by capital-labour composite combined with energy and the constant elasticity of substitution between energy and value added is set to 0.5. With regard to the capital closure, investment demand is included with government expenditure, firms demand for capital depends on cost of capital and the aggregate capital stock is kept fixed. The labour market is modelled with fixed aggregate supply of labour. The shock consists of a 1% change in the efficiency factor for use of energy in production in all modelled sectors. In the central simulation the rebound effect estimated is around 53%. Furthermore the paper shows that rebound effect increases as energy/capital-labour, labour/capital and level of energy composite substitution elasticities increase.

Finally, Allan et al. (2006), Hanley et al. (2005) and Turner (2009) use a similar model, which is a variant of the AMOSENVI and UKENVI4 model to investigate the rebound effect in Scotland and UK respectively. The production of gross output is obtained by combining value added (capital and labour) and intermediate inputs which in turn are a CES combination between Energy and Material. The elasticity of substitution between energy and material is set to 0.3. The capital closure consists of a period-by-period capital stock updating in line with difference between actual and desired capital stocks; when desired and actual capital stocks are equal to those required by the economy for long run equilibrium. Labour market imperfections are modelled via a bargained real wage equation (Blanchflower and Oswald, 1994). They simulate a 5% improvement in efficiency of energy use across all production sectors (including energy sectors). The magnitude of the rebound is greater than 100% for Scotland and 37% for the UK.

3. The Model for Italy

3.1. General model features

As mentioned above, in this work we analyse and quantify the impact of an efficiency improvement in the industrial use of energy in Italy. The analysis is performed by using a numerical general equilibrium model.

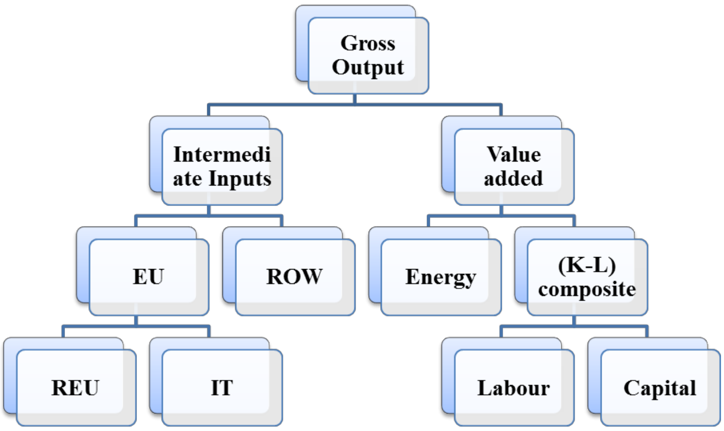
The model's dynamic structure allows us to model agents with either forward looking or myopic expectations. In the second case, the structure and the dynamics of the model are recursive (or can be solved simultaneously maintaining the absence of forward-looking agents' behaviour) and agents use adaptive expectation abstracting from future periods. In the rational expectation case, where all periods of the model have to be solved simultaneously, firms and consumers have perfect foresight and react to anticipated future events. The model incorporates 21 industries, 4 of which are energy sectors (Coal, Oil, Gas and Electricity)[5]. With regard to the production side, it is characterized by cost minimization with standard production functions. Firms sell output in competitive markets. In the simulations carried out throughout, the work wage setting follows a bargaining procedure where the real wage is inversely related to the unemployment rate.

3.2. Production structure

The production structure of the model is represented by a nested production function reported in Figure 1[6]. Three institutional sectors (firms, households and government) and two external sectors (rest of Europe, ROE and rest of the World, ROW) are considered.

[4] A micro macro model for Scotland plus environment and UK environmental model.
[5] The structural breakdown is reported in Table 1.
[6] Figure1 refers to the production structure specification used in the Central Case Scenario.

Figure1. The model's production structure



Value added is given by a CES combination of energy and capital and labour composite. First order conditions of profit maximisation provide the demand equations for these inputs. The gross output is obtained by value added and the intermediate inputs combined in a Leontief technology production function. Intermediate inputs can be purchased in the domestic market or imported from the Rest of Europe (ROE) and from the Rest of the World (ROW). Regional and imported goods are combined under the so called Armington assumption through a CES function with intermediate goods produced locally or imported considered as imperfect substitutes.

Finally, each economic sector considered produces goods and services that can be sold in the national market ore exported. Thus, an export demand function closes the model where the foreign demand for Italian goods depends on the terms of trade effect and on the export price elasticity.

3.2.1 Introducing Energy to KLEM nested production function

We use the well-known KLEM approach and Energy is treated as a component of the Value Added. As pointed out in Lecca et al. (2011), the use of nested CES production function is common in studies that use KLEM production function (Chang, 1994; Kemfert, 1998; Kemfert and Welsch, 2000; Kuper and Van Soest, 2002; Prywes, 1986).

Figure 1 implies that:

$$KLEM_i = \left[\alpha_{(KL)EM,i} KLE_i^{\frac{\sigma_{(KL)EM,i}-1}{\sigma_{(KL)EM,i}}} + (1-\alpha_{(KL)EM,i}) M_i^{\frac{\sigma_{(KL)EM,i}-1}{\sigma_{(KL)EM,i}}} \right]^{\frac{\sigma_{KLEM,i}}{\sigma_{(KL)EM,i}-1}} \tag{1}$$

$$KLE_i = \left[\alpha_{(KL)E,i} KL_i^{\frac{\sigma_{(KL)E,i}-1}{\sigma_{(KL)E,i}}} + (1-\alpha_{(KL)E,i}) E_i^{\frac{\sigma_{(KL)E,i}-1}{\sigma_{(KL)E,i}}} \right]^{\frac{\sigma_{KLE,i}}{\sigma_{(KL)E,i}-1}} \tag{2}$$

$$KL_i = \left[\alpha_{KL,i} K_i^{\frac{\sigma_{KL,i}-1}{\sigma_{KL,i}}} + (1-\alpha_{KL,i}) L_i^{\frac{\sigma_{KL,i}-1}{\sigma_{KL,i}}} \right]^{\frac{\sigma_{KL,i}}{\sigma_{KL,i}-1}} \tag{3}$$

Where K, L, E, M are capital, labour, energy composite goods (Coal, Oil Gas, Electricity) and intermediate inputs respectively. KL and KLE are capital labour composite and capital-labour energy composite. σ is the elasticity of substitution and it assumes different values at each nest[7].

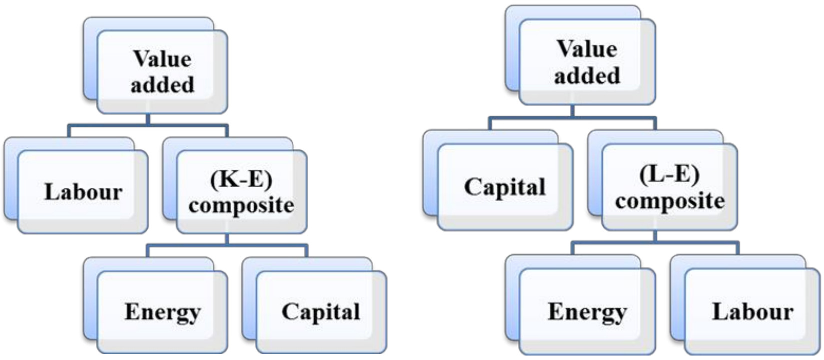
There is still a debate on the appropriate specification of the KLEM production function, in particular on how energy should combine with other inputs since, as demonstrated in Lecca et al. (2011), different combinations of the KLEM production function specification can lead to different estimates of the size of rebound. Thus, in order to show the importance of the separability assumption, we perform a sensitivity analysis by changing the structure of the production function itself and calculating (under the same disturbance) the size of the rebound in the case of Energy combined with Capital (Case A) or Labour (Case B), as shown in Figure 2.

Essentially, we modify the way in which value added is obtained: KL composite and E in the central case, KE composite and L in case A and, finally, LE and K in the last case (B).

[7] See paragraph 3.6

Figure 2. Alternatives KLEM production function specification.

Case A. Energy in Value-Added – (KE) +L   *Case B. Energy in Value-Added – (LE) +K*



3.3. Consumers

Following Go, 1994 and Devarajan et al., 1998, the representative consumer maximizes his discounted Utility (U) of aggregate consumption, as summarized by the lifetime utility function which takes the following form:

$$Max\sum_{t=0}^{\infty}(1+\rho)^{-t}\frac{C_t^{1-\nu}-1}{1-\nu} \tag{4}$$

Where C is the consumption at time period t, ν is the constant elasticity of marginal utility[8] and ϱ is the constant rate of time preference. It is a homogeneous utility function, additively separable and U is discounted by the consumer's constant and positive rate of time preference. The dynamic budget constraint takes the form:

$$\dot{W} = Y_t + r_t W_t - Pc_t C_t \tag{5}$$

Where

$$\mathrm{W_t} = FW_t + NFW \tag{6}$$

Y is the current income, W is wealth, financial (FW) and non-financial (NFW) wealth. In particular, FW is defined as the present value of the future capital income and NFW as the discounted labour income after tax plus net transfers from government.

The budget constraint ensures that the discounted present value of consumption must not exceed total household wealth (W). Once the optimal path of consumption is obtained from the solution of the inter-temporal problem, the aggregate consumption is

[8] In the model, its value is set to 1.2. Note that we do not test the sensitivity of our results to different constant elasticity of marginal utility since in the long run (steady state) the consumption rate is constant. Indeed, the time path of consumption to the long run equilibrium would be different for different elasticity values.

allocated between sectors through a constant elasticity of substitution (CES) function. Household demand for regional and imported goods is the result of the intra-temporal cost minimization problem and similar to the production side, domestic and imported commodities are imperfect substitutes.

3.4. Investment

Investment decision is modelled following the works of Abel (1980) and Hayashy (1982). The rate of investment is a function of marginal q (or average q) defined as the ratio of the value of firms (VF) to the replacement cost of capital (Pk·K). The path of investment is obtained by maximizing the present value of the firm's cash flow given by profit (π) less private investment expenditure, subject to the presence of adjustment cost g where:

$$\text{Max } \sum_{t=0}^{\infty} \frac{1}{(1+r)^t} \left[\pi_t - I_t(1 + g(x_t))\right] \qquad \text{subject to } \dot{K}_t = I_t - \delta K_t \qquad (7) – (8)$$

The solution of the dynamic problem gives us the law of motion of the shadow price of capital, and the time path of investment related to the tax-adjusted Tobin's q (Tobin, 1969). Moreover, since adjustment cost g is quadratic, the direct implication is that firms are unable to achieve the desired stock of capital immediately.

3.5 Labour Market

The labour market is characterized by imperfect competition, the wage rate is not obtained by the first order condition but it is determined through a wage bargaining function (wage curve) as in Blanchflower and Oswald (1994) according to which real wages and unemployment are negatively related:

$$\ln(W_t) = \beta_u - \mu * \ln(u_t) \qquad (9)$$

Where W is the consumption wage defined by the ratio w/cpi (cpi is the price consumer index), β is the value at the steady state, μ is the elasticity (of wages) and it is related with regional unemployment rate (u). The wage-unemployment elasticity is -0.03 as estimate in Devicienti et al., 2008. Indeed, this closure implies wages flexibility so that they respond to the local excess demand for labour. There is no change in natural population.

3.6 Dataset and model parameterization

The benchmark data set is the Italian Social Accounting Matrix (SAM) for the year 2010 developed by us through the make and use tables provided by ISTAT (2010). Data related on energy consumption by industries and final consumers were provided by ISTAT (2014). The Table below reports energy use for four types of fuels in million tons of Oil Equivalent (TOE).

Table1. Energy consumptions for four types of fuels. Millions of Tons of Oil Equivalent (TOE).

	COAL	OIL	GAS	ELECTRICITY
Agriculture, forestry and logging	0,000	2,378	0,140	0,396
See fishing and See firming	0,000	0,225	0,000	0,033
Mining and extraction	0,000	0,234	0,068	0,147
Mfr food, drink and tobacco	0,210	0,488	2,334	1,040
Mfr textiles and clothing	0,043	0,425	1,619	0,652
Mfr chemicals etc	0,873	4,624	7,066	3,430
Mfr metal and non-metal goods	7,260	4,105	7,293	3,202
Mfr transport and other machinery, electrical and inst eng	0,041	0,932	1,572	2,222
Other manufacturing	0,003	0,167	0,145	0,249
Water	0,000	0,015	0,000	0,506
Construction	0,001	4,611	0,120	0,137
Distribution	0,004	5,746	0,783	2,627
Transport and Communications	0,011	15,041	0,165	1,236
finance and business	0,000	0,250	0,066	0,201
R&D	0,001	1,994	0,257	1,177
Education	0,000	0,138	0,337	0,128
Public and other services	0,975	1,795	1,214	1,329
COAL (EXTRACTION)	0,000	0,000	0,000	0,000
OIL (REFINING & DISTR OIL AND NUCLEAR)	0,845	99,797	2,557	0,489
GAS	0,000	0,039	0,001	0,000
Electricity	9,460	9,182	25,660	3,520

Source: our elaboration on data provided by ISTAT, 2014

With regard to the parameters of the model, most of them are obtained from the SAM by the well-known calibration method. However some behavioural and structural parameters are based on econometric estimation or best guesses.

For all the simulations carried out in section 5 and for all sectors considered, the elasticity of substitution between primary factors of production (KLE) are taken from the work of Van Der Werf (2008) who estimates these values also for Italy[9] and where the test for common elasticity over the two nests leads to the result that the production function for ITALY could not have a single elasticity of substitution and hence it has to be nested.

Furthermore, following Sorrel (2008), one of the most important criticism moved to the CGE models results is that, often, they are very sensitive to the best guess estimations of elasticity of substitution that, in turn, are estimated using different production function specification, trans-log or Cobb-Douglas for example. Instead, Van Der Werf elasticity are estimated using all the three nested KLE-CES production functions specification we used in this work so that we can overtake the problem above. In Table 2 elasticity values are shown[10].

[9] To the best of our knowledge, there are no other econometric estimations of this elasticity for Italy.
[10] In table 2 we named Central Case the value added specification depicted in Figure 1. In fact, with regard to energy-climate CGE models, the (KE)L form is employed by Burniaux and Truong (2002) (the GTAP–E model) and Van der Mensbrugghe (1994) (the GREEN model) but, (KL)E form appears to be more popular and is used, between others, in Bosetti et al. (2006) (the WITCH model), Manne et al. (1995) (the MERGE model), Paltsev et al. (2005) (the EPPA model) and Takeda (2005).

Table2. Elasticity of substitution used in the value added nested CES production function.

Central Case	*Case A*	*Case B*
$\sigma_{(KL)E} = 0.2417$	$\sigma_{(KE)L} = 0.9218$	$\sigma_{(LE)K} = 0.4651$
$\sigma_{KL} = 0.5216$	$\sigma_{KE} = 0.9799$	$\sigma_{LE} = 0.8037$

4. Simulation set up and results discussion.

The disturbance simulated is an exogenous and costless improvement of 1.014% in the efficiency of energy inputs used by all production sectors (use-efficiency shock). The size of the shock is determined according to the rates of factor-specific technological change for Italy estimated by Van Der Werf (2008) for the production structure we used.

We perform the shock as one-off step change in energy efficiency use[11]. Thus, a positive supply-side disturbance is introduced which would be expected to reduce the price of energy measured in efficiency units, the price of outputs and, in turn, stimulating economic activity. In other words, for each sector, there is a 1.014% increase in the efficiency with which energy combines (for the Central Case) with the KL composite to produce value added.

The resulting changes in key energy and economic variables due to the shock are reported, unless otherwise specified, in terms of the percentage change from the base year values given by the 2010 Italian SAM. Moreover, the economy is calibrated to be in long-run equilibrium so that we are able to run the model forward in the absence of any disturbance in order to replicate the base year dataset in each period. We refer to percentage changes in the endogenous variables relative to the initial steady state equilibrium; hence, all the effects detected can be directly attributed to the stimulus to energy efficiency use.

Two time frames are considered: short run and long run. We refer to the short run as the first period (year) after the efficiency policy implementation and supply constraints (capital stocks are fixed at their base year values) are imposed. Conversely, in the long run, constraints are removed and capital stocks adjust fully to their desired sectoral values, given the efficiency shock and a fixed interest rate. In the next paragraph, results for the central case scenario are discussed and, in the subsequent paragraph, a comparison of the estimated rebound size obtained with the alternative KLEM production function (Figure 5) is made.

Moreover, In Van der Werf (2008), the goodness of fit of the nesting structures (KL)E, (KE)L and (LE)K) was investigated and, based on the R-squared, Van der Werf concluded that the (KL)E structure mostly fits the data. Moreover, the work of Medina and Cervera (2001), where a trans-log cost function is estimate for Italy and Spain, concludes that only for Italy, there is an higher substitution of labor in favor of energy (confirmed also by the values estimated in Van Der Werf, Table 2.). Thus, the reason to include also this specification.

[11] Note that in our analysis, we apply the efficiency shock not only to the use of domestically supply energy (as in the Turner (2007), Allan et al. (2006)), but also on imported energy inputs. Thus, we can expect that simultaneous efficiency improvements in imported energy might lead to even higher economy-wide rebound impacts because there will be a stronger decline in the actual prices of energy than that when productivity improvements occur only in domestic production.

4.1. Central Case Scenario results

We present the results for the central case scenario (CCS). The characteristic of this shock is such that the increase in efficiency introduces a positive supply-side disturbance, whose primary effect is to raise production efficiency, particularly in energy intensive sectors. The efficiency gains stimulate economic activity through downward pressure on the prices, including the price of energy output since the energy supply sector itself is typically energy intensive.

The energy efficiency improvements increases generate an increase in economic activity from the outset. GDP increases by 0.06% and 0.19% in the short and long-run respectively. Employment rises in both periods by 0.06% and 0.13%[12]. In the long run, changes in employment are lower than the GDP reflecting an increase in the capital-labour ratio. The increase in efficiency in the industrial use of energy reduces the price of energy, measured in efficiency units, which in turn tend to lower the price of output (and commodities) not only in the energy sector (see Figure 3). This stimulates competitiveness with additional effect on economic activity. Total exports increase in all sectors, especially in the energy intensive sectors through a reduction in their relative price.

In the short and long run total import of goods and services are below their steady-state values. This drop in imports can be explained by the fall in the price of locally produced goods relative to the price of goods and services imported from the ROE and ROW. This also means that the relative price effect dominates the positive stimulus that arises from the expansionary effect on the economic activity. Both in the short and long-run, real wages rise since the increase in energy efficiency stimulates labour demand, increasing the bargaining power of workers that now can claim for more real income.

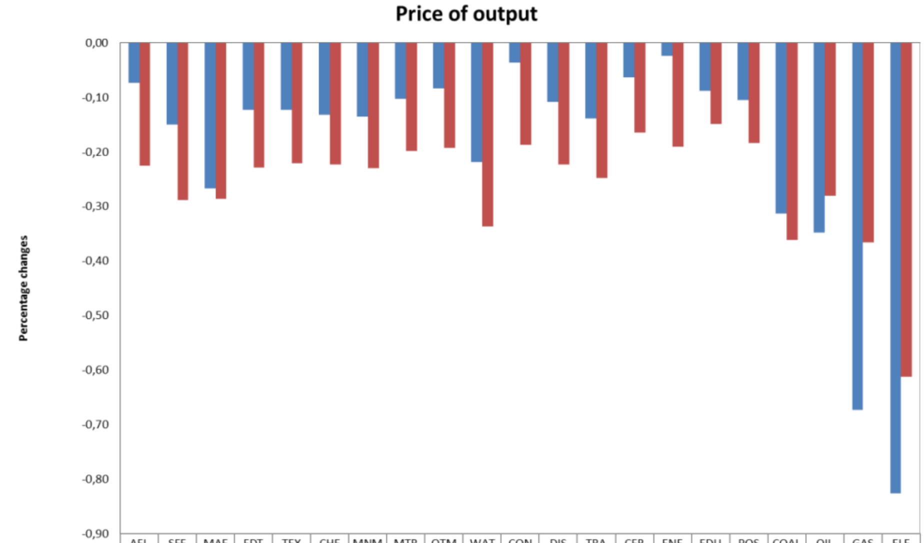
From Figure 3, where the impact on output price is shown, sectoral differences that generally reflect the energy intensity of the sector are immediately clear. In the long run, prices in the manufacturing (no chemicals or metals) and essentially service sectors show a smaller decrease, reflecting the relatively low use of energy inputs in these sectors; the largest impact on the price of output, generally, comes in the four energy sectors themselves both in the short and long run. This is the result of the production techniques in these sectors. The largest reductions in price occur in electricity and gas sectors. In these sectors together with oil sector, the fall in the long run price is smaller than the short run one; coal sector, however show the opposite due to demand effect, i.e. the exports increase. In Figure 4, we show the short and long run sectoral changes in output. As one would expect, the increased efficiency in energy use has increased the output of all non-energy sectors with the exception of mining sector. In the education and public services sectors, output increase is smaller than the other non-energy sectors reflecting their lower energy intensities.

On the other hand, the output of the four energy sectors falls in both the short and long run, and, long run reduction is greater for Electricity and Gas sectors. As regard to the Coal and Oil the large reduction in price in the short run go to offsetting the fall in demand that occurs in the short run. However, note that in both the short and long run, the reduction in output is less than the 1.014% improvement in energy efficiency use. Coal is the exception and it can be explained looking at the very low industrial demand for coal (See

[12] See table 4

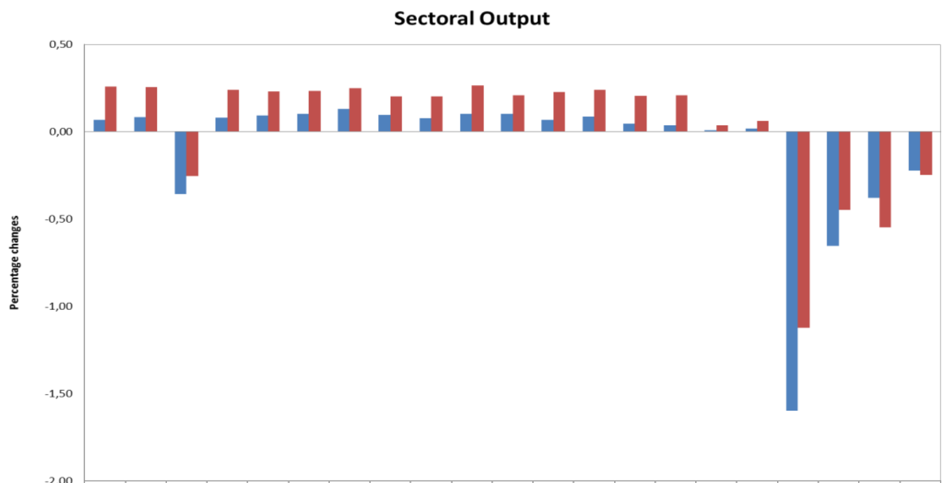
table1) where the efficiency improvement has a stronger impact on this sector. In the next section, the rebound effect raised from the disturbance is described.

Figure 3. Percentage changes in price of output in Italian production sectors in response to a 1,014% increase in energy efficiency in all sectors



	AFL	SFF	MAE	FDT	TEX	CHE	MNM	MTR	OTM	WAT	CON	DIS	TRA	CFB	ENE	EDU	POS	COAL	OIL	GAS	ELE
Output price SR	-0,07	-0,15	-0,27	-0,12	-0,12	-0,13	-0,14	-0,10	-0,08	-0,22	-0,04	-0,11	-0,14	-0,06	-0,02	-0,09	-0,10	-0,31	-0,35	-0,67	-0,83
Output price LR	-0,23	-0,29	-0,29	-0,23	-0,22	-0,22	-0,23	-0,20	-0,19	-0,34	-0,19	-0,22	-0,25	-0,16	-0,19	-0,15	-0,18	-0,36	-0,28	-0,37	-0,61

Figure 4. Percentage change in output in Italian production sectors in response to a 1,014% increase in energy efficiency in all sectors



	AFL	SFF	MAE	FDT	TEX	CHE	MNM	MTR	OTM	WAT	CON	DIS	TRA	CFB	ENE	EDU	POS	COAL	OIL	GAS	ELE
Output SR	0,07	0,08	-0,36	0,08	0,09	0,10	0,13	0,10	0,08	0,10	0,10	0,07	0,09	0,05	0,04	0,01	0,02	-1,60	-0,65	-0,38	-0,22
Output LR	0,26	0,25	-0,26	0,24	0,23	0,23	0,25	0,20	0,20	0,26	0,21	0,23	0,24	0,20	0,21	0,04	0,06	-1,12	-0,45	-0,55	-0,25

4.1.1 Italian Economic wide-rebound effect

There is evidence of economy-wide rebound effects[13] after the improvement in efficiency in the energy use: 20.6% in the short run and 26% in the long run. In other words, after the disturbance simulated, from a general equilibrium perspective, does not correspond a reduction of energy consumption of the same size (the pure engineering effect).

However, for this production function specification the magnitude of the rebound for Italy is quite small when compared with those found in other empirical works. However, sensitivity analysis is required to test the robustness of the findings.

As pointed out in section 2, rebound effects may arise from the more efficient use of energy and different and related effects determine them. Firstly, the efficiency effect takes place since energy demand falls because a lower amount of energy input is necessary to produce a given level of output. Secondly, the price of using energy relative to other inputs falls, inducing a positive substitution effect in favour of energy. Thirdly, there is a change in the composition of output at the aggregate level since the more energy-intensive products benefit most from the fall in energy prices (actual and/or current): composition effect.

Figure 4, in fact, shows that in the more energy intensive sectors there are larger increases in output in the long run. Also, as in the previous section, output price falls in all sectors directly involved by the disturbance, (all sectors here) so that there is an increase in economic activity and associated energy use that leads to increase exports (competitiveness effect). Finally, the income effect: incomes increase and have a further positive impact on production and consumption activity levels, including energy use.

Moreover, where energy is locally produced and is an input to energy production itself, as in the case of Italy, there are two additional effects (supply side response to the disturbances that take place). We discuss them in turn; a negative multiplier effect (Turner, 2009) and the disinvestment effect (Allan et al., 2007). The former arises from the reduction in energy demand, -0.95% in the short run and -0.91% in the long run, caused by the improvement in energy efficiency and, if it is strong enough to "entirely offset increased energy demand at the macro-level", there is a negative economy-wide rebound effect (Turner, 2009. We find such a result in the case of Coal and Oil in the short run, -39% and -20% respectively.

The second effect arises from the initial reduction in demand for the output of energy suppliers sectors, which causes a contraction in the market price as confirmed by the fall of output shown in Figure4. Thus, if disinvestment effect is large enough, short run rebound may be greater than long run rebound as pointed out in the analysis carried out for the UK economy (Allan et al., 2007 and Turner, 2009).

Such a result is the opposite of what we have obtained but in line with the theoretical provision of Saunders (2007) who argues that, where supply side constraints are removed long run rebound is larger because of economic growth. Looking at the sectoral rebounds (Table 3), in the case of gas there is evidence of a long run rebound (26.6%) smaller than the short run (39.5%) one, so that the long run disinvestment effect in this case is large enough to constrain the related long-run rebound effect. As regard to the Electricity we obtain the same size of rebound for both time periods (around 60%) and the fall in

[13] Note that in in this analysis we divided the economy wide rebound effect in sectoral specific rebound: coal, oil, gas and electricity (Table 3).

output is almost the same for both time frames; hence, the explanation of our results arise from Coal (-40% in short run and 2% in long run) and Oil (-19% and 15% in long run) sectors behaviour; firstly, the very high negative multiplier effect in Coal and Oil sector. Thus, the explanation of these results can be found in the export orientation of Italian energy suppliers.

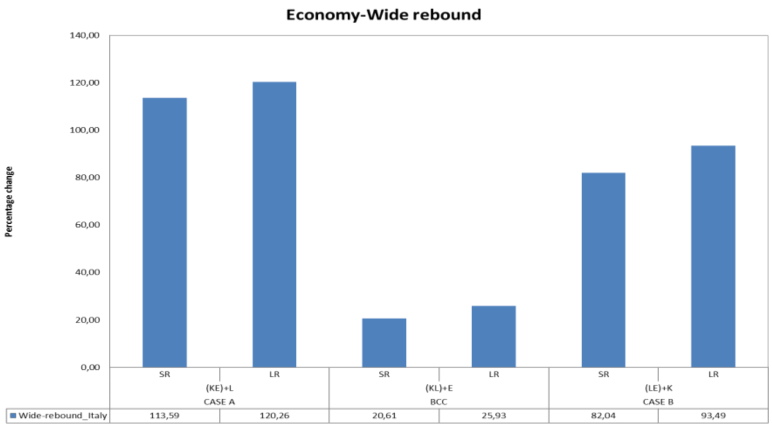
Table 3. Economy-Wide Rebound. Base Case Scenario percentage changes.

	SR	LR
Economy-wide rebound	20,61	25,93
Coal	-39,6	1,773
Oil	-19,2	15,32
Gas	39,53	26,64
Electricity	59,33	60,84
Energy output	-0,49	-0,49
Total Energy demand by industries	-0,95	-0,91

4.2. Alternative KLEM specification, Case A and Case B.

We start considering the estimated size of the rebound effect obtained modifying the way in which valued added composite is obtained, bearing in mind that the disturbance simulated is the same as in the CCS. In Figure 5, we see that, compared to the CCS, Case A and Case B show a very high rebound effects. For case A the rebound effects is above 100% (backfire effect): 114% and 120% in the SR and LR respectively. The reason why for Case A we obtain such a huge rebound effect is the positive change in domestic energy consumption and total energy demanded by industry as we show in Table 4. Consequently, also energy and non-energy output increase (0.26% and 0.21% in the LR, respectively).

Figure 5. Economy-Wide Rebound. Central Case Scenario, Case A and Case B percentage changes.



On the other hand, if we look at the Case B, we find LR rebound effects very close to 100%, situation in which the efficiency gains are completely offset by the increased demand for energy and, in fact, domestic energy consumption in the LR in quite similar to steady-state, only 0.05% above (Table 5).

In terms of economic growth (GDP), in the LR, we have the lower value (0.19%) in the CCS and the higher in Case A and B, 0.22% and 0.23% respectively. Clearly, one has to be very carefully in analysing these figures since we are comparing not only results derived from different Value added specification but, more important, at each nest, we set the elasticity of substitution estimated in Van Der Werf (2008) for the corresponding KLE combination and their values range are from 0.24 to 0.98[14]. In fact, as pointed out in the conclusions drawn by previous theoretical analysis (Sorrell, 2007, and Sounders, 2008) the role played by these elasticities is the most important in determining the size of rebound effects.

Thus, in the next paragraph we conduct a sensitivity analysis on CCS, Case A and Case B in order to discuss the role played by both the elasticity of substitution between factors and, also, if the different KLE specification can lead to different results.

Table 4. Summary impacts in percentage changes from the initial steady state.

	CASE A (KE)+L		CCS (KL)+E		CASE B (LE)+K	
	SR	LR	SR	LR	SR	LR
GDP	0,14	0,22	0,06	0,19	0,09	0,23
Consumer Price Index	-0,20	-0,27	-0,11	-0,22	-0,16	-0,27
Unemployment Rate	-0,27	-0,66	-0,54	-1,17	0,10	-0,67
Total Employment	0,03	0,07	0,06	0,13	-0,01	0,07
Nominal Gross Wage	-0,18	-0,21	-0,07	-0,11	-0,17	-0,21
Real Gross Wage	0,02	0,06	0,05	0,11	-0,01	0,06
Total Import	-0,07	-0,05	-0,17	-0,14	-0,10	-0,07
Energy output	0,21	0,26	-0,49	-0,49	-0,04	0,05
Non Energy output	0,12	0,21	0,06	0,19	0,09	0,22
Domestic Energy consumption	0,22	0,27	-0,54	-0,54	-0,05	0,05
T.Energy demand by industries	0,12	0,17	-0,95	-0,91	-0,23	-0,14

5. Sensitivity analysis.

We perform the sensitivity analysis comparing the effects of the simulated energy efficiency gains when the degree of factor substitution in the KLEM - CES function are set to σ =0.01, σ =0.9, σ = 0.5 and a scenario where technology is more flexible, σ =1.5. We select the elasticities of substitution subject to sensitivity analysis considering those that affect the upper nest in which energy is combined with another input, and the lower nest where the KLEM composite or domestic production is obtained.

Additionally, this simulation strategy allows comparing and drawing conclusions about the relevance that KLEM separability assumptions might have over the evaluation of energy and environmental policies in general and, particularly, over the economy-wide rebound effects.

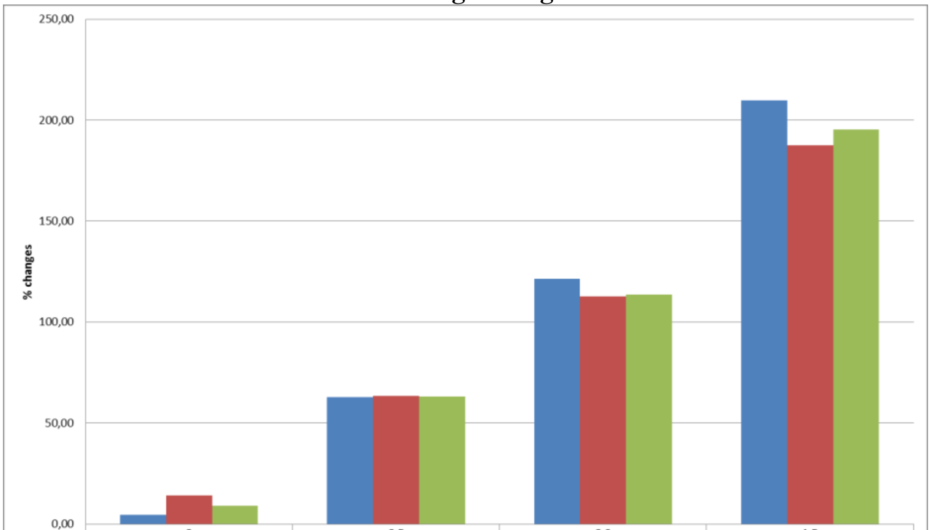
[14] See Table 2 in Section 3.

5.1. Comparing Economy-Wide Rebound Effects among different KLEM specifications.

The results of the LR economy-wide rebound effect are presented in Tables 6. According to these results the size of the economy-wide rebound/backfire effect is more sensitive to the variations of the elasticity of substitution between energy and the other composite than to the changes of the lower bound elasticity. These empirical results are consistent with those found by previous theoretical work of Sorrell (2007) and Sounders (2008).

Looking at Figure 6 we can easily compare the sensitivity of the LR economy-wide rebound effects under the different KLEM separability assumptions, i.e. specifications CSS, Case A and Case B. In this Figure we present economy-wide rebound effects for each KLEM specification only considering the evaluated economy-wide rebound impacts when the values of the elasticity of substitution in the upper and lower nest coincide. As can be asserted, the production function specification is not very determinant in the size of the rebound in the case of Italy. However, when the elasticity is very low, Case A exhibits a higher rebound (14%) than the others do. When elasticity is very high (1.5), we find the higher rebound effect is the CCS specification. Finally, for all specification considered, with high elasticities values there is evidence of backfire effect.

Figure 6. Sensitivity of LR Economy-Wide Rebound to different KLEM specification. Percentage changes



	0	0,5	0,9	1,5
BCC	4,62	62,92	121,43	209,64
A	14,12	63,38	112,83	187,43
B	9,10	63,17	113,48	195,21

6. Final comments.

The main contribution of this work is to study the impact of energy efficiency improvement in the use of energy in industrial sectors and to show the resulting economy-wide rebound figures for Italy.

We investigate and quantify the general equilibrium rebound effects using an inter-temporal, dynamic, multi-sectoral general equilibrium model developed for the Italian economy where dynamics arise from consumption and investment decision of forward looking economic agents. In doing this, we consider all the value added specification and for each of them we test our result. We can confirm both that in the case of Italy there is evidence of rebound effect (and backfire effect) and that long run rebound is higher than the short run according with the earlier cited theoretical works of Sounders and Sorrel. Moreover, we stress the determinant role played by the elasticity of substitution in determining the magnitude of the rebound effect so that specific estimation for Italy are needed.

However, we have analysed a costless efficiency improvement so that the research should be enriched by the inclusion of the costs of such efficiency improvement. In addition, not only the rebound effects on the industrial sectors should be analysed but also those related to the households consumption of energy.

Finally, since efficiency improvements are strictly related with environmental issues; an analysis of the consequences on the CO_2 emissions would be essential in order to provide a complete picture to the policy makers, considering the 20-20 20 European Union Program that aims to reduce not only energy consumption but also emissions in the environment.

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