The impact of industrial energy savings on New Zealand economy (An intertemporal dynamic CGE model)

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Abstract

Increasing energy efficiency during past decades has resulted in a reduction of industrial energy intensity. However, due to higher industrial production, growth in energy demand exceeded energy saved. The adoption of energy-saving technologies will likely impact relative prices, supply, patterns of production and consumption, and investment within the sector and, possibly, throughout the economy. So, a technological change can impact investment decisions by public and private investors resulting in capital moving between sectors to achieve a higher return. To capture the impact of a technological change, we need to consider interactions between sectors. In this paper, an intertemporal dynamic CGE model is developed for New Zealand to capture the impact of 10% energy-savings in the industrial sector on investment decisions and the economy. A dynamic CGE model is solved the model for entire period simultaneously. Equations show how the economy adjusts to technological innovation over time. Our results show that capital will move to energy-intensive sectors and an increase in the production of these sectors is observed. Production in other sectors declines as they face a reduction in capital stock in the first few years of introducing technological change. However, these sectors return to the long run equilibrium after few years. Generally, we can see a higher output for whole the economy. This is in line the concept of the role of technology in economic growth theories.

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Introduction

Industrial energy demand has increased globally by 1.5% annually since 2010. Not only has coal consumption doubled since 2000 but also, we had 80% growth in consumption of non-biomass renewables, such as geothermal and solar thermal. In 2014 non-renewables had the highest growth rate of any fuel at 7%. Structural effects based on changing shares of industrial subsectors, as well as regional shifts in production, could partly explain this, but the growth in renewable energy use in industry is nonetheless an encouraging sign (IEA, 2017).

Increasing energy efficiency during past decades has resulted in a reduction of industrial energy intensity. However, due to higher industrial production, growth in energy demand exceeded energy saved. Industrial energy use and associated greenhouse gas emissions are expected to increase as a result of the expectation of double or triple industrial productivity in the following 40 years (IEA, 2011). Currently, industrial production is about one-third of total energy demand and 40% of emitted greenhouse gases(IEA, 2017). Improved energy efficiency can limit energy demand and industrial greenhouse emissions as it results in decreased fossil fuel energy consumption. One of the most cost-effective ways to reduce greenhouse gas emissions is increasing energy efficiency (Ryan & Campbell, 2012), and also, it is an important way to mitigate climate change.

Introducing disruptive (or innovative) technologies into industrial processes can play a significant role in achieving national goals for energy efficiency. Cost-effective improvements in energy efficiency will decrease production costs and contribute to the profitability of processing plants. Furthermore, considering their relative share of energy demand, the adoption of energy-saving technologies will likely impact relative prices, supply, patterns of production and consumption, and investment within the sector and, possibly, throughout the economy. To capture the impact of a technological change, we need to consider interactions between sectors.

Improvements in the productivity of industrial procedures can come in different ways, including lower capital and operating costs, increased yields, and a decrease in demand for energy from natural and fossil fuel resources. Technological change (TC) will incorporate one, or more of these improvements. Although some technological change is designed for a particular purpose, generally it may have an impact on other aspects of the production process.

Some technologies are defined as energy-efficient as they aimed at reducing energy use. However, they will add additional enhancements to the production process. Lower maintenance costs, safer working environment, an increase in production and many others are referred to as productivity benefits or non-energy benefits. Therefore, using an energy-efficient technology will enhance the productivity of the firm as well. Many studies have found a direct relationship between energy efficiency and productivity using different methodology and datasets. (Worrell, Laitner, Ruth, & Finman, 2003)

The economic impact of introducing energy savings technology into industrial process is not limited to this sector. Energy demand reduction from this sector release, more energy to the economy and can have an indirect impact on other sectors. TC can impact investment decisions by public and private investors resulting in capital moving between sectors to achieve a higher return.

This paper focuses on the diffusion stage of TC as classified by Schumpeter (1934). An intertemporal dynamic CGE model is developed for New Zealand to capture the impact of industrial TC on investment decisions and the economy.

Importance of energy efficiency in industry

Since the 1970s energy efficiency in the industrial sector has been considered as an important part of energy studies. Furthermore, higher efficiencies are required as an updated component of environmental protection. In industry, energy efficiency can be improved by three different approaches: energy management, industrial energy saving by policies/regulations, and industrial energy-saving technologies.

Energy management

Energy management is the strategy aimed at meeting energy demand when and where it is needed. By adjusting and optimizing energy-using systems and procedures, energy input per unit of output can be controlled and the total cost of production reduced or at least held constant. Energy management began to be considered as the main part of industrial management since 1970s as a result of an increase in energy prices and concerns about scarcity of world natural resources.

Since then, the role of energy demand management has expanded in industries. Nowadays planning for energy demand projects on a regular basis is an important part of the top management team of a firm. Energy management programs should have four main activities to be more effective: analyzing historical data, energy audit and accounting, engineering analysis, and personal training and information.

Industrial energy savings by governmental policies

Energy policy is the tool by which government has decided to address issues of energy development including production, distribution, and consumption of energy. Energy policy may include legislation, taxation, and incentive to investment, agreements, and guidelines for energy conservation, international treaties, energy guide labels and energy efficiency standards. Energy policies are used in the industrial sector to meet specific energy demand or achieve energy efficiency targets. They can be viewed as a tool for mid and long-term strategic planning covering a period of 5-10 years aimed at increasing energy efficiency and reducing greenhouse gas emissions. There are many types of policies and programs that have been used in countries around the world to improve energy efficiency. Some of these policies are regulation/standards, agreements/targets, and reporting/benchmarking.

Energy savings technologies

Technological improvement has an enormous potential to reduce industrial energy consumption. There are different ways to reduce energy demand in this sector. Use of a variable speed drive in motor operated systems, high efficiency motors, efficient nozzles in the compressed-air system, waste heat recovery, etc. are some common methods to control energy consumption by industrial production (Abdelaziz, Saidur, & Mekhilef, 2011).

Studies of energy consumption across time

In 1970s studies about energy use started with a series of papers by (Hoffman & Jorgenson, 1977), (E. R. Berndt & Wood, 1975). A flexible form of cost or production function was used to derive factor demand equations. In these papers energy demand in American industries was investigated using translog cost functions. Technological change was introduced into these models by Jorgenson. He simply modeled technological change by including a time trend in the regression. Fraumeni & Jorgenson, (1981) used a time trend to show technological change. They found that technological change was energy using. That is energy use per unit of output increased over time. However, they used 1958 to 1974 data that does not cover technical change in energy consumption because of the two energy crises of the 1970s. Their results may not be be relevant to today.

More recent studies, e.g. (K. D. Berndt, Beunink, Schroeder, & Wuethrich, 1993), (Mountain, Stipdonk, & Warren, 1989), and (Sterner, 1990) find that technological change is energy saving. All these papers used a time trend to represent technological change. Using a time trend has two disadvantages. First, improvements in energy-saving technology do not occur randomly over time, but are correlated with changes in energy prices. Therefore, the results of these papers are sensitive to the period of study. The second drawback is that a time trend only captures the overall impact of technological change. It cannot tell us whether all of the technological change that occurs during this time period results in more or less energy use. As an example, technological advances that lead to increased dependence on capital might increase energy use per unit of output as more energy is required to run additional machines. However, energy consumption may be more efficient than before.

In both cases, using time trends make it impossible to attribute the effect of technological change only to energy consumption. For example, (Mountain et al., 1989), find that technological advances were natural gas using during the period. This was because the natural gas price was low at that time. As a result, technological change tended to take advantage of low gas prices by using more gas than other energy resources. However, there may have been technologies that improved the efficiency of natural gas use during that period. This effect could not be identified because it only captures the total effect of technological change. Using patents, as is done by Mountain et al. (1989) , as an indicator of technological advances, avoids these problems. It is possible to identify the impact of technologies specifically related to energy consumption through the identification of those patents that are related to energy efficiency. Combining information on energy savings with information on the development of new patents with information resulting from new patents makes policy simulations possible (Popp, 2001).

Technological change in economic models

Technological change that increases output without an increase in productive inputs by product innovations can decrease energy demand and lower the cost of greenhouse gasses abatement policies. e.g., the higher energy efficiency of existing production processes and process innovations.

In general, technological change is considered as a non-economic, exogenous variable in economic models. Therefore economic activities and policies have no impact on new technologies. However, there is much evidence showing that technological change is endogenous variable and cannot be easily defined outside of the model. Therefore, a new generation of economic-environmental models treat technological change as endogenous that responds to policy variables, prices and investment in R&D. This approach makes it difficult to analyze the complicated process of technological change and empirical evidence of the determinants of technological change are still not clear (Löschel, 2002).

Modeling approaches: Bottom-up vs. top-down

There are two broad ways to capture the impact of technological change on the economy. They differ on the details of technology in the model. Bottom-up engineering is based on partial models that use a high level of details to measure substitution of energy resources at the primary and final energy level, process substitution, efficiency improvement or energy savings. Lack of interaction between other parts of the economy is the main disadvantage of these models. Technological change occurs once one technology substituted by another. Least cost optimization to meet a given demand for final energy subject to constraints selects the most effective technology in this type of models.

Technological change often involves the penetration of new technologies. New technologies are very quickly adopted in optimizing models because of higher efficiencies. Absolute shifts in these models neglect transaction costs in the energy system and market failures in demand and thus result in too optimistic estimates.

The top-down approach, on the other hand, has fewer details of the energy system and mainly considers interactions between economic sectors. They describe the energy system in a highly aggregated way by neoclassical production functions to capture substitution possibilities through substitution elasticities. There is not a description of technologies in these models and technology is considered as the cost of production at a commodity or industry level. Top-down models are classified as open (demand driven Keynesian) and closed (general equilibrium) models.

Macroeconometric models are based on time series data and consist of econometrically estimated equations without equilibrium assumptions. They include many economic variables but little structural detail. They are suitable for short or medium term evaluation and forecasting.

Computable general equilibrium(CGE) models have become the standard tool for the analysis of economy-wide impact of energy and environment policy and technological change. They concern the interactions between consumers and producers in the market. Household preferences and production of goods are usually captured by nested constant elasticity of substitution (CES) functions. They provide a consistent framework for studying price dependent interactions between energy system and rest of the economy. It is important as any change in energy system cause not only direct adjustments in energy markets but also indirect spillovers to other markets which in turn feed back to the economy (Böhringer & Löschel, 2012).

Technological change in top-down models is described as the relationship between inputs and outputs. Existing technologies are replaced as relative prices of alternative technologies change. Change in technologies are the result of substitution along a given production isoquant and shifts in the isoquant through changes in factor demand.

Moving from a static to a dynamic CGE

For dynamic models, the point of interest is far in the future when all short-run behavior has died out. The purpose of using a dynamic model is to represent how the variables of interest change over time. A change in endogenous variables by the consumer, producer and other agent's behavior in the economy or shock in exogenous variables or a parameter can shift the equilibrium relationships during the time (Ginsburgh & Keyzer, 2002).

This shift in equilibria can happen in a finite or an infinite time horizon. Some of the dynamic CGE models are designed for a finite time horizon. (e.g., T-period, temporary equilibrium, and single-period equilibrium models). The other category of dynamic models assumes an infinite period. (e.g., Negishi weights, OLG models).

(Dixon & Parmenter, 1996) classified dynamic CGE models in four categories:

The first group assumes that investment is exogenous in the equilibrium closure. The second category considers investment and capital accumulation in year t depend on expected rates of return in year t+1. These dynamics models assume that investment and capital are determined by actual returns and cost of capital in year t.

The third class of dynamic models assumes that expected rates of return for year t+1 are equal to actual rates of return for year t+1. Therefore, expectations are rational, and the model is consistent. The last category of dynamic models assumes that the behavior of investors is explicitly optimizing. Therefore, we continue to assume consistent model expectations.

There are two ways to move from a static to a dynamic model. The first method involves sequencing static equilibria for different and upcoming time periods. These are recursive dynamic models. A series of static CGE models are linked across periods by an exogenous and endogenous variable updating procedure.

The second approach is to write a CGE model in an entirely dynamic format and solve the model for the entire period simultaneously. This method is called non-recursive. The first two categories of mentioned models are recursive dynamic while the last two categories are no longer recursive as in Dixon and Parmenter (1996).

Equations in intertemporal models show how the economy develops. These models are best suited to focus of finding the trajectory of the economy. Although, the intertemporal model is harder to develop and build than static models, there are reasons to put effort into creating such models. First, policymakers are usually interested in how fast the economy moves toward the long run equilibrium, and the trajectory taken and whether or not path is smooth. It is useful to run an intertemporal model when the short and long-term effects of TC or policy are different.

The second reason is to incorporate intertemporal behavior by agents. If some agents decide to optimize their objective function by choosing between current and future resources, we need some form of intertemporal modeling. For example, a firm may choose to allocate resources across current and future production. Therefore, we have to use an intertemporal optimization function to find the optimal solution.

Finally, it is vital to integrate investment behaviour into CGE models. In such models, each firm chooses its level of investment to maximize the stock market value of equity. Market value in return depends on expected earnings in the future. A change in expectation changes the market value and therefore investment.

In this paper, an intertemporal dynamic CGE model is developed for the NZ economy. This kind of dynamic CGE is the result of intertemporal optimization behavior by agents.

Model

The intertemporal dynamic CGE model developed in this paper aims to study the dynamic impact of technological change in the industrial sector on the New Zealand economy focusing on investment decisions. We follow the assumption of a small open economy. The model classified the NZ economy into five economic sectors. Agriculture and Dairy (AFD), Fossil fuels (FOL), electricity generation and distribution (ELE), industrial sector (IND) and rest of the economy (ROE).

The household's endowments are capital (K) and Labour (L) on the demand side.

No	Economic sectors
1	Fossil fuels
2	Electricity generation and distribution
3	Industrial sector
4	Agriculture, farming and dairy products
5	Rest of the economy

Table 1 economic sectors in the model

No	Production factor
1	Capital
2	Labour

Table 2 production factors in the model

No	Final demand
1	Household
2	Government
3	Investment

Table 3 final demand sectors in the model

Model formulation

In this section, we start with the production side of the model and then move to dynamic behavior of capital and investment, and finally, the intertemporal utility function by consumers.

Non-energy output

Labor and capital are mixed at the lower nest, factor production is combined with an energy composite, after capital-labor and energy are merged with intermediate inputs. Finally, the product enters the domestic market or export overseas.

$$\prod\nolimits_{i,t}^{Y} = \left(\theta_i^X \left(p_{i,t}^X\right)^{1-\eta} + (1-\theta_i^X) p_{i,t}^{1-\eta}\right)^{\frac{1}{1-\eta}} - \left(\sum_{j \notin E} \theta_{ji} p_{j,t}^A\right) - (\theta_i^{KLE}) \left[\theta_i^E \left(AEEI.\, p_{i,t}^E\right)^{1-\rho KLE} + (1-\theta_i^E)\left(w^{\theta_i^L} r_K^{1-\theta_i^L}\right)^{1-\rho KLE}\right]^{\frac{1}{1-\rho KLE}} = 0$$

Where:

- AEEI : Autonomous Energy Efficiency Index,
- θ_i^X is the value share of ROW exports in sector i,
- $\theta_{ji}$is the cost share of non-energy intermediate input j,in sector i,
- θ_i^{KLE} is the cost share of KLE aggregate in sector i,
- θ_i^E is the cost share of energy in the KLE aggregate of sector i,
- θ_i^L is the labour cost share in sector i,
- η is the elasticity of transformation between production for the domestic market and production for exported market,
- ρKLE is the elasticity of substitution between the energy aggregate and the value added in non-energy production,
- Y is the associated complementary variable with non-energy output.

Energy Composite

In the energy part of the model, we have fossil fuels as an aggregated product (oil, gas and coal). Electricity combined with them to have energy composite as an input for other sectors.

The unit profit function for energy aggregate can be written as:

$$\prod\nolimits_{i,t}^{E} = P_{i,t}^E - \left[\theta_i^{ELE}\left(P_{ELE,t}^A\right)^{1-\rho ELE} + (1-\theta_i^{ELE})\left(P_{FOL,t}^A\right)^{1-\rho ELE}\right]^{\frac{1}{1-\rho ELE}} = 0$$

Where,

- θ_i^{ELE} is the cost share of electricity in energy demand by sector i,
- ρELE is the elasticity of substitution between electricity and non-electricity energy goods in production,
- E is the associated complementary variable.

Armington Production

Armington assumption used for international trade. Intermediate goods that we use for the production is a mixture of domestically and imported goods which a virtual firm combine them together and sell the final product to domestic market.

The unit profit function for Armington composite can be written as:

$$\prod_{i,t}^{A} = P_{i,t}^{A} - \left[\theta_i^A \left(P_{i,t}\right)^{1-\rho A} + \left(1-\theta_i^A\right)\left(P_{i,t}^{M}\right)^{1-\rho A}\right]^{\frac{1}{1-\rho A}} = 0$$

Where:

- θ_i^A is the cost share of domestic variety i in Armington aggregate good,
- ρA is the Armington substitution elasticity between domestic and imported varieties of the same good,
- A is the associated complementary variable.

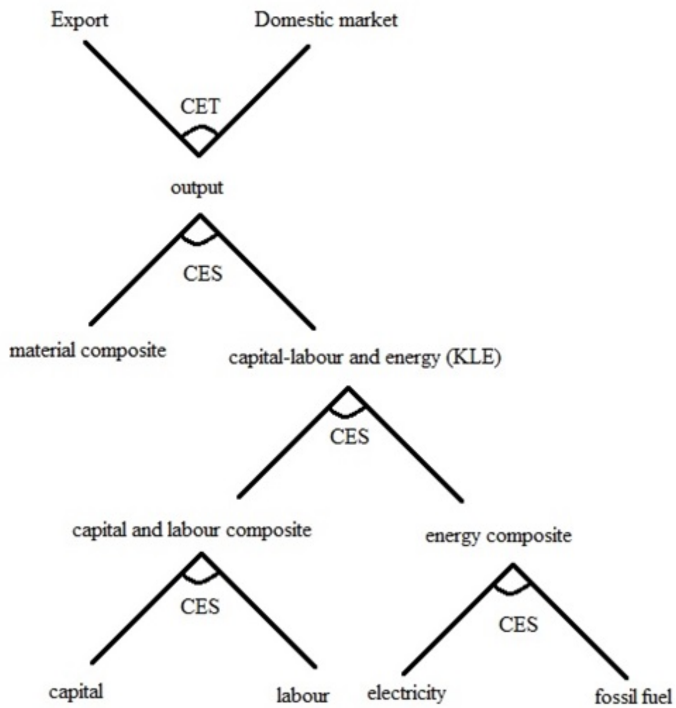

Figure 1 nesting structure of production in intertemporal dynamic CGE model

$$\prod_{i,t}^{A} = P_{i,t}^{A} - \left[\theta_i^A \left(P_{i,t}\right)^{1-\rho A} + \left(1-\theta_i^A\right)\left(P_{i,t}^M\right)^{1-\rho A}\right]^{\frac{1}{1-\rho A}} = 0\theta_i^A \rho AA\mathrm{A}$$

Capital

We assume full employment of factors in the model. There is a difference between capital in a static CGE model and an intertemporal dynamic CGE. While capital consumed in one period in a static model, the next period capital stock is built from investment and capital less depreciation in an intertemporal framework. Investment decisions in one period have an impact on the next year and following periods.

Capital accumulates as follows:

$$K_{t+1} \geq (1-\delta_t)K_t + I_t$$

To assure the intertemporal zero-profit conditions an efficient allocation of capital, i.e., investment is necessary. The cost of a unit investment, return to capital, and the price of a unit capital stock in period t is given by:

$$\prod_t^K = P_t^K - r_t^K - (1-\delta)p_{t+1}^K$$

And also,

$$\prod_t^I = p_t^I - p_{t+1}^K \geq 0$$

Where:

P_t^K is the value of one unit capital stock(purchase price) in period t

δ is the depreciation rate,

p_t^I is the cost of one unit investment in period t (equals to p_t^A in this model),

K_t is the associated complementary variable that shows the activity level of capital stock formation in period t,

I_t is the associated complementary variable that shows activity level of aggregate investment in period t.

Market Clearance Conditions

Market clearance conditions show that a commodity that has a positive price should have a balance between supply and demand. Therefore, any good with excess supply should have a zero price. By differentiation of the unit profit function with respect to the price, we can get compensated supply and demand quantities. The price of each quantity is the associated complementarity variable.

Capital

Market clearance condition for capital is:

$$\overline{K_t} = Y_t \frac{\partial \prod_t^Y}{\partial v_t}$$

Labour

Market clearance condition for labor force is:

$$\overline{L_t} = Y_t \frac{\partial \prod_t^Y}{\partial w_t}$$

Shows the supply-demand balance for labor, where:

$\overline{L_t}$ is the exogenous endowment of time in period t

Time endowment grows at a constant rate. This rate (g) determines the long run growth rate of the economy (Steady-state)

Output for domestic markets

$$Y_t \frac{\partial \prod_t^Y}{\partial p_t} = A_t \frac{\partial \prod_t^A}{\partial p_t}$$

Output for export markets

$$Y_t \frac{\partial \prod_t^Y}{\partial p_t^X} = A_t \frac{\partial \prod_t^A}{\partial p_t^X}$$

Armington Aggregate

$$A_t = Y_t \frac{\partial \prod_t^Y}{\partial p_t^A} + C_t \frac{\partial \prod_t^C}{\partial p_t^A} + I_t \frac{\partial \prod_t^I}{\partial p_t^A}$$

Household Consumption aggregate

$$C_t = D_t$$

Where:

D_t is uncompensated final demand, derived from lifetime utility maximization.

Household

A representative household combines fossil fuel and electricity in the lower nest for energy composite and then mixed that with non-energy Armington goods for the final consumption.

The unit profit function for the production of the final consumption good is:

$$\prod^{C,t} = P_{c,t} - \left\{\theta_C \left[\prod_{i \notin EG} (P_{i,t}^A)^{\gamma_i}\right]^{1-\rho C} + (1 - \theta_C)\left[\theta_{ELE}^C (P_{ELE,t})^{1-\rho_{ELE}^C} + (1-\theta_{ELE}^C)\left[P_{ff,t}\right]^{1-\rho_{ELE}^C}\right]^{\frac{1-\rho^C}{1-\rho_{ELE}^C}}\right\}^{\frac{1}{1-\rho^C}} = 0$$

Where:

- θ_C is the cost of non-energy composite in aggregate household consumption,
- θ_{ELE}^C is the cost of electricity in household energy aggregate demand,
- γ_i is the cost share of non-energy good i in non-energy household demand,
- ρC is the elasticity of substitution between energy and non-energy goods in household consumption,
- ρ_{ELE}^C is the elasticity of substitution between electricity and non-electricity energy in household consumption,
- C is the associated complementary variable.

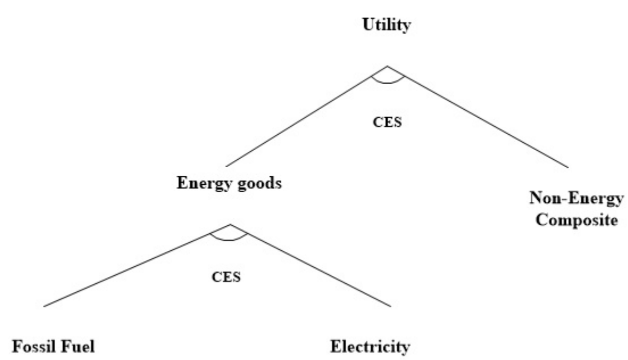

Figure 2 Utility nested function of representative household in the intertemporal dynamic CGE

In a Ramsey model a representative consumer maximizes the present value of lifetime utility:

$$W = max \sum_{t=0}^{\infty} \left(\frac{1}{1+\rho}\right)^t U(C_t)$$

$$s.t. \sum_t p_t^c C_t = M$$

Where:

$U(C_t)$ is the instantaneous utility function of representative agent,

ρ is time preference rate of representative agent (discount rate),

M is the lifetime income of representative agent,

In our model, a representative household receives its income (M) from providing primary factors, capital and labor.

$$M = P_L L + P_K K_0$$

P_L is the wage for labour and P_K is the price for capital.

The isoelastic lifetime utility of instantaneous utility function:

$$(C_t) = \frac{C_t^{(1-1/\emptyset)}}{1-1/\emptyset}$$

Where:

$\emptyset$ is the constant intertemporal elasticity of substitution

Uncompensated final demand function is:

$$D_t(p_t^c, M) = \frac{(1+\rho)^{-t\phi}}{\sum_t (1+\rho)^{-t\phi} p_t^{c\,1-\phi}} \frac{M}{p_t^{c\,\phi}}$$

Terminal condition

We cannot solve an intertemporal model for an infinite number of periods and a finite horizon is needed to solve the problem numerically. However, this approximation causes problems with capital accumulation. Therefore, to avoid such a problem, we should somehow terminal the capital (Paltsev 2004; Lau et al. 2002). Without this condition, all the capital will be consumed in the last period and there is no capital remaining for the next period's investment. This condition forces investment for an increase in proportion to final consumption demand. The post terminal capital K_{T+1} is introduced as an endogenous variable and the terminal condition follows (Lau et al.,2002). This condition means terminal investment growth rate equal to steady state growth rate.

$$I_T / I_{T-1} = 1 + gr$$

Where:

- gr is the growth rate

Data

We used the most recent available Social Accounting Matrix of New Zealand published in 2007 by NZ Statistics. There are 106 industries and 205 commodities groups in the national accounts. The primary purpose of this study is to investigate the impact of industrial energy efficiency improvement on the economy, especially on dynamic variables. We used a reduced form of social accounting matrix by aggregating industries in five sectors. Fossil fuels (FOL), electricity generation and distribution (ELE), industrial sector (IND), agriculture, farming and dairy products (AFD), rest of the economy (ROE) are production sectors in this model.

Also, for calibration of dynamics, we used the official cash rate as a discount rate and factor growth. To be consistent with other data, we used the OCR in 2007 that was 8%. Intertemporal elasticity of substitution is assumed to be 2 and obtained from the literature. Also, long term growth rate is equal to 2.9 percent that has been the long run GDP growth of New Zealand. The model is calibrated through 2030.

Results

In this part, we calibrate our model according to 2007 data for New Zealand. The pathway of the economy with the current rate of economic growth until 2030 shows how economy develops. Also, we can see the capital stock growth in each sector until 2030. Figure 3, 4 shows the steady state of output for each sector in baseline scenario. We can see the long run growth rate is defined as 2.9 percent per year.

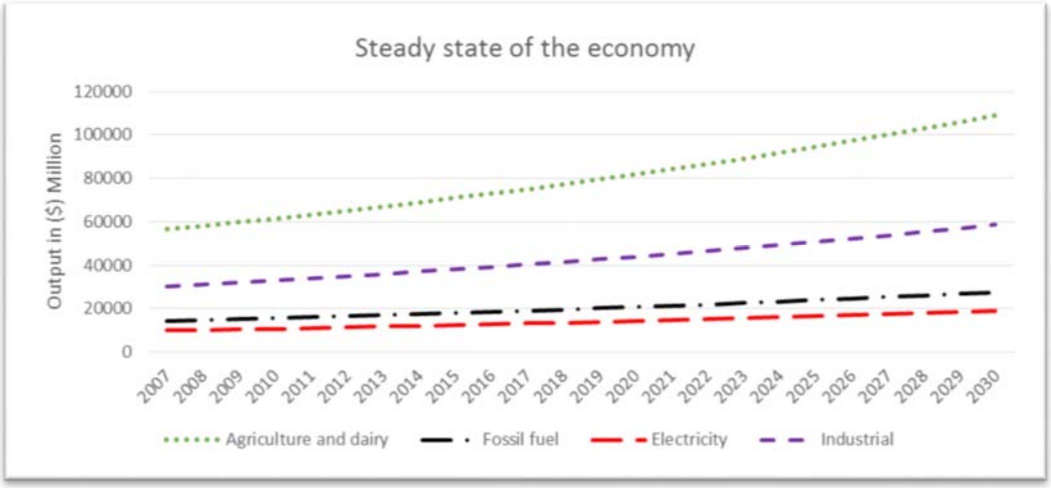

Figure 3 steady state of the economy in reference scenario

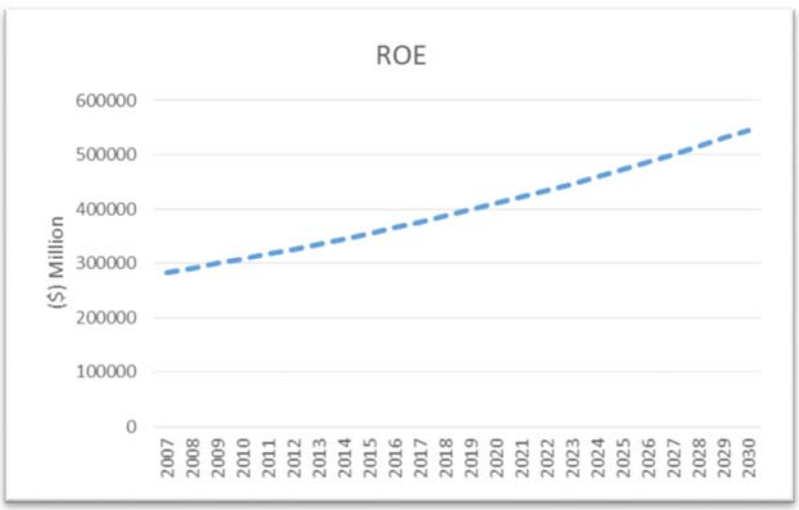

Figure 4 steady state of rest of the economy in reference scenario

Agriculture, farming and dairy had the highest share of production compared to industrial, electricity and fossil fuel in NZ GDP in 2007.

However, figure 5 shows the capital stock pathway in the baseline scenario. We can see that the industrial sector has the highest share of capital stock compared to other sectors, showing that industrial production is capital intensive.

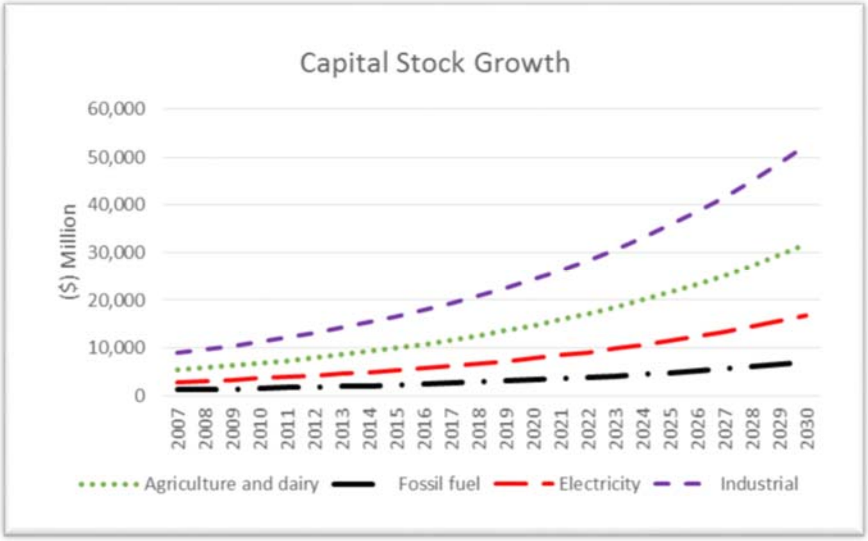

Figure 5 capital stock growth in the baseline scenario

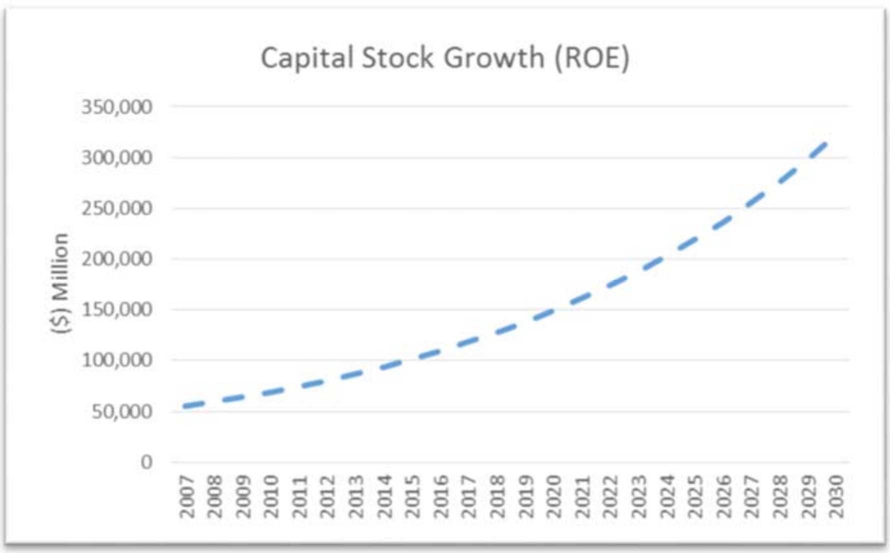

Figure 6 capital stock growth in the baseline scenario in the rest of the economy

Energy savings simulation

In this part, we examine the impact of introducing an energy-efficient technology by industry, assuming 10 percent energy savings for the entire industrial sector in New Zealand. This can be the result of innovated domestically or imported technology. We apply 10% change in AEEI parameter in the production function of industrial sector. By comparing results with the baseline scenario, we can see how these energy savings have an impact on output and capital stock in different sectors of the economy.

Agriculture and farming

This sector had a relatively high share in the New Zealand economy in 2007 (baseline year). Our results show that after applying an energy savings technology in the industrial sector, agriculture output decreased until 2011 because capital moves to industrial sector as a result of higher demand for capital to invest in industrial production. The main reason for this is that industrial production is more profitable compared to other economic sectors. However, after 2011, agriculture and farming output increased and returned back to the steady state of the economy again because there is no new demand for capital in the industrial sector and labour substitution in agriculture production. Also, demand for agriculture, farming and dairy products put pressure on supply for this sector resulting in a rise in the output.

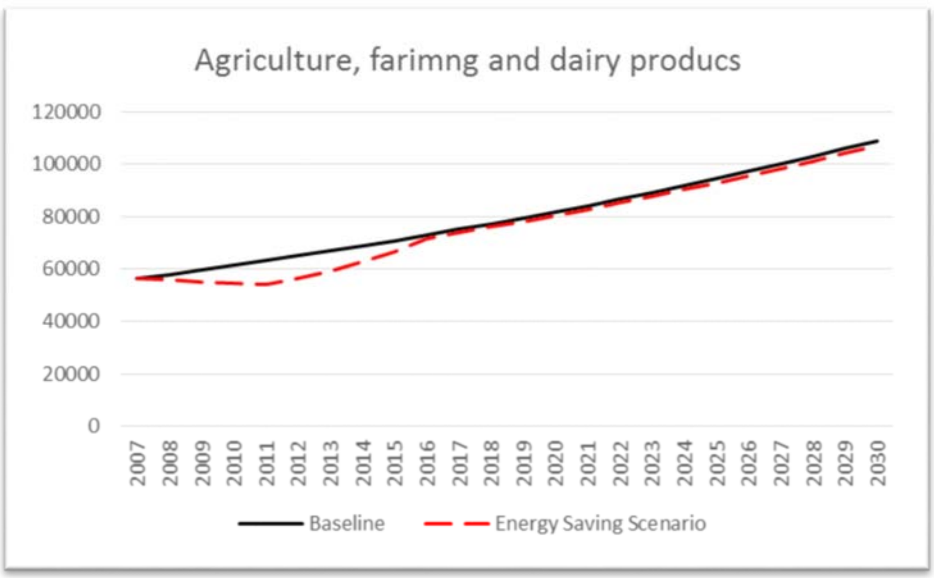

Figure 7 steady state of agriculture and farming output

In the first year there is no change in capital stock; however, investors find industrial sector more attractive to invest and they move their capital to the industrial sector and no new investment in the agriculture occurs until 2011. Investors bring back their investment into the agriculture sector as a result of saturation of capital in the industrial sector and an ongoing demand for agriculture and farming products that make it profitable sector. Figure 8 shows how capital stock in Agriculture, farming and dairy returns back to its long run growth after implying TC in industrial sector.

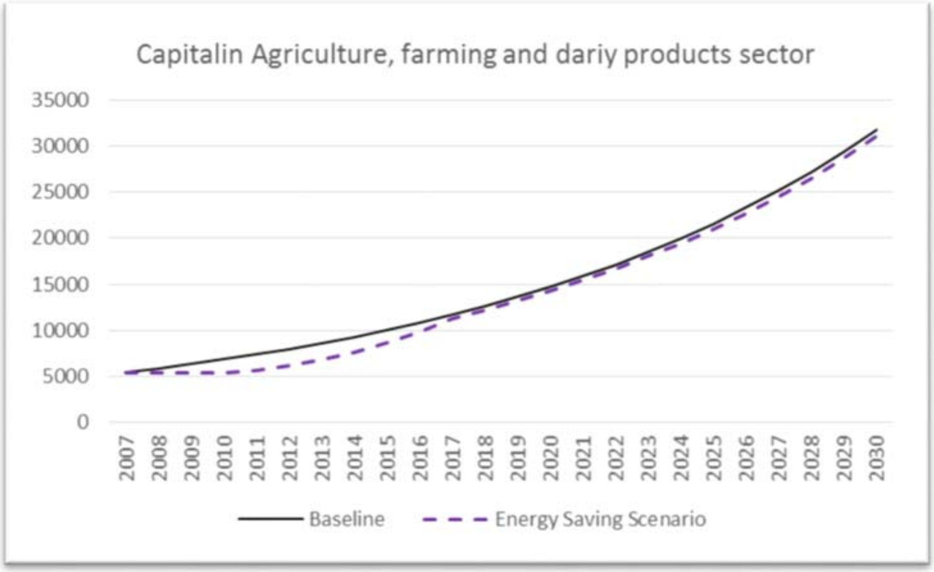

Figure 8 capital stock growth of agriculture and farming and dairy sector

Fossil fuel

Because around one-third of energy is consumed by industry, introducing TC into the industrial sector, we expect demand for energy is fall. The output of fossil fuel decreases through 2011. This is because of a lower demand by industrial and electricity sector to generate electricity. From 2011 output increases as a result of an increase in demand for energy arising from increased industrial production (higher profit in this sector). So, we can see the negative impact of industrial TC on fossil fuel consumption. In 2016, fossil fuel production returns to the long run steady state of the economy.

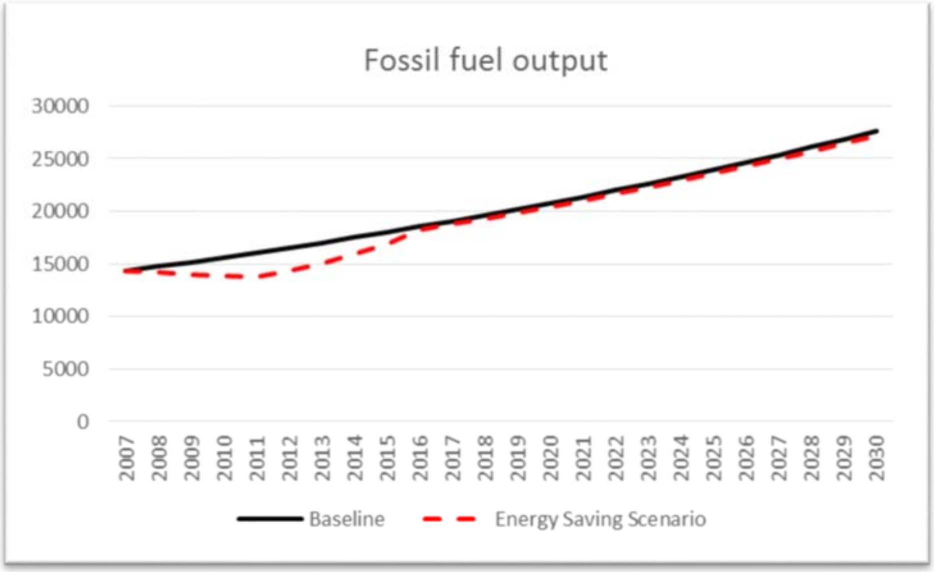

Figure 9 steady state of fossil fuel sector

Figure 10 shows how capital stock growth during the time for fossil fuel sector. Similar to agriculture and farming sector, in the first year no change in the capital stock is observed. However, growth in capital stock is flat until 2011 and then increase afterward. This trajectory arises from the high cost of moving capital and investment requires a longer time to have a return in this sector. Infrastructure (capital) in this sector are not easy to move to other sectors. So, it takes longer to move capital from this sector. However, new demand for fossil fuels after 2011 does not allow capital movement.

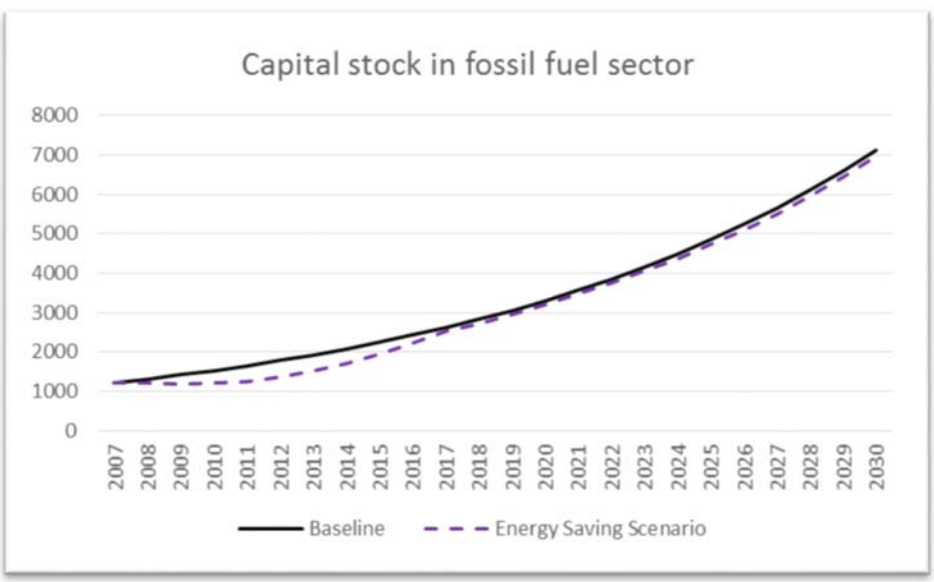

Figure 10 capital stock growth of fossil fuel production

Industrial sector

TC in this sector is expected to result in an increase in industrial production. More efficient use of energy results in more output with the same amount of input. Applying energy savings technology in 2007, we observed in output increase until 2014. However, after 2014 a reduction in industrial output happens and continues until 2018. The reason for this reduction is that inputs such as labour, capital and raw materials are more proportionally employed in other sectors. A competitive market for inputs will change the direction of inputs to those sectors. However, after 2018 we come back to the steady state of the economy with a higher amount of output from industry compare to the baseline scenario.

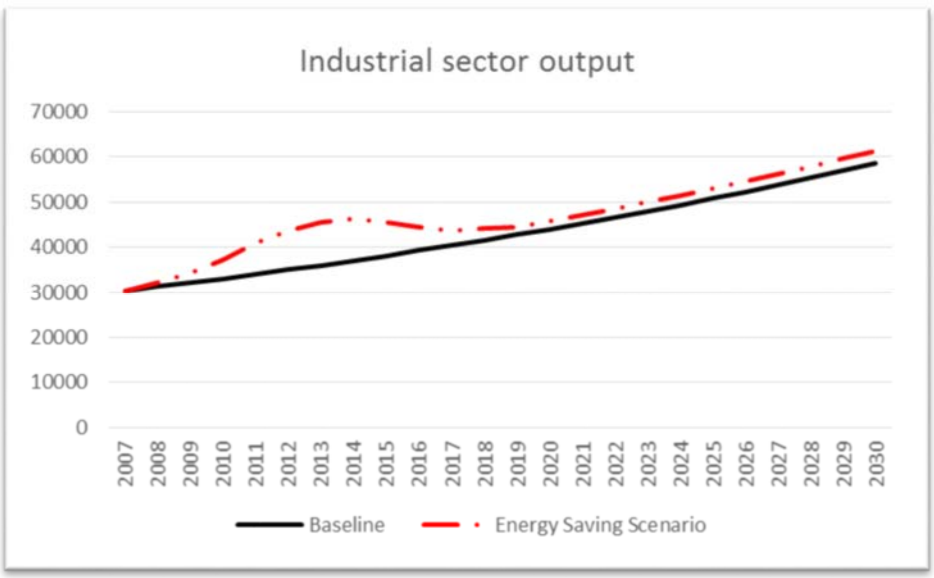

Figure 11 steady state of industrial output

In contrast to other parts of the economy, we see the flow of capital to industrial production. This is the result of a higher return to capital in this sector. Although we have a reduction in capital stock between 2014 and 2015, this trend is always positive.

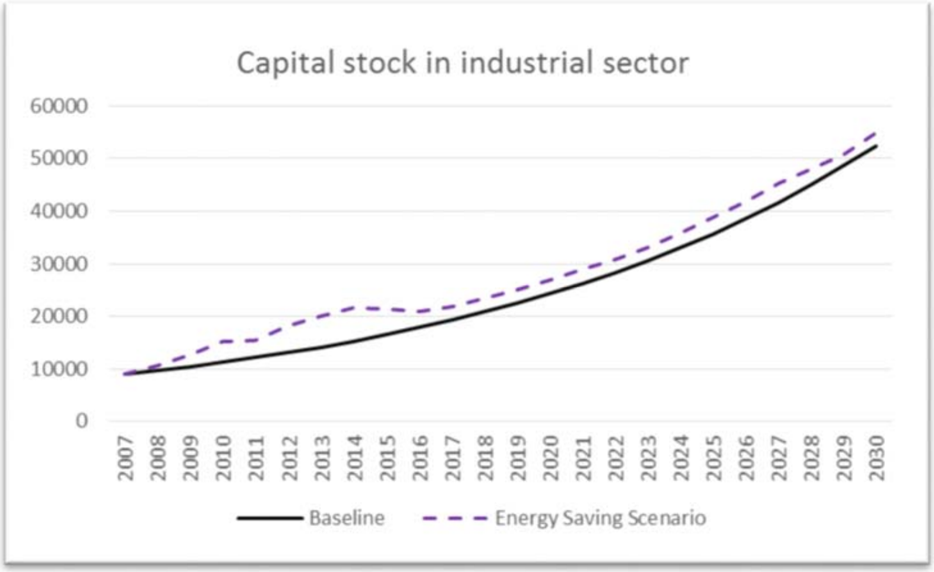

Figure 12 capital stock growth of industrial production

Electricity

Electricity is the primary source of energy for most industrial production in New Zealand. we expect a decrease in output will happen to this sector as a result of introducing TC into the industrial sector. However, electricity is inelastic and we cannot expect a huge decrease in electricity demand as a result of energy savings technology especially from residential sector. After 2011, increasing trend of production will continue until we get to the steady state of the economy.

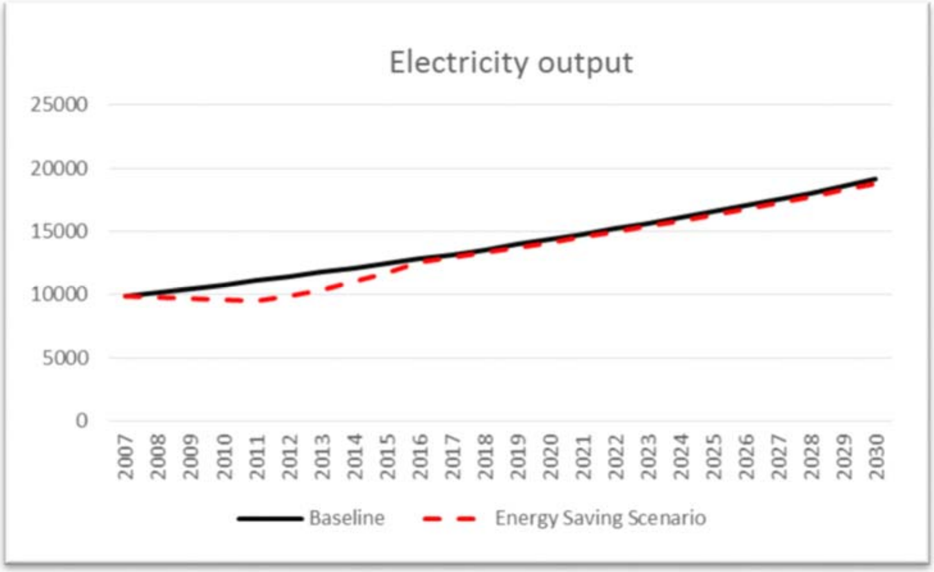

Figure 13 steady state of electricity generation and distribution

Figure 14 shows there is not a new investment in electricity sector until 2011; the capital stock is almost fixed until 2011, however, the new investment required as a result of higher electricity demand by growth in the industrial sector.

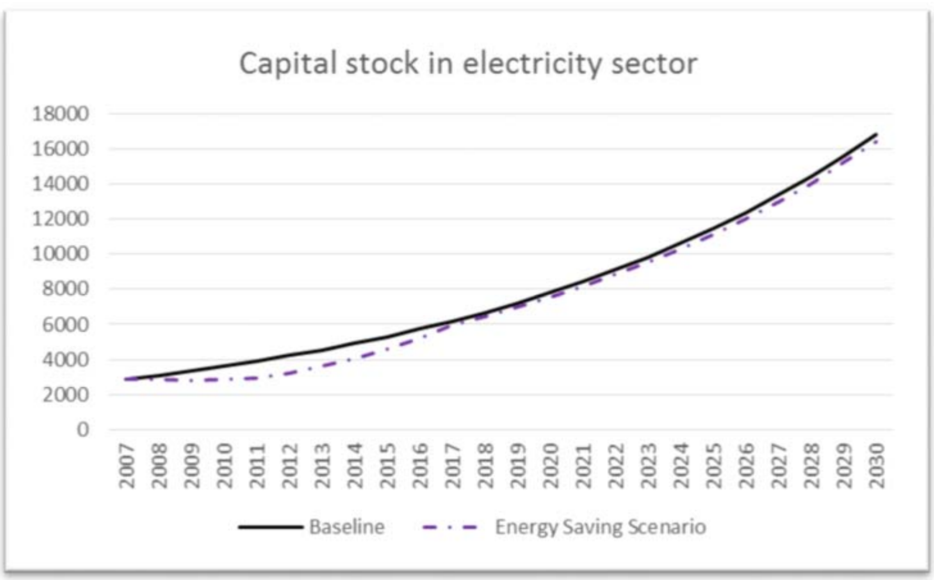

Figure 14 capital stock growth electricity sector

Rest of the economy

In this paper, rest of the economy is considered as an aggregate of non-energy intensive sectors. A change in relative prices, especially input prices can impact output. Our result shows a relatively fixed level of output until 2011. However, this sector returns back to the long run equilibrium pathway with a higher rate between 2011 and 2014 as a result of capital movement.

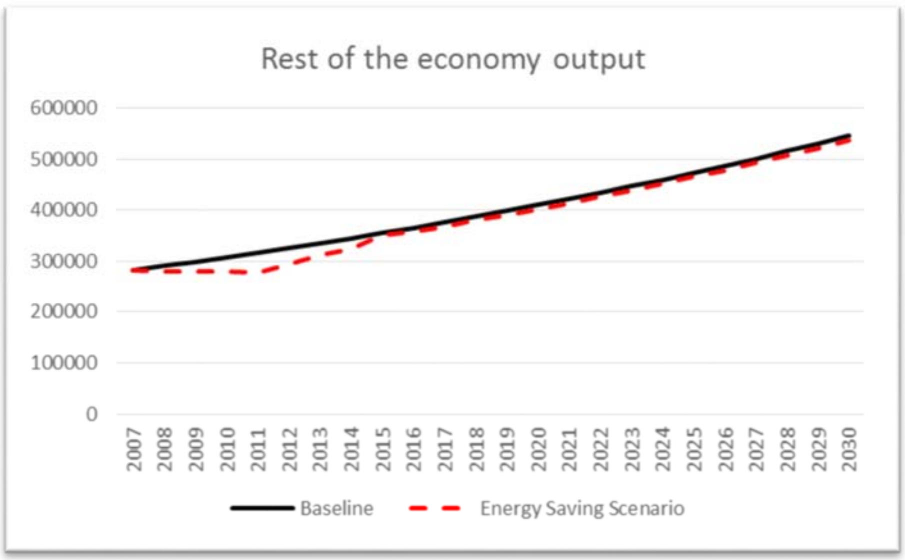

Figure 15 steady state of rest of the economy

Figure 16 shows capital stock in the rest of economy, until 2010 there is no change in capital stock in this sector. This is because investors find industrial sector more attractive to invest. However, investors take out their capital from industrial sector and invest in the other sectors of the economy after 2010.

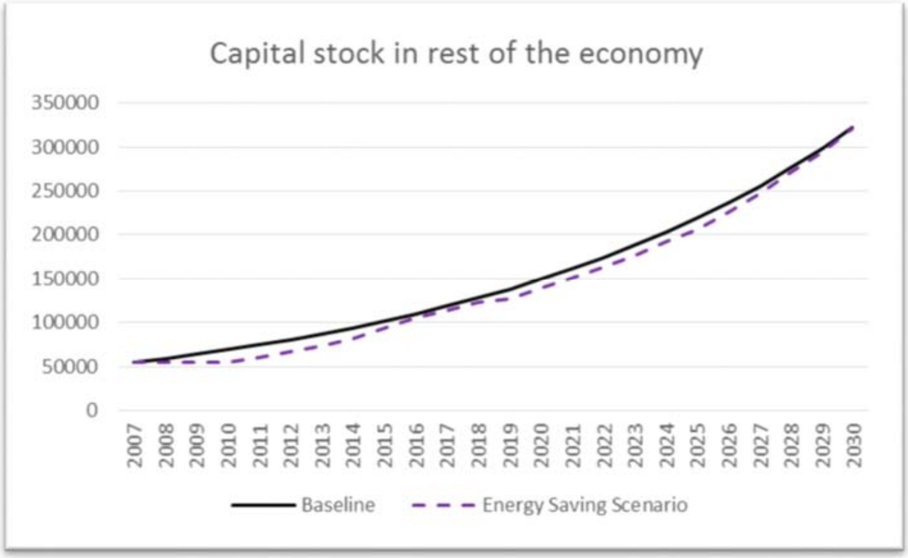

Figure 16 capital stock growth in the rest of the economy

Sensitivity analysis

Sensitivity tests are check the model's robustness. Considering alternative energy efficiency improvements for the industrial sector at 7% and 12%, we conduct a sensitivity test of energy efficiency improvement into industrial sector compared to the 10% scenario.

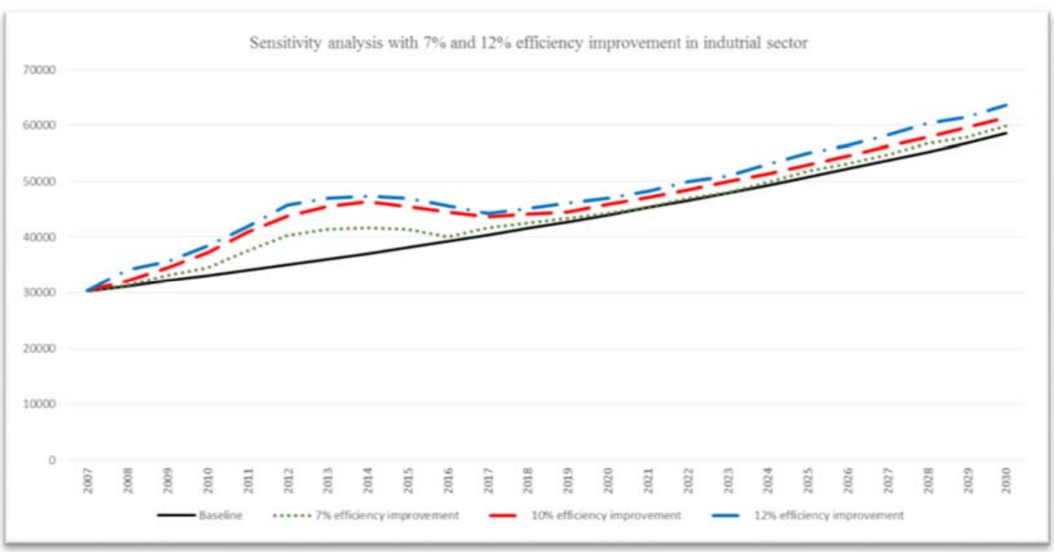

Figure 17 sensitivity test at different levels of efficiency improvement in the industrial sector

Figure 17 shows a higher output in industrial sector at 12% efficiency improvement while a lower output observed with 7% increase in energy efficiency. However, output with 10% remains between 7% and 12% in the whole period. Also, at any level of efficiency improvement, we can see a higher output in industrial sector compare to the baseline scenario.

Conclusion

Increasing energy efficiency during past decades has resulted in a reduction of industrial energy intensity. However, due to higher industrial production, growth in energy demand exceeded energy saved. Improved energy efficiency can limit energy demand and industrial greenhouse emissions as it results in decreased fossil fuel energy consumption. Considering relative share of energy demand, the adoption of energy-saving technologies will likely impact relative prices, supply, patterns of production and consumption, and investment within the sector and, possibly, throughout the economy. To capture the impact of a technological change, we need to consider interactions between sectors. TC can impact investment decisions by public and private investors resulting in capital moving between sectors to achieve a higher return. In this paper we focused on the diffusion stage of TC as classified by Schumpeter (1934). An intertemporal dynamic CGE model is developed for New Zealand to capture the impact of industrial TC on investment decisions and the economy.

We explained the structure of an intertemporal dynamic CGE model. This approach is to specify a CGE model in an entirely dynamic format and solve the model for entire period simultaneously. Equations in these models show how the economy adjusts to technological innovation over time. Following are the main advantages of an intertemporal dynamic compared to a recursive CGE model.

- It is possible to find how fast the economy moves toward the long run equilibrium and whether the trajectory is smooth or not. It is particularly insightful to run an intertemporal model when the short and long-term effects are different.
- We can incorporate intertemporal behavior by agents. If face the choice of deciding between current and future investments, we need some form of intertemporal modeling.
- The investment behavior is important to integrate into a CGE model. In such a model, firms choose its level of investment to maximize the stock market value of equity. Market value in return depends on expected earnings in the future. Therefore, change in expectation changes the market value and therefore investment.

In order to link investment behavior to TC, we studied the role of an energy savings technology in the industrial sector. By implying AEEI parameter and assuming a 10% energy efficiency in industrial production, our results show that capital will move to energy-intensive sectors and an increase in the production of energy-intensive sectors is observed. However, in the long term we will get back to the equilibrium in industrial sector. This is because the economy has not enough capacity to expand industrial production (e.g., limitation in the intermediate goods for production and/or labor force, etc.) and also other sectors will compete to absorb capital to get back to the equilibrium growth pathway. However, equilibrium growth returns at a higher level of output as a result of this TC. Our results show that only industrial production will have a jump in the output and motivate investors to move their capital to this sector. This is because of a higher return to capital as a result of a TC. Production in other sectors declines as they face a reduction in capital stock in the first few years of introducing a TC. However, they return back to the long run equilibrium after few years. Generally, we can see a higher output for whole the economy as a result of this TC for all sectors. This is in line the role of technological change in economic growth theory.

Limitations for this research includes lack of updated data and complexity of an intertemporal dynamic CGE model that force us to use some assumption to simplify the model. Also, we assumed 10% energy savings by using efficient technology to simulate the economy after a direct TC. However, we are not sure about such an improvement in the economy as a result of domestically or imported technology, especially in whole the economy. Also, we should consider endogenous TC as a result of investment in other sectors as well as spillover of TC on the other sectors. A suggested area for future study is to include endogenous TC by modelling investment in R&D.

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