# Rebound Effects of Electricity Efficiency Improvements in Iran: A CGE Approach

**Davood Manzoor**[*]
*Assistant professor, Imam Sadiq University*
manzoor@isu.ac.ir
**Mohammad Ebrahim Aghababaei**
*Ph.D. Candidate in economics, University of Tehran*
aghababaei@ut.ac.ir
**Iman Haqiqi**
*Ph.D. Candidate in economics, School of Economic Sciences*
haqiqi@ses.ac.ir

## Abstract:

Efficiency improvements in electricity uses lead to a decrease in its demand and consequently a decline of electricity price. It is expected that the induced increase in electricity demand due to this price effect offset part of the primary reduction in consumption — a phenomenon known as "Rebound Effects”. The ignorance of these effects in policymaking causes overestimation of the benefits of policies aiming efficiency improvement.

In this paper we try to determine the parameters that influence the magnitude of rebound effects theoretically and to evaluate the consequences of an exogenous and costless efficiency improvement in electricity uses in the context of a computable general equilibrium (CGE) model. This model is calibrated using Micro Consistent Matrix (MCM) set up based on Social Accounting Matrix (SAM) of I.R.Iran ٢٠٠١ assuming a small open economy.

Our results indicate that electricity efficiency improvement leads to rebound effects of ١٤.٢ percent— it means that ١٤.٢ percent of a primary decrease in demand is offset by rebound effects. According to our results, there are significant differences of rebound effects across electricity consuming sectors. The oil and gas sectors face the highest rebound effects. Sensitivity analysis to test the response of rebounds to the specification of elasticity of substitution between electricity and fossil fuels shows that economy-wide rebound effects changes from ١١.٦٪ to ١٤.٢٪ due to changes in the elasticity of substitution from ٠.١ to ٠.٩, which implies the robustness of the results to different elasticity of substitution.

**JEL Classifications**: C٦٨; D١٢; D٢١; D٥٨; Q٤١; Q٤٣

**Key words***:* Computable General Equilibrium; Electricity Efficiency; Rebound Effects, Iran.

---

[*] Faculty of Economics, Imam Sadiq University- P.O. Box: ١٤٦٥٩-٤٣٦٨١ Tehran, Iran.
Tel/Fax: +٩٨-٢١ ٨٨٠٨١٤٠٤

## ١. Introduction

From supply side, more than ٩٠ percent of electricity in Iran is being produced by the thermal power plants. Low of efficiency in these power plants causes huge resource losses each year. According to "Energy Balance of Iran ٢٠٠٧ ", published by the ministry of energy (MOE, ٢٠٠٨), lost rate of electricity in transmission and distribution network is about ١٩.٩٪, while the corresponding world average rate is ٨.٤%.

From demand side, population growth, increase in electricity penetration rate and the economic growth leads to high growth in electricity consumption. Iran currently manages an electricity sector that has about ١٠٪ annual peak demand growth rate, nearly the highest rate in the world (Ghazizadeh, et al., ٢٠٠٧). Inefficient use of electricity made the electricity intensity as high as ٠.٩٢ Wh/USD in Iran, while the world average rate is about ٠.٤٦ Wh/USD (MOE, ٢٠٠٨). Furthermore, highly subsidized electricity prices have encouraged rapid consumption growth in recent years. Generally, high inefficiency in electricity production, high growth rate of consumption, high rates of transmission losses, altogether with global advices for clean development make the electricity efficiency improvement policies unavoidable in Iran.

The first likely impact of efficiency improvement is decrease in demand but it may not be as much as it is generally expected. The "rebound effects" may get in the way and reduce the size of the 'energy savings' achieved. The rebound occurs when the increased efficiency decreases the effective price of energy and consequently increases the demand will increase. In some cases the price fall may totally offset the energy savings due to efficiency improvement and results into a net increase in energy consumption, a phenomenon known as "backfire effects". The rebound effects directly reduce the expected benefits of efficiency improvement policies (Turner, ٢٠٠٩).

Analysis of rebound effects, especially in the context of macro-economy, is a new field of economic research and recently, there have been extensive debates in the literature on the impacts of energy efficiency improvements (Turner, ٢٠٠٩; Sissine, ٢٠٠٦; Lorentz & Woersdorfer, ٢٠٠٩).

This paper explores the factors affecting the rebound effects theoretically and tries to measure the magnitude of rebound effects due to an exogenous electricity efficiency improvement in all electricity consuming sectors using a computable general equilibrium (CGE) model for Iran.

The paper is organized as follows. Section ٢ is a brief literature review. In section ٣, we present a multi-sector Computable General Equilibrium (CGE) model for Iran as a small open economy. Then we explore theoretically how the electricity efficiency improvements may trigger economic forces that offset the potential savings from using more efficient technologies. Section ٤ reports the magnitude of rebound effect from ١٠٪ efficiency improvement of electricity use by different sectors, and examines the robustness of results to the specification of key parameters using a sensitivity analysis. In section ٥ we end up the paper by some concluding remarks.

## ٢. Literature review

The term "rebound" describes the discrepancy between potential and actual energy savings:

> *"Rebound effects (or take-back effects) result from the impact of increased efficiency in the use of energy on effective energy prices (price of energy per unit of production or consumption) and on actual energy prices (where there is domestic energy supply). Reductions in effective and/or actual energy prices lead to positive substitution, output/competitiveness, composition and income effects that act to offset the decreases in energy consumption that accompany pure efficiency effects" (Turner, ٢٠٠d).*

The rebound effect is a phenomenon based on economic theory and historical studies, but as with all economic observations its magnitude is a matter of considerable dispute. Its significance for energy policy has increased over the last two decades, by energy analysts in the ١٩٧٠s (Brookes, ١٩٧٨; Khazoom, ١٩٨٠; Hannon, ١٩٧٥), and later by environmentalists in the late ١٩٨٠s (Keepin & Kats, ١٩٨٨; Brookes, ١٩٩٠).

The direct rebound effect was first brought to the attention by Daniel Khazzoom (١٩٨٠) and has since been the focus of much research. (Greening et.al. ٢٠٠٠) But even if there is no direct rebound effect for a particular energy service (e.g. even if consumers choose not to drive any further in their fuel-efficient car), there are a number of other reasons why the economy-wide reduction in energy consumption may be less than simple calculations suggest. These are the so-called indirect rebound effects. The overall or economy-wide rebound effect from an energy-efficiency improvement represents the sum of these direct and indirect effects and will depend upon the size, nature and location of the energy efficiency improvements. It is normally expressed as a percentage of the expected energy savings from an energy-efficiency improvement (Herring & Sorrell, ٢٠٠٩). With regard to the economic mechanism, the literature distinguishes between the following effects (Turner, ٢٠٠٩; Herring & Sorrell, ٢٠٠٩):

**A. The substitution effect:** the increase in demand for an energy service that becomes cheaper as a result of the increase in energy efficiency.

**B. The income effect:** the increase in available income as a result of the reduced price of the energy service, which leads also to increase in other energy-consuming purchases.

**C. Secondary effects (input-output effects):** energy efficiency improvement reduces the cost of production; price reduction will increase demand for goods and services; the increased activity needs more energy.

**D. Economy-wide effects or market-clearing price and quantity adjustments:** If energy efficiency reduces the demand for fuel, the fuel price will go down. As a result of the fuel price reduction, more fuel will be bought.

The first two effects, sometimes also called direct rebound effects, are micro effects that play themselves out on the level of the single household. The last two effects are macro effects that result from the interaction between different actors, both producers and consumers, in the economy (Hertwich, ٢٠٠٥).

The increased consumption of energy services due to efficiency improvement may be expected to offset some of the predicted reduction in energy consumption. The increased consumption in some cases may dominate the initial reduction in energy consumption. Hence, we face three possible situations:

**١. Negative rebound effects:** it means that the final reduction is more than the expected initial decline in the energy use. This case is unconventional mode and occurs only in certain conditions.

**٢. Rebound effects between zero to ١٠٠ percent:** in this case, the final reduction in the energy use is less than the expected initial decline. Most practical studies ended up with this situation.

**٣. Rebound effects more than ١٠٠ percent:** in this case, the final reduction in the energy use is negative. This case is known as "Jevons paradox" or "Backfire effects". In Jevons paradox, improving energy efficiency may increase energy consumption.

Analysis of rebound effects is very complex and challenging, because they influence most economic relations, including simple demand responses to price and income changes as well as dynamic adjustments. The rebound effects can undermine the rationale and effectiveness of energy efficiency instruments.

The claim that energy efficiency improvements would reduce national energy consumption was first challenged by Len Brookes (١٩٧٩) and Daniel Khazzoom(١٩٨٠). Khazzoom believes that energy efficiency improvement reduces the marginal cost of energy services, and hence leads to an increase in demand for those services. The reduction in energy demand will be less than proportional to the reduction in energy use. Brookes (١٩٧٨; ٢٠٠٠) argues that energy efficiency will lead to economic growth, which in turn may lead to a net increase in energy demand. Saunders (١٩٩٢) presents a formal economic model for this hypothesis. Wirl (١٩٩٧) argues that while higher prices reduce the demand unambiguously, the impact of efficiency is ambiguous and an improvement in efficiency may not lower the consumption. These studies triggered a discussion that addressed both the mechanisms and the magnitude of this rebound effect.

Semboja (۱۹۹٤) and Hanley et al. (۲۰۰٦) measure the system-wide rebound effects using CGE approach for an efficiency improvement of energy use both in production sectors and in household consumption. They ended up with "backfire case". Dufournaud et al. (۱۹۹٤) also presented a CGE model to measure the effects of efficiency improvement in wood-burning stoves. Vikstrom (۲۰۰٤) and Washida (۲۰۰٤) estimate the rebound of efficiency improvement in energy use. They apply a sensitivity analysis for elasticity of substitution to test the robustness of results*. Grepperud and Rasmussen (۲۰۰٤) present a dynamic model for Norway to measure the effects of oil and electricity efficiency improvement for ٦ selected activities. Allan et al. (۲۰۰۷) estimate economy-wide rebound effects for the UK. The model allows for the gradual updating of capital stocks, which enables to estimate long-run rebound effect as well as short run. Sensitivity tests in this study reveal a major impact on the rebound effect. Saunders (۱۹۹۲) and others stress the importance of the 'elasticity of substitution' between energy and other inputs in production, other characteristics such as the elasticity of supply of capital and labor, the own-price elasticity of demand for the product of each sector, the energy intensity of producing sectors, the scope for substitution between different consumption goods, the income elasticity of the demand for goods and the manner in which government revenue is redistributed are also potentially important.

## ۳. Model Specification

CGE models are calibrated to reflect the structural and behavioral characteristics of particular economies and in principle can indicate the approximate order of magnitude of direct and indirect rebound effects from specific energy efficiency improvements. Moreover, these effects derive from 'pure' energy efficiency improvements and therefore do not rely upon simultaneous improvements in the productivity of capital and labor inputs.

We apply a CGE model for Iran as a small open economy. This model includes ۱۲ production sectors, rural and urban households, government and finally imports and export sectors. The three main assumptions of CGE modeling, namely market clearance, income balance and zero profit condition for each sector are included in our proposed model.

After calibrating the model, we analyze the impacts of ۱۰٪ electricity efficiency improvements in all sectors. We assume that efficiency improvement is exogenous and costless.

### ۳-۱. Production Structure

The production technology is represented by a nested tree-structure of CES-aggregates, which reduces the number of substitution possibilities since pair wise combinations of factors represent the substitution possibilities. The production sector in the model is categorized in ۱۲ sub-sectors including: crude oil and natural gas, coal, oil products, electricity, iron ores, copper mines, glass production, manufacturing, transport, agriculture and animal husbandry, water and services. Goods are produced using capital (K), labor (L), energy (E) and material (M) or KLEM. Energy is divided into electricity and fossil fuels. Substitution possibilities between the two forms of composite energy (electricity and fuels) are the key parameter for our sensitivity analysis.

Figure ۱ presents the production structure of the model. The nested structure of the production is depicted by nested CES functions.

---

* The elasticity of substitution between inputs – i.e. the extent to which one input can substitute for another while keeping output constant- may has a strong influence on the estimated magnitude of rebound effects.

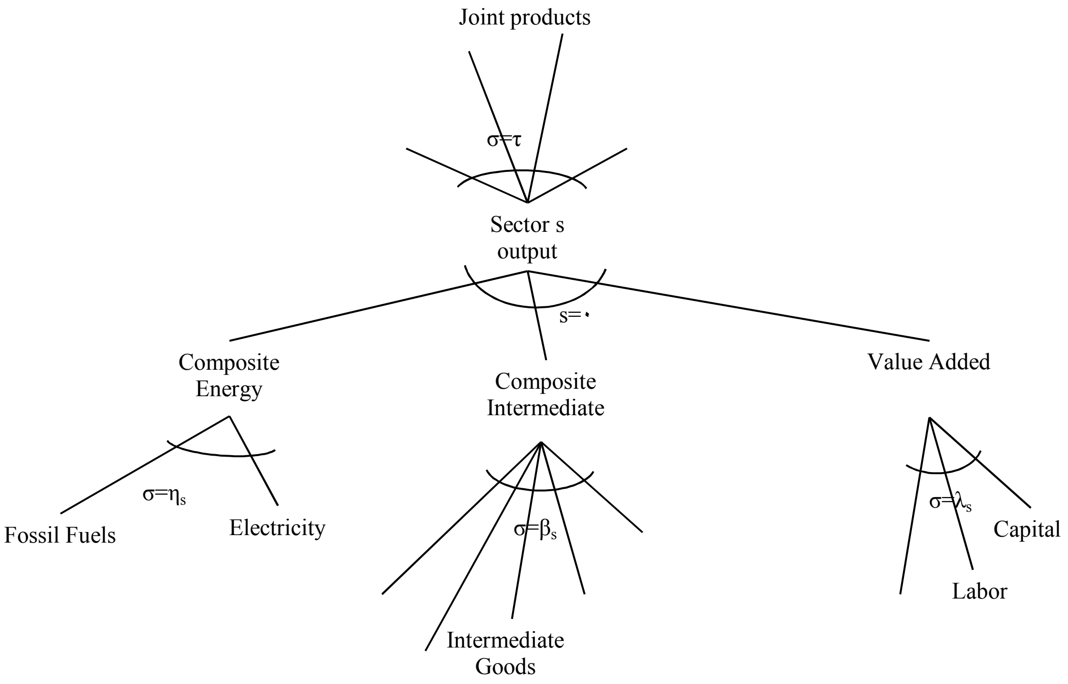

**Fig. ١: Nesting in production sector**

Products are allocated to domestic consumption and export using a constant elasticity of transformation function (CET).

### ٣-٢. Utility Structure

Consumption and saving results from utility maximization of a representative consumer. The aggregate consumption bundle combines demands for energy and non-energy commodities. The representative household maximizes utility from consumption of energy and non-energy goods and services. She can save according to a constant exogenous saving rate.

The household is restricted by a budget constraint as we assume that her endowments of labor and capital are fixed. Figure ٢ provides a generic graphical exposition of the utility structure.

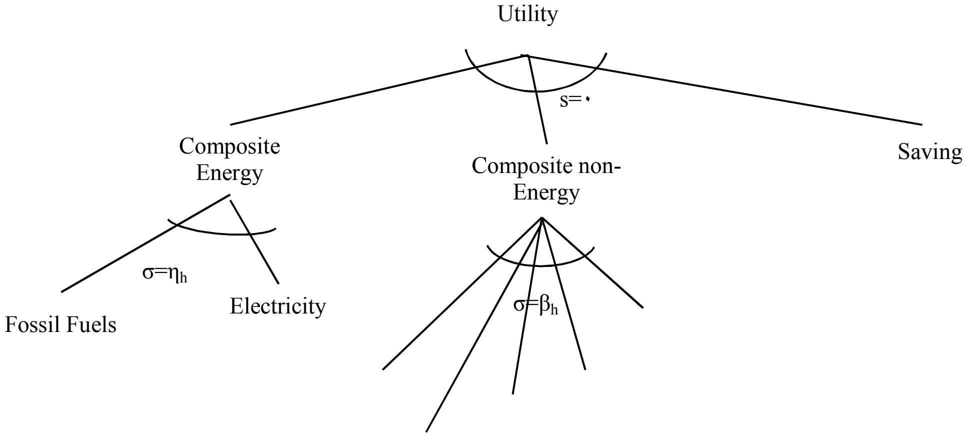

**Fig. ٢: Demand structure and utility function**

## ۳-۳. The Competition Requirements

Three groups of conditions characterize the competitive equilibrium in our model: zero profit conditions, income balances and market clearance conditions.

Considering CES production function, zero profit condition in each production sector requires that:

$$\Pi^s = \left( \sum_i \omega_i^s \left(P_{\mathrm{i}}\right)^{1-\tau_s} \right)^{\frac{1}{1-\tau_s}}$$

$$- \left( \omega_f^s \left( \sum_f \theta_f^s \left(P_f\right)^{1-\lambda_s} \right)^{\frac{1}{1-\lambda_s}} + \omega_j^s \left( \sum_j \theta_j^s \left(P_j\right)^{1-\beta_s} \right)^{\frac{1}{1-\beta_s}} + \left(1-\omega_f^s-\omega_j^s\right) \left[ \theta_e (P_e)^{1-\delta} + \left(1-\theta_e\right) \left( \left( \sum_{ne} \theta_{ne}^s \left(P_{\mathrm{ne}}\right)^{1-\eta_s} \right)^{\frac{1}{1-\eta_s}} \right)^{1-\delta} \right]^{\frac{1}{1-\delta}} \right) = 0$$

(١)

Where $\Pi$: profit level;
$P$: price level of inputs and output;
$\omega$: input and output share from total input and output in the first layer of production structure respectively;
$\theta$: input share from total inputs in the second layer;
$\tau_s$: elasticity of transformation
$\lambda$: elasticity of substitution between inputs in the second layer;
$\beta$: elasticity of substitution between intermediary inputs in the second layer;
$\delta$: elasticity of substitution between electricity and fossil fuel in the third layer;
$\eta$: elasticity of substitution between fossil fuels in the fourth layer;
$s$: underlying sector;
$i$: output;
$f$: labor and capital;
$j$: non-energy intermediary inputs;
$e$: electricity;
$ne$: fossil fuels.

Furthermore, Armington aggregate function determines, on the one hand the substitution of export with domestic supply and on the other hand the substitution of import and domestic production. In this function, the summation of export and domestic supply goods is equal to summation of import and domestic production of goods. Modified Armington aggregate is specified as:

$$\Pi^{ar} = \left( \mu_g^{Px} (Px)^{١-\omega_g} + \mu_g^{P_g} \left(P_g\right)^{١-\rho_g} \right)^{\frac{١}{١-\rho_g}} - \left( \gamma_g^{Ps} \left(Ps_g\right)^{١-\varphi_g} + \gamma_g^{Pm} (Pm)^{١-\varphi_g} \right)^{\frac{١}{١-\varphi_g}} = ٠ \qquad (٢)$$

Where $Px$: export prices;
$Ps_g$: domestic prices;
$Pm$: import goods prices;
$\mu$: share of export and domestic supply;
$\gamma$: share of import and domestic production;
$\rho$: elasticity of substitution between export and domestic supply;
$\varphi$: elasticity of substitution between import and domestic production.

Income balance condition that guarantees the equality between household's income and expenditure can be written as:

$$\left[\omega_j^h\left(\sum_i \theta_i^h (P_i)^{1-\tau_h}\right)^{\frac{1}{1-\tau_h}} + \left(1-\omega_{sa}^h-\omega_j^h\right)\left[\theta_e (P_e)^{1-\delta} + (1-\theta_e)\left(\left(\sum_{ne}\theta_{ne}^s (P_{\mathrm{ne}})^{1-\eta_h}\right)^{\frac{1}{1-\eta_h}}\right)^{1-\delta}\right]^{\frac{1}{1-\delta}}\right] E_h = \sum_f W_f . EN_f^h - Sa \tag{٣}$$

Where $Sa$: saving index;
$E_h$: household expenditure level;
$EN$: household initial endowment of factors of production;
$\tau_h$: elasticity of substitution between non-energy consumption goods;
$h$: representative household.

Left hand side of equation (٣) shows the household expenditures based on a CES utility function and right hand side is total household income.

Market clearance condition requires equilibrium in all input and output markets. Using Shephard's lemma, compensated factor demand functions and output supply are derived out of differentiating the profit function with respect to input and output prices respectively. These equations are used to set up market clearance conditions.

Market clearance condition for each factor of production (f):

$$EN_f = \sum AL_s \frac{\partial \Pi^s}{\partial w_f} \tag{٤}$$

Where, AL represents activity level.

Market clearance condition for each domestically consumed commodity ($P_g$)

$$AL_{ar}\frac{\partial \Pi^{ar}}{\partial P_g} - \sum AL_s \frac{\partial \Pi^s}{\partial P_g} = ٠ \tag{٥}$$

Market clearance condition for each domestically produced commodity(Ps)

$$AL_s \frac{\partial \Pi^s}{\partial Ps_g} - AL_{ar}\frac{\partial \Pi^{ar}}{\partial Ps_g} = ٠ \tag{٦}$$

Market clearance for imports (Px)

$$AL_{ar}\frac{\partial \Pi^{ar}}{\partial Px_g} - Px_g . XL_g = ٠ \tag{٧}$$

Market clearance condition for exports (Pm)

$$Pm_g . ML_g - AL_{ar}\frac{\partial \Pi^{ar}}{\partial Pm_g} = ٠ \tag{٨}$$

## ٣-٤. Introducing Rebound Effects in the Model

Electricity efficiency improvements are expected to decrease the production costs and increase the sector activity level. Assuming zero elasticity of substitution between factors of production in the first layer, production function of sector s can be specified as[*]:

$$Q_S = Q[H(L, K), G(I), J(E, NE)] \tag{٩}$$

Where, H: the composite of factors of production;

G: the composite of intermediary goods;

J: the composite of energy carriers.

In which,

$$J(E, NE) = S_{en}\left|\theta_e^{\frac{١}{\delta}}\left(\frac{١}{\alpha}E\right)^{\frac{\delta-١}{\delta}} + (١-\theta_e)^{\frac{١}{\delta}}(NE)^{\frac{\delta-١}{\delta}}\right|^{\frac{\delta}{\delta-١}} \tag{١٠}$$

---

[*] see Mysen (١٩٩١);Uzawa (١٩٦٢); Grepperud & Rasmussen (٢٠٠٤)

Where L, K and I: labor, capital and intermediary goods respectively;

$S_{en}$: energy share from total inputs in section s.

In this equation, α is the electricity productivity index, equal to one in the reference case. Accordingly, corresponding unit cost function is:

$$C = C[h(P_l, P_k), g(P_i), j(P_e, P_{ne})] \qquad (۱۱)$$

Where,

$$j(P_e, P_{ne}) = S_{en}\left|\theta_e\left(\frac{۱}{\alpha}P_e\right)^{۱-\delta} + (۱ - \theta_e)(P_{ne})^{۱-\delta}\right|^{\frac{۱}{۱-\delta}} \qquad (۱۲)$$

Electricity demand by each sector demand for electricity can be derived using Shephard’s lemma:

$$D_{e} = \frac{\partial C}{\partial P_{e}} = {}_{e}\frac{1}{\ }{}_{en}\left[\frac{\left\{\theta_{e}(\frac{1}{\alpha}P_{e})^{1-} + \left(1-\theta_{e}\right)(P_{ne})^{-}\right\}^{\frac{1}{1-}}}{\frac{1}{\alpha}P_{e}}\right]^{\delta}$$

$$= \theta_{e}\frac{1}{\alpha}S_{en}\left[\frac{\left(\theta_{e}(\frac{1}{\alpha}P_{e})^{1-} + \left(1-\theta_{e}\right)(P_{ne})^{-}\right)^{\frac{1}{1-}}}{\frac{1}{\alpha}P_{e}}\right]^{\delta} \qquad (۱۳)$$

Using equation (۱۳), we can derive theoretically the impacts of electricity efficiency changes ($\alpha$) on its demand. Mathematically rebound effect is defined as:

$$R = \left(۱ + \frac{g_D}{g_\alpha}\right) \times ۱۰۰ = \left|۱ + \frac{\frac{D_e^{۲} - D_e^{۱}}{D_e^{۱}}}{\frac{\alpha_۲ - \alpha_۱}{\alpha_۱}}\right| \times ۱۰۰ \qquad (۱۴)$$

Where $g_D$ and $g_\alpha$ represent electricity demand and efficiency improvement growth, respectively. Accordingly, the ratio $\frac{g_D}{g_\alpha}$ can be interpreted as efficiency elasticity of electricity demand ($\varepsilon_\alpha$). Using this definition, we can rewrite equation (۱۴) as:

$$R = (۱ + \varepsilon_\alpha) \times ۱۰۰ \qquad (۱۵)$$

Therefore, If efficiency improvement causes demand to decrease in the same proportion, i.e. $\varepsilon_\alpha = -۱$, rebound is zero. In the case that demand decreases less than proportionate growth in efficiency, i.e. $-۱ < \varepsilon_\alpha < ۰$, rebound would be between zero and ۱۰۰٪. Finally, efficiency improvement may cause demand to increase. This means rebound is more than ۱۰۰٪, i.e. $\varepsilon_\alpha > ۰$, and we face "fire-back effects".

Now, we can analyze factors affecting the amount of the rebound effects in more detail. For this purpose, we derive $\varepsilon_\alpha$ based on model parameters. By definition,

$$\varepsilon_\alpha = \frac{\partial \log D_e}{\partial \log \alpha} = \frac{\partial D_e}{\partial \alpha}\frac{\alpha}{D_e},$$

Hence, using equation (۱۳), we have:

$$\frac{\partial D_e}{\partial \alpha} = \theta_e\left(\frac{-A}{\alpha^۲}\right)S_{en}Z + \left(\frac{A}{\alpha}S_{en}\right)\frac{\partial C}{\partial \alpha} \qquad (۱۶)$$

Where C is equal to:

$$Z = \frac{١}{\alpha} P_e^{-\delta} \Big|\theta_e \left(\frac{١}{\alpha} P_e\right)^{١-\delta} + (١ - \theta_e)(P_{ne})^{١-\delta}\Big]^{\frac{\delta}{١-\delta}} \tag{١٧}$$

Re-arranging (١٧), we have:

$$\varepsilon_\alpha = (\delta - ١) - \delta\theta_e Z^{\frac{\delta-١}{\delta}} \tag{١٨}$$

According to equation (١٨), the efficiency elasticity of electricity demand is mainly affected by the elasticity of substitution between energy components and electricity share in energy aggregate. Based on this equation, zero rebound effects require:

$$\theta_e Z^{\frac{\delta-١}{\delta}} = ١ \tag{١٩}$$

Because the term $Z^{\frac{\delta-١}{\delta}}$ is bigger than unity for all $\alpha > ١$[*] and also electricity share from energy is always less than unity, this case seems to be probable.

Rebound effects equal to or bigger than ١٠٠٪ requires:

$$(\delta - ١) \geq \delta\,\theta_e Z^{\frac{\delta-١}{\delta}} \tag{٢٠}$$

All terms in right hand side are positive; hence the "back-fire case" may happen when $\delta > ١$ , meaning that elasticity of substitution between electricity and fossil fuels being bigger than ١.

Replacing equation (١٨) into equation (١٤) yield the rebound effects of electricity efficiency improvement:

$$R = (١ + \varepsilon_\alpha) \times ١٠٠ = \Big|\delta\Big(١ - \theta_e C^{\frac{\delta-١}{\delta}}\Big)\Big|\Big| \times ١٠٠ \tag{٢١}$$

According to equation (٢١), rebound effects in each sector depends on i) the electricity share from total energy of the sector ($\theta_e$); the higher the share of electricity cost is, the less the rebound effects. ii) the elasticity of substitution ($\delta$).

## ٤. Results

This model calibrated using Micro Consistent Matrix (MCM)[†] based on Iran Input-Output table of ٢٠٠١. In the base scenario, the elasticity of substitution between electricity and fossil fuels is supposed to be ٠.٥. We assume that efficiency improvement is exogenous and costless and it includes electricity efficiency both in production sectors and household consumption. The impact of a hypothetical ١٠٪ electricity use efficiency improvement is shown in table ١.

**Table ١: Rebound effects of ١٠٪ electricity efficiency improvement in production sectors & consumption**

| Sector | Rebound | Sector | Rebound |
|---|---|---|---|
| Agriculture and Animal Husbandry | ١٨٪ | Manufacturing | ٩٪ |
| Coal | ٩٪ | Water | ١٢٪ |
| Crude Oil and Natural Gas | ٢٤٪ | Transportation | ٢٢٪ |
| Iron ores | ١٥٪ | Services | ٧٪ |
| Copper Mines | ٢٠٪ | Rural household | ١٩٪ |
| Oil Products | ٠٪ | Urban household | ١٨٪ |
| Glass | ٢٠٪ | | |

---

[*] At the benchmark in CGE models it is assumed that $P_e = ١$ , $P_{ne} = ١$ and $\alpha = ١$, hence C=١.

[†] Shahmoradi, Asghar et. al, ٢٠٠٩. Impact analysis of price policies: A CGE approach, Iranian Ministry of Energy (MOE).

As table ١ depicts, rebound effects vary significantly across sectors. In energy intensive sectors, such as crude oil and natural gas, transportation and glass sectors, the rebound is more than ٢٠٪. In this scenario only oil products sector faces zero rebound.

In this scenario, total rebound effects is ١٤.٢٪, it mean that ١٠٪ electricity efficiency improvement will result in about ٨.٦٪ decreases in electricity demand. The electricity export will increase ٣.٨٪ mainly because of decline in domestic consumption. Rural and urban household welfare also increase ٠.٦%.

The magnitude of the direct and indirect impacts of efficiency improvement is different among countries. This happens due to different behavioral characteristics of economies. Economists put some of these characteristics in the concept of elasticity. Therefore a key parameter in CGE models is the so-called elasticity of substitution between different inputs. This determines the extent to which one input can substitute for another while keeping output constant. The elasticity of substitution between energy and other inputs has a strong influence on the estimated magnitude of rebound effects.

The elasticity of substitution is calculated from own and cross price elasticities and the share parameters. In some cases, the results are sensitive to the choice of production function, and for some functions depend on the assumptions made about the elasticity of substitution between electricity and other factors. Hence, we carry out a sensitivity analysis to test the response of rebounds to the choice of this key parameter. As table (٢) shows, varying the assumed elasticity of substitution between electricity and fossil fuels from ٠.١ to ٠.٩, economy-wide rebound effect changes between ١١.٦٪ and ١٤.٤٪. The impacts of changes in this parameter on electricity export and household welfare is reported in table (٢).

**Table ٢: Sensitivity analysis of elasticity of substitution between electricity and fossil fuels**

| **Elasticity of Substitution** | ٠.١ | ٠.٢ | ٠.٣ | ٠.٤ | ٠.٥ | ٠.٦ | ٠.٧ | ٠.٨ | ٠.٩ |
|---|---|---|---|---|---|---|---|---|---|
| Rebound Effects | ١١.٦٪ | ١٣.٤٪ | ١٤.٤٪ | ١٤.٤٪ | ١٤.٢٪ | ١٣.٨٪ | ١٣.٤٪ | ١٣٪ | ١٢.٨٪ |
| Electricity Export | ٥٪ | ٤.٤٪ | ٤٪ | ٣.٩٪ | ٣.٨٪ | ٣.٧٪ | ٣.٧٪ | ٣.٦٪ | ٣.٦٪ |
| Rural household welfare | ٠.٢٪ | ٠.٥٪ | ٠.٦٪ | ٠.٦٪ | ٠.٦٪ | ٠.٦٪ | ٠.٦٪ | ٠.٥٪ | ٠.٥٪ |
| Urban household welfare | ٠.٩٪ | ٠.٨٪ | ٠.٨٪ | ٠.٧٪ | ٠.٦٪ | ٠.٥٪ | ٠.٤٪ | ٠.٣٪ | ٠.٣٪ |

## ٥. Conclusions and Policy Implications

This paper examines the impacts of an exogenous ١٠٪ efficiency improvement in electricity use by all sectors. A key debate about energy efficiency is the extent of its 'rebound effects': to what extent does energy use increase due to efficiency improvements? We apply a ١٢ sector computable general equilibrium model to measure the amount of rebound effects. As results show the efficiency improvements reduces the price and consequently increases the consumption and neutralizes primary decrease in electricity consumption. Theoretically rebound effects depend on parameters of model, especially factor's elasticity of substitutions, and other characteristics of production sectors. Furthermore, empirical results show that the rebound effects in energy intensive sectors, such as crude oil and natural gas, transportation and glass sectors, are highest one. Only oil products sector faces zero rebound. Total rebound effects in this model is ١٤.٢٪. Also, ٠.٦٪ increase in household's welfare results from ١٠٪ electricity efficiency improvement. Sensitivity analysis shows the change in assumed elasticity of substitution between ٠.١ and ٠.٩, have little effects in economy-wide rebound effects.

Based on these results, policy makers should consider both the rebound and welfare effects in designing energy production and consumption optimization strategies and choose appropriate policy tools. Naturally, in sectors that face high rebound effects, to encourage energy saving and efficiency improvement, price and tax instruments that lead to energy price increases are more effective than non-price policies that mainly reduce consumption and therefore make prices decline.

## References

Allan, G., N. Hanley, P.G. McGregor, J.Kim Swales, K. Turner, ٢٠٠٧. The impact of increased efficiency in the industrial use of energy: a computable general equilibrium analysis for the United Kingdom. Energy Economics. ٢٩, ٧٧٩-٧٩٨.

Bhattacharyya, S. C., ١٩٩٦. Applied general equilibrium models for energy studies: a survey. Energy Economics. ١٨, ١٤٥-١٦٤.

Birol F.; Keppler J.H., ٢٠٠٠. Prices, technology development and the rebound effects. Energy Policy. ٢٨, ٤٥٧-٤٦٩.

Brookes, L. G., ١٩٧٨. Energy policy, the energy price fallacy and the role of nuclear energy in the UK. Energy Policy. ٦(٢), ٩٤-١٠٦.

Brookes, L. G., ١٩٩٠. The greenhouse effect: The fallacies in the energy efficiency solution. Energy Policy. ١٨(٢), ١٩٩–٢٠١.

Brookes, L. G., ٢٠٠٠. Energy efficiency fallacies revisited. Energy Policy. ٢٨(٦-٧), ٣٥٥-٦٦.

Dimitropoulos, J., ٢٠٠٧. Energy productivity improvements and the rebound effect: An overview of the state of knowledge. Energy Policy. ٣٥, ٦٣٥٤–٦٣٦٣.

Dufournaud, Christian M., Quinn, John T., Harrington, Joseph J., ١٩٩٤. An Applied General Equilibrium (AGE) analysis of a policy designed to reduce the household consumption of wood in the Sudan. Resource and Energy Economics. ١٦ (١), ٦٧-٩٠.

Ghazizadeh, M.S., Sheikh-El-Eslami, M.K., Seifi, H., ٢٠٠٧. Electricity restructuring. Power and Energy Magazine, IEEE. Vol. ٥(٢), ١٦-٢٠.

Gottron, F., ٢٠٠١. Energy efficiency and the rebound effect: does increasing efficiency decrease demand?. CRS Report for Congress. Order Code RS٢٠٩٨١.

Greening, L. A., D. L. Greene, C. Difiglio, ٢٠٠٠. Energy efficiency and consumption: the rebound effect - a survey. Energy Policy. ٢٨(٦-٧), ٣٨٩-٤٠١.

Grepperud, S., Rasmussen, I., ٢٠٠٤. A general equilibrium assessment of rebound effects. Energy Economics. ٢٦(٢), ٢٦١–٢٨٢.

Hanley N.D., McGregor P.G., Swales J.K., Turner K., ٢٠٠٦. The impact of a stimulus to energy efficiency on the economy and the environment: A regional computable general equilibrium analysis. Renewable Energy, ٣١; pp.١٦١-١٧١

Hannon, B., ١٩٧٥. Energy Conservation and the consumer. Science, ١٨٩, ٩٥-١٠٢.

Henly, J., H. Ruderman, M. D. Levine, ١٩٨٨. Energy savings resulting from the adoption of more efficient appliances: a follow-up. Energy Journal. ٩(٢), ١٦٣-١٧٠.

Herring, H, Sorrell, S., ٢٠٠٩. Energy Efficiency and Sustainable Consumption (Rebond Effect). Palgrave Macmillan, U.K.

Hertwich, G., ٢٠٠٥. Consumption and the Rebound Effect. Massachusetts Institute of Technology and Yale University, Vol. ٩, No. ١–٢.

Keepin, B., Kats, G., ١٩٨٨. Greenhouse warming, competitive analysis of nuclear and efficiency abatement strategies. Energy Policy, Vol. ١٦, (٦), ٥٣٨-٥٦١.

Khazzoom, J. D., ١٩٨٠. Economic implications of mandated efficiency in standards for household appliances. Energy Journal. ١(٤), ٢١-٤٠.

Khazzoom, J. D., ١٩٨٧. Energy Savings Resulting from the Adoption of More Efficient Appliances. The Energy Journal. ٤, ٨٥-٨٩.

Lorentz, A., Woersdorfer, J., ٢٠٠٩. Energy-efficient household appliances and the rebound effect - A model on the demand for washing machines. Working paper on ٨th International Conference of the European Society for Ecological Economics.

Lovins, A. B., J. Henly, H. Ruderman, M. D. Levine, ١٩٨٨. Energy saving resulting from the adoption of more efficient appliances: another view; a follow-up. The Energy Journal. ٩(٢), ١٥٥.

MOE, ٢٠٠٨. World and country energy data (٢٠٠٧), Iranian Ministry of Energy (MOE).

Saunders, H. D., ١٩٩٢. The Khazzoom-Brookes postulate and neoclassical growth. The Energy Journal. ١٣(٤), ١٣١.

Semboja, Haji Hatibu Haji, ١٩٩٤. The effects of energy taxes on the Kenyan economy: A CGE analysis. Energy Economics. ١٦, (٣), ٢٠٥-٢١٥.

Shahmoradi, A., Haqiqi, I., Zahedi, R., ٢٠٠٩. Impact analysis of price policies: A CGE approach, Iranian Ministry of Energy (MOE).

Sissine, F., ٢٠٠٦. Energy efficiency policy: budget, electricity conservation, and fuel conservation issues. CRS Report for Congress, Order Code RL٣٣٥٩٩.

Turner, K., ٢٠٠٩. Negative rebound and disinvestment effects in response to an improvement in energy efficiency in the UK economy.Energy Economics. ٣١, ( ٥), ٦٤٨-٦٦٦.

Vikström, P., ٢٠٠٤. Energy efficiency and energy demand: a historical CGE investigation on the rebound effect in the Swedish economy ١٩٥٧. Umeå University. Umea, Sweden.

Washida, T., ٢٠٠٤. Economy-wide Model of Rebound Effect for Environmental Efficiency. International Workshop on Sustainable Consumption, University of Leeds.

Wirl, F., ١٩٩٧. The economics of conservation programs. Kluwer, Dordrecht.