Capital Accumulation, Growth and Redistribution: General Equilibrium Impacts of Energy and Pollution Taxes in UK

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ABSTRACT

This paper investigates how the capital accumulation across sectors generates higher rates of economic growth across sectors but also raises the level of pollution analysing the results from the multisectoral and multi household dynamic general equilibrium models of energy and environment taxes for the UK economy (GEMEETUK). Growth and redistribution are analysed simultaneously including the optimal labour leisure choices of households who are under their budget constraints and subject to lower level of lifetime utility because of environmental taxes. The pollution taxes on the use of capital and labour inputs in production across sectors link the energy, environment and growth of economy where air, water, land pollution is essentially a by-product of processes of production. How the evolution of economy differs with and without energy and pollution taxes are shown using dynamic series of model results on output, employment, investment and capital stocks by sectors and households at micro level and corresponding aggregates at the macroeconomic level with a conclusion that the mechanism of pollution control should rely on energy saving or energy efficiency measures than on the energy and environmental taxes to let economy move in the balanced growth path.

Key words: **Growth, redistribution, energy, pollution, UK economy**

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I. Introduction

How the man made factors of production, buildings and structures, machines and equipment, networks of transport and communication, skill and expertise including those contained in the specialised software enhance the productivity of workers is well investigated in the literature (Maddison (1991), Ramsey (1928), Hicks (1937), Harrod (1939), Domar (1947), Solow (1956), Kaldor (1961), Uzawa (1962) Cass (1965), Koopmans (1965), Lucas (1988), Romer (1989), Parente (1994), Perroni (1995), Sargent and Ljungqvist (2005)). How they fit in the multisectoral dynamic real economy benchmarked to the detailed micro-consistent data contained in the input output table of an economy is of more recent development (Auerbach and Kotlikoff (1987), Rutherford (1995)[2], Kehoe, SriNivashan and Whalley (2005)). Earlier multisectoral models such as Leontief (1949), Harberger (1962), Jorgensen (1961) Ballard-Fullerton-Shoven-Whalley (BFSW(1985)), and Robinson (1991), Fullerton and Rogers (1993), Mercenier and Srinivasan (1994) and Dixon et al. (1992) had mainly relied in the comparative static framework. Bohringer and Rutherford (2004) Grubb (2004) Green and Newbery (1992), Manne and Richel (1992), McFarland, Reilly and Herzog (2002) Nordhaus (1979), Perroni and Rutherford (1993), Backus and Crucini (2000), Boyd and Doroodian (2001), Coupal and Holland (2002), Grepperud and Rasmussen (2004), Jansen and Klaassen (2000), Kumbaroglu (2003), Spear(2003) and Thompson (2000) use partial or general equilibrium models with the electricity sector to examine how does pollution arise in process of generating energy required for efficient functioning of the economy. How the production in a modern economy generates pollution at the national level and how it affects the climate change and burden and dividend sharing from improvement of environment from emission control at the global level among economies under the Montreal or Kyoto protocol and their consequences in economic growth are examined in several studies including those of Aronsson, (1999), Bohringer and Conrad and Loschel (2003), Crettez and Aronsson (1999), Crettez (2004) Dissou, Mac Leod, and Souissi (2002), Faehn and Holmoy (2003) Nordhaus and Yang (1996),

[2] The development of the mixed complementarity solution technique in 1990s, particularly with the GAMS/MPSGE software in recent years has made it easier to solve large scale models (Brook, Kendrick and Meeraus (1992), Rutherford (1997), Dirkse and Ferris (1995)).

Proost and Van Regemorter (1992), Rasmussen (2001), Kumbaroglu (2003), Roson (2003) , Uri and Boyd (1996) and Vennemo (1997). Despite so many studies in these areas there apparently lacks a study that measures and demonstrates the level of pollution generated in the process of production and how the environment and energy sector taxes in the use of labour and capital inputs in production can be used to control such pollution and to show the effects of such measure on the growth, investment and capital accumulation in the UK economy. This paper aims to answer these questions with a dynamic multisectoral and multi-household general equilibrium model of energy and environmental taxes for the UK (GEMEETUK). The model specification is based on Bhattarai (1999, 2003, 2007).

Large scale dynamic models are able to trace the impact of policy changes on investment and saving activities and accumulation and growth of capital stocks, on growth rates of output, employment and functional distribution of income in those sectors, improvement in the living standards as reflected in the level and growth of utilities for each categories of households and on the level of pollution rising as a consequence of these activities. These models can be used to find answers to measure the damage that occurs to the economy from pollution generated by vehicles, aircrafts and ships and submarine transports, factories, electricity generators that have raised the level of global warming and resulted in unprecedented environmental catastrophes including hurricanes, soil erosions, floods, draught and deforestation and see how these have cumulatively led to degradation in the quality of lives of human and animal, birds and sea animals over the coming years. Economists together with other scientists have attempted to assess the amount of damage of such encroachment into environment using dynamic general equilibrium models of one or multiple economies with proper appreciation of interactions among them. The pollution generated in this manner affects not only the national economy but has global consequences. This study aims to provide an assessment on such consequences based on a fairly decentralised market economy model benchmarked to the micro-consistent data contained in the input-output table for the UK economy.

Capital stock at any point of time is result of the investment undertaken over years and such investment is possible from savings made by households who sacrifice current consumption in anticipation of higher rate of consumption in future years. An economy where the choices and activities of households are well coordinated over time can generate higher amount of capital stock compared to one that cannot coordinate such activities because of inefficient financial system and hence lags behind in the process of accumulation and growth. Right set of policies can lead to environment friendly growth and wrong policies produce harmful pollutants, perhaps at a faster rate than that of capital. A dynamic model with many households and firms is a right tool to investigate these important issues.

The GEMEETUK model includes ten categories of households differentiated by their levels of income who decide on consumption, labour-leisure and savings considering their life time budget constraints and preferences. The major objective of each household is to maximise their life time utility subject to its time and capital endowments. Investors, in each period of the model, allocate investment across sectors looking at the marginal productivity of capital among industries making sure that more productive sectors get more investment than less productive ones. Economy is open to trade with the rest of the world, either with requirement that the trade need to balance in each period or on the inter-temporal basis. The government collects direct and indirect taxes to provide for public consumption or to transfer some of it to low income households. By Walras' law relative prices change until the demand equals supply in all goods and factor markets for each period and for the entire model horizon.

II. General Description of the Model

A general equilibrium model is a complete specification of the price system in which quantities and prices are determined by the interaction of both demand and supply sides of goods and factor markets. It can be applied to measure consequences of economic policy on growth, accumulation and pollution over time and also to determine how a government can influence market outcomes by distorting the equilibrium prices by means of taxes and transfers. It can show how the labour leisure choice of households and employment level of firms, growth rate of output, employment and capital and the investments occurs through the optimization process of the households, firms and traders and how one set of policies can be more efficient than others in generating the optimal levels of utility for all households leading to just and best social welfare result for the economy.

a. Preferences

Various specifications of utility functions are used to represent the level of welfare of households from consuming goods and services and leisure in an economy. Time separable constant elasticity of substitution (CES) utility function with three levels of nests is used here to capture the intra- period and inter temporal substitution between consumption and leisure based on relative prices and wage rates in the economy. The first level of nest aggregates the goods and services in composite consumption good, then the second level nest aggregates these composite goods with leisure. Then there is the nest of time separable utility functions to arrive at the life time utility for each household. Pollution reduces household utility as households pay for its abatement. The consumption shares of various goods are calibrated from the benchmark dataset (see Barker, Blundell and Micklewright (1989) for more in depth study on demand side parameters of household demand functions).

b. Production technology

A production technology shows how inputs are transferred into outputs. Usually labour, the human toils and trouble in process of production; capital, the man made means of production, as reflected in building, structures including highways, communication networks and education, health and environmental system; natural resources including clear air, water, and mineral and energy products represent such inputs. In addition there are intermediate inputs as presented in the 123 sector input output table. Intensity of use of these factors in a specific industry or a firm is reflected by a production function, the CES categories of these functions being the most commonly used ones in the economic literature as they capture the cross price elasticity more efficiently than any other linear or Cobb-Douglas production functions.

c. Trade arrangements

It is well known from the time of Ricardo that an economy benefits from trade by exporting products in which it is more efficient and by importing ones in which its comparative advantages are minimal. In a free trade regime the volume of trade is significantly influenced by the efficiency of production technology of firms and preferences of households for the domestic and foreign products. Such preferences implicitly determine the elasticity of substitution and transformation between domestic and foreign products as well as the terms of trade among trading partners.

d. Government sector balances

Government receives revenues from direct and indirect taxes and tariffs. These taxes affect the marginal first order conditions for optimal conditions of demand and supply functions for efficient allocation of resources for consumption, production and trade. The government may strategically adopt a number of policies adopting the balanced or deficit or cyclically balanced budget and get debt levels tied to the certain percentage of GDP as fixed by the Maastricht treaty. Which one of the tax instruments is optimal and most efficient source of revenue may partly depend on preferences of households and the size of the government in economic activities.

e. Definition of equilibrium for a growing economy

Equilibrium is a point of rest, where the opposing forces remain in balance. Theoretically there has been much work, since the time of Adam Smith and Walras to Arrow-Debreau-Hahn-McKenzie for finding whether it exists, or is unique or is stable along with analysis of Pareto efficiency for a centralised or decentralised economy. In abstract level existence of equilibrium or Walras' law is proved using a unit simplex and Brouwer's fixed point theorem in which the uniqueness is guaranteed by the choice of preferences and technology and trade functions that fulfil continuity, concavity or convexity or twice differentiability properties. In applied policy work, numerical methods are adopted to find the solutions of these models as the explicit analytical solutions are possible only for very small scale models that hardly represent highly complicated mechanism in a modern economy.

Theoretically a general equilibrium in an economic system is described by a system of $n(n-1)$ relative prices that clear all goods and factor markets. It is stated in terms of vectors of prices, demand and supply and excess demand functions for inputs and outputs. Given the vector of prices $p=\left(p_1, p_2,.,..,p_j,..,.,..,p_n\right)$, demand for commodities are expressed in terms of the price vector $X_j^d = X_j^d(p) = X_j^d\left(p_1, p_2,.,..,p_j,..,.,..,p_n\right)$ and supply functions defined similarly $X_j^S = X_j^s(p) = X_j^S\left(p_1, p_2,.,..,p_j,..,.,..,p_n\right)$ and the excess demand functions reflect the gap between demand and supply for each commodity $E_j(p) = X_j^d(p) - X_j^S(p)$ for j = 1,2, …….n. Economy has n excess demand functions $E(p) = \left(E_1(p), E_2(p),..,.,..,E_j(p),..,..,E_n(p)\right)$. The general equilibrium is a price vector, p^*, such that $p^* \geq 0$, $E(p^*) \leq 0$ if $E(p^*) < 0$ $p^* = 0$. The excess demand functions are single valued continuous function, bounded from below $E(p) \geq b$ for all p and it is homogenous of degree zero in all prices $E(\alpha p) = E(p)$ for all α ; only relative price matter and satisfies the Walras' law; $p.E(p) = \sum_{i=1}^{n} p_i E_i(p) = 0$ for all $p \geq 0$. If the excess demand functions satisfy above properties then, the existence of the general equilibrium is guaranteed by fixed point theorems. The fixed equilibrium point is found by continuous transformation of the nonempty convex set onto itself $p^* \rightarrow E(p^*) \rightarrow p^*$.

The Hicksian method of determining the uniqueness of equilibrium is to see if the principal minors of Jacobian matrix of the excess demand functions, J alternate in sign, its values being positive for even number of rows and columns and negative for uneven number of rows and columns.

$$J = \begin{pmatrix} \frac{\partial E_1}{\partial p_1} & \frac{\partial E_1}{\partial p_2} & \cdots & \frac{\partial E_1}{\partial p_{n-1}} \\ \frac{\partial E_2}{\partial p_1} & \frac{\partial E_2}{\partial p_2} & \cdots & \frac{\partial E_2}{\partial p_{n-1}} \\ . & . & \cdots & \\ \frac{\partial E_{n-1}}{\partial p_1} & \frac{\partial E_{n-1}}{\partial p_2} & \cdots & \frac{\partial E_{n-1}}{\partial p_{n-1}} \end{pmatrix}$$

An equilibrium system consisting of demand and price vectors $x = (x_1, x_2, ., ., ., x_j, ., ., ., ., ., x_n)$, $p = (p_1, p_2, ., ., ., p_j, ., ., ., ., ., p_n)$ is locally stable if $\lim_{t \to \infty} p(t) = p^*$ given $|p(t_0) - p^*| < \delta$ where t_0 denote the initial starting point and $|p(t_0) - p^*|$ the Euclidean norm in the price space. Equilibrium is globally stable if it is reached regardless of any starting point $\lim_{t \to \infty} p(t) = p^*$ for any $p(t_0)$ .The classical approach to Walrasian *tatonement* process is to raise the price if the total market demand is greater than supply and lower the prices if the demand is less than supply and keep price unchanged in the total market demand equals total market supply as:

$$\frac{\partial p_j}{dt} = \dot{p}_j \begin{Bmatrix} > \\ < \\ = \end{Bmatrix} 0 \quad if \;\; E_j(p) \begin{Bmatrix} > \\ < \\ = \end{Bmatrix} 0 \quad j = 1,2,..,.n..$$

Dynamic general equilibrium is essentially a system of relative prices of commodities, factors of production such as wage rate and interest rate that balance demands and supplies for each product or factor of production in the market for each period as well as for the entire model horizon. When a model is properly calibrated to the benchmark micro-consistent data set, such prices reflect the degree of scarcity and desirability for those goods in the economy that balance cost and benefits to the suppliers and consumers in the economy.

An economy may not always be in competitive equilibrium. Imperfections either in goods and input markets are common and monopolistic or oligopolistic situations arise. Numerical models pick up such imperfections by the mark-ups over cost covering prices though these can further require considerations of strategic interactions at various fronts between consumers and producers, firms and government or between the national economy and the Rest of the World, each player in the game is trying to shift the burden of pollution or taxes onto others creating discreteness or non-convexities in opportunity sets making it harder to find the equilibrium even though that may exist in the system.

f. Nature of policy experiments

Even a small distortion or reform in policy for a particular sector, such as the electricity, can have a large impact on the growth of other sectors or welfare of households over time when that is well integrated through the positive or negative externalities to other sectors of the economy. Policies aim to find the best society given the preferences and technical possibilities and constraints need to look at detrimental impacts of pollution and good impacts of positive externalities before determining the best action among all available alternatives. The general equilibrium model, like the current one, can act as a policy where these various possibilities can be tested and their impacts be measured.

III. Preferences and Technology in the GEMEETUK Model

Household preferences and technology of firms in this model are similar to those in Bhattarai (1999, 2003, 2007). Households solve the inter-temporal allocation problem:

$$\text{Max } U_0^h = \sum_{t=0}^{\infty} \beta^t U_t^h \left(C_t^h, l_t^h\right) - \sum_{t=0}^{\infty} \psi EM_t^h \qquad (1)$$

Subject to

$$\sum_{t=0}^{\infty} R_t^{-1}\left[P_t(1+t^{vc})C_t^h + w_t(1-t_l)l_t^h + PP_t EM_t^h\right] = \sum_{t=0}^{\infty}\left[(1-t_l)w_t L_t^h + (1-t_k)r_t K_t^h + TR_t^h\right] \qquad (2)$$

where U_0^h is lifetime utility of the household *h*, C_t^h , l_t^h and L_t^h are respectively composite consumption, leisure and labour supplies of household *h* in period *t*, PP_t is the price of pollution abatement, EM_t^h is the amount pollution burden in household *h* $R_t^{-1} = \prod_{s=0}^{t-1} 1/(1+r_s)$ is an objective discount factor whereas β is the subjective discount factor of consumer for future consumption relative current consumption; r_s represents the real interest rate on assets at time *s*; t^{vc} is value added tax on consumption, t_l is labour income tax rate, and K_t^h the capital endowment of household *h*, P_t is the price of composite consumption (which is based on goods' prices), i.e. $P_t = \vartheta \prod_{i=1}^{n} \alpha_i p_{i,t}^{\alpha_i}$, and C_t^h is the composite consumption, which is composed of sectoral consumption goods, $C_t^h = \prod_{i=1}^{n} C_{i,t}^{\alpha_i^h}$.

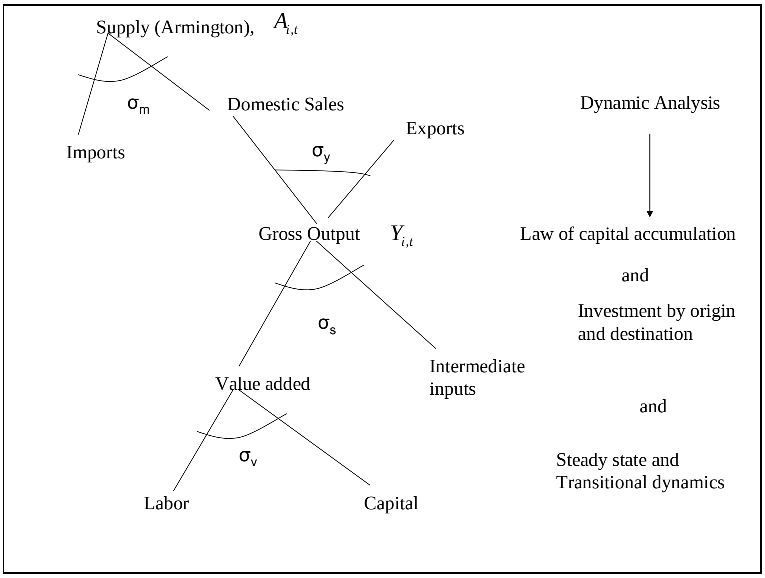
Industries of the economy are represented by firms that combine both capital and labour input in production and supply of goods and services to the market to maximise their profits:

$$\Pi_{j,t}^y = [((1-\delta_i^e)PD_{i,t}^{\frac{\sigma_y-1}{\sigma_y}} + \delta_i^e PE_{i,t}^{\frac{\sigma_y-1}{\sigma_y}})]^{\frac{1}{\sigma_y-1}} - \theta_j^v PY_{j,t}^v - \theta_j^d \sum_i a_{i,j}^d P_{i,t} \qquad (3)$$

where: $\Pi_{j,t}^y$ is the unit profit of activity in sector *j;* $PE_{j,t}$ is the export price of good *j* $PD_{j,t}$ is the domestic price of good *j;* $PY_{j,t}^v$ is the price of value added per unit of output in activity *j;* σ_y is a transformation elasticity parameter ; $P_{i,t}$ is the price of final goods used as intermediate goods; δ_j^e is the share parameter for exports in total production; θ_j^v is the share of costs paid to labour and capital; θ_j^d is the cost share of domestic intermediate inputs; $a_{i,j}^d$ are input-output coefficients for domestic supply of intermediate goods.

Figure 1

Structure of Production and Trade in the Dynamic Multi-household Models



This is an open economy model in which goods produced at home and foreign countries are considered close substitutes by Armington assumption, popular in the applied general equilibrium literature. The production, trade and supply processes by sectors is easy to comprehend with a four level nests of functions for each as in Figure 1.

Households pay taxes to the government, which either it returns as transfers to low income households and spends rest of it to pay for public consumption.

$$REV_t = \sum_{i,h} t_i^k r_t K_{i,t} + \sum_i t_i^{vc} P_{i,t} C_{i,t}^h + \sum_i t_i^{vg} P_{i,t} G_{i,t} + \sum_i t_i^{vk} P_{i,t} I_{i,t} + \sum_{i,h} t_l wLS_t^h + \sum_i t_i^m PM_{i,t} M_{i,t} + \sum_i t_i^p P_{i,t} GY_{i,t} \quad (4)$$

where REV_t is total government revenue and t_i^k is a composite tax rate on capital income from sector i, t_l^{vc} is the *ad valorem* tax rate on final consumption by households, t_i^{vg} is that on public consumption and t_i^{vk} is the ad valorem tax rate on investment, t_l is the tax rate on labour income of the household, t_i^p is the tax on production, and t_i^m is the tariff on imports.

The steady state equilibrium growth path of the economy is determined by relative prices of goods and factors such as the rental rate and the interest rate, that ultimately depend on parameters of the model such as subjective and objective discount factors, elasticities of substitution and many other shift and share parameters. By Walras' law these prices eliminate the excess demand for goods and factors. These conditions emerge from the resource balance and zero profit conditions for the economy and for each household and for the government and for the rest of the world sectors in each period as well as over the entire model horizon. Government tax and transfers policies can alter this equilibrium. Income of each type of household evolves over time as a function of the relative prices of goods and share of households in total endowment of capital and labour.

The production process releases emissions that manifests itself in the forms of air, water, land and noise pollutions. Pollution is a by product of production process. This is included by an emission function in the model as following:

$$EMIS_t = \sum_i \phi_i Y_{i,t} \qquad (5)$$

where $EMIS_t$ represents the total amount of emission and ϕ_i is the pollution coefficient for industry i the rate of pollution generated in producing output $Y_{i,t}$. It is assumed to remain constant for this model. Higher rate of pollution is harmful for growth and hence for the welfare of households. While the consumption of goods generates utility to the households and such pollution generates negative externality. Their utility level falls with the increased amount of emission as it effectively reduces households' life time income.

IV. Calibration to Benchmark Economy

The dynamics in this model arise from an endogenous process of capital accumulation and exogenous growth rate of the labour force. We rule out uncertainty in aggregate and rely on the perfect foresight of households and firms, which means that actual and expected values of variables are the same.

There are essentially five steps involved in calibration of this dynamic model. The first step relates to forming a relation between the price of investment good at period t, P_t and the price of capital in period $t+1$, P^k_{t+1}. It also needs specifying a link between prices of capital stock at periods t and $t+1$, P^k_t and P^k_{t+1}, with due account of the rental on capital and the depreciation rate. For instance, one unit of investment made using one unit of output in period t produces one unit of capital stock in period $t+1$. This implies, $P_t = P^k_{t+1}$, where P_t is the price of one output in period t and P^k_{t+1} is the t period price of one unit of capital in period $t+1$.

Capital depreciates at the rate of δ . One unit of capital at the beginning of period *t* earns a rental R_t^t and delivers *(1-δ)* units of capital at the end of period t (or at the start of the *t+1* period), $(1-\delta)P_{t+1}^k$. Here R_t^t is also measured in term of P_{t+1}^K or P_t .We therefore must have:

$$P_t^k = R_t^t + (1-\delta)P_{t+1}^k \tag{6}$$

In a perfect foresight world price of capital in period *t* really reflects the sum of discounted rental over time.

The second step of calibration involves setting up a link of the rental rate with the benchmark interest rate and the depreciation. The rental covers depreciation and interest payment for each unit of investment. When rental is paid at the end of the period

$$R_t^t = (r+\delta)P_t = (r+\delta)P_{t+1}^k \tag{7}$$

where *r* is the benchmark real rate of interest.

Thirdly step of calibration involves forming relation between the future and the current price of capital. Use equation (6) and (7) together to get

$$\frac{P_{t+1}^k}{P_t^k} = \frac{1}{1+r} \approx 1-\delta \, . \tag{8}$$

This means that the ratio of prices of the capital at period *t* and *t+1* equals to the market discount factor in the model, which is $(1-\delta)$. This discount factor can also be approximated by $\frac{1}{1+r}$.

The fourth step of calibration involves setting up equilibrium relation between capital earning (value added from capital) and the cost of capital. We compute values for sectoral capital stocks from sectoral capital earnings in the base year. If capital income in sector *i* in the base year is $\overline{V_i}$, we can write $\overline{V_i} = R_i K_i$. Thus investment per sector is tied to earnings per sector. Since the return to capital must be sufficient to cover interest and depreciation, we can also write

$$\overline{V_i} = (r+\delta_i)P_{t+1}^k K_i \text{, or} \qquad K_i = \frac{\overline{V_i}}{(r+\delta_i)} \qquad \text{Since } P_t = P_{t+1}^k = 1 \tag{9}$$

The fifth step of calibration involves setting up relation between the investment and capital earning on the balanced growth path. Investment should be enough to provide for growth and depreciation, $I_i = (g_i + \delta_i)K_i$, which together with (9) implies

$$I_i = \frac{(g_i + \delta_i)}{(r + \delta_i)} \overline{V_i} \tag{10}$$

The balance between investment and earnings from capital is restored here by adjustment in the growth rate g_i that responds to changes in the marginal productivity of capital associated to change in investment. Readjustment of capital stock and investment continues until this growth rate and the benchmark interest rates become equal.

If the growth rate in sector *i* is larger than the benchmark interest rate then more investment will be drawn to that sector leading to an increase in the capital stock in that sector. By the process of diminishing return to capital more investment eventually will lower growth rate of that sector eliminating the excess returns that attracted investment in the beginning. In the benchmark equilibrium, all reference quantities grow at the rate of labour force growth, *g*, and reference prices are discounted on the basis of the benchmark rate of return as given by equation (8) above.

IV. Micro-Consistent Benchmark Data Set

The model is calibrated using the micro-consistent industry specific data set obtained from the 123 sector input-output table of the UK economy published by the Office of National Statistics (ONS), income distribution data among households obtained form the Department of Works and Pension and the tax rate information gathered from the Inland Revenue, Custom and Excise. The data set has been prepared to calibrate the model at various levels of aggregation: nine, eleven, sixteen, twenty one and 123 sectors. Elaticities of substitution in consumption and production are based on values generally accepted in the literature.

Organisation of data for the model is illustrated below in the prototype input-output table in Figure 2 as the presentation of full data set would require enourmous space. The top left hand corner is the input-output transaction table, top right hand contains information on final demand, bottom left hand corner shows value added such as payment to labour, capital and taxes on inputs and the bottom right hand corner has information on domestic and international transfers such as remittances. These data elements are demonstrated in notations further below.

Figure 2

Micro-consistent Dataset for the Economy

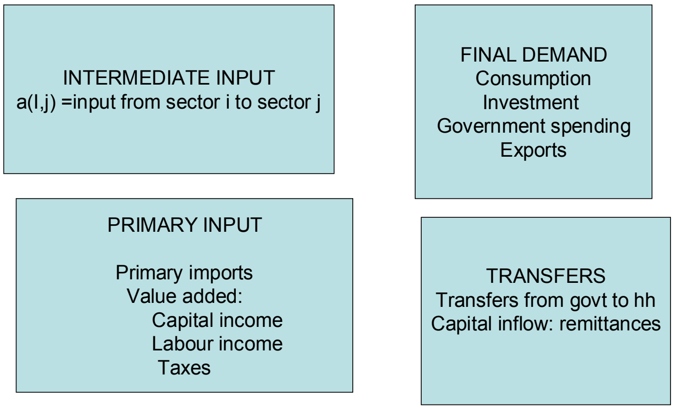


Figure 3

Structure of input-output table for micro consistent data set

	ENERGY	*NON-ENERGY*	*C*	*I*	*G*	*X*	*M*	*Total*
ENERGY	X_{11}	x_{12}	C_1	I_1	G_1	X_1	M_1	GY_1
NON-ENERGY	X_{21}	x_{22}	C_2	I_2	G_2	X_2	M_2	GY_2
Labour	L_1	L_2						wL
Lab-tax	$T_{l,k}$	$T_{l,k}$						TL
Capital	K_1	K_2						rK
Cap taxes	$T_{1,k}$	$T_{2,k}$						TK
Total	GY_1	GY_2	C	I	G	X	M	

Figure 4

Backward and Forward Linkages across Industries

$$A = \begin{bmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{bmatrix}$$

Input-Output Coefficients for the UK Economy: Thee sector aggregation

	Manufacturing	Distribution	Services
Manufacturing	0.327263	0.123182	0.074824
Distribution	0.044565	0.031169	0.016667
Services	0.119756	0.264192	0.286766

The multisectoral model presented here demonstrates how the relative prices and quantities interact in the economic system. Such interactions occur through complicated process of intertemporal and intra-temporal income and substitution effects. Expansion or contraction of a certain industry affects not only the employment and output and prices of its own but also have widespread circulatory impacts on upstream and downstream sectors. Growth in one sector pulls the growth rate of the other sectors, through the process of backward and forward linkages contained in the input-output system and inter-linked markets in the economy through accumulation and substitution processes both in consumption and production sides of the economy. For instance as shown in Figure 4, one unit of manufacturing output requires 4.4 percent input from the distribution sector and 12 percent from the services sector. This is the backward linkage for the manufacturing sector. At the same time distribution and services sectors use manufacturing output as their inputs. Distribution requires 12.3 percent of its inputs from the manufacturing sector and the service sector requires 7.4 percent of its inputs from the manufacturing sector. This is forward linkage of the manufacturing sector. Similar backward and forward linkages apply to all other sectors. Level of production in each sector respond to final demand for products of that sector by households, firms government or the ROW and that generates the demand for labour and capital inputs. The level of income of households changes in response to changes in capital and labour income and changes in household income translate into the change in final demand. This completes the first circle and if economy is allowed to function automatically this sets series of another rounds of such circles until the economy converges to the inter-temporal equilibrium. Shocks or reforms in one sector transmit to other sectors and have large cumulative impacts in the economy, which can be quite large.

Table 1
Basic Parameters of the GEMEETUK model

Intertemporal elasticity of substation between consumption and leisure	1.15
Elasticity of substitution between capital and labour	1.5
Growth rate of output in the benchmark across sectors	0.03
Benchmark rate of interest	0.05
Rate of depreciation of the capital stock across sectors	0.02
Rate of intertemporal substitution	0.95

Source: based on Bhattarai (1999, 2003)

In addition to information on benchmark prices and quantities, the numerical implementation of the model requires information on shift, share, elasticity and policy parameters defining various equations in consumption and production sides of the economy. Values of key parameters used for computation of the current model are given in Tables 1,2 and 3.   These are the set of parameters that have desirable properties required for demand and supply functions for which the equilibrium exists, is unique and stable. Sensitivity tests are used to test the robustness of model results to different values of these parameters.

Table 2
Sectoral Parameters in the GEMEETUK Model

	Capital tax	Labour tax	Depreciation	Growth rate	Pollution Coefficient	Counter fact L-tax	Counter Fact Ktax
Agric	-0.0011	-0.0021	0.02	0.03	0.01	0.25	0.05
Min	0.0018	0.0188	0.02	0.03	0.01	0.25	0.05
Manu	0.0106	0.014	0.02	0.03	0.01	0.25	0.05
Energy	0.0388	0.1934	0.02	0.03	0.01	0.25	0.05
Const	0.0269	0.0041	0.02	0.03	0.01	0.25	0.05
Distb	0.0079	0.0107	0.02	0.03	0.01	0.25	0.05
Trans	0.0303	0.0398	0.02	0.03	0.01	0.25	0.05
Busi	0.0121	0.0404	0.02	0.03	0.01	0.25	0.05
othSect	0.0426	0.0078	0.02	0.03	0.01	0.25	0.05

Source: Derived from the input output table

Table 3
Endowment of labour and capital of households in the GEMEETUK

	H1	H2	h3	H4	h5	h6	h7	h8	h9	h10
wage	3436	9935	18974	29170	37692	47379	54874	61726	72055	97817
intr	2682	1370	4257	6006	9155	12975	17115	15599	21022	105197
Leisure	2577	7451	14230	21877	28269	35535	41156	46294	54041	73363
HH Inc Tax	0	0.05	0.1	0.15	0.2	0.25	0.3	0.35	0.4	0.45
Cons share	0.0177	0.0255	0.041	0.0573	0.0737	0.0935	0.1108	0.1175	0.1412	0.3219
Transfer	1520	1913	4291	6388	8796	11628	14279	14641	18185	54500
Ini. Consmp.	5671	12497	24869	37904	49829	63532	74858	81973	97409	179081

Source: Department of work and Pension, 2005.

Figure 4.a

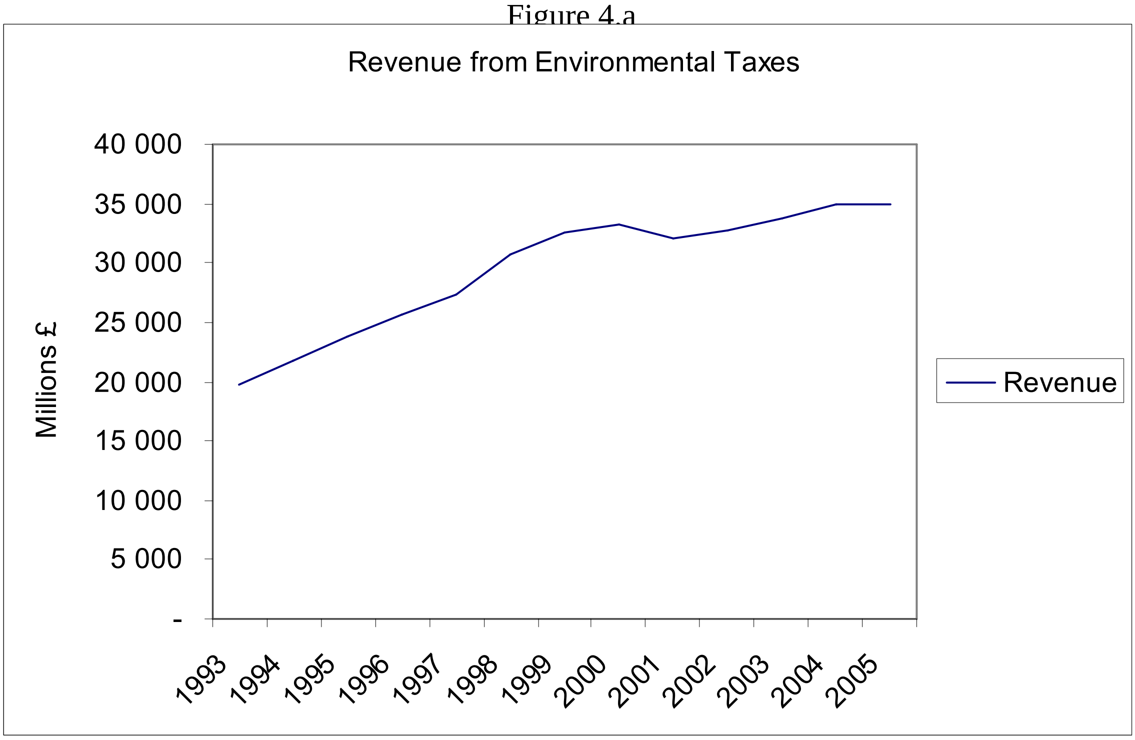


Figure 4.b

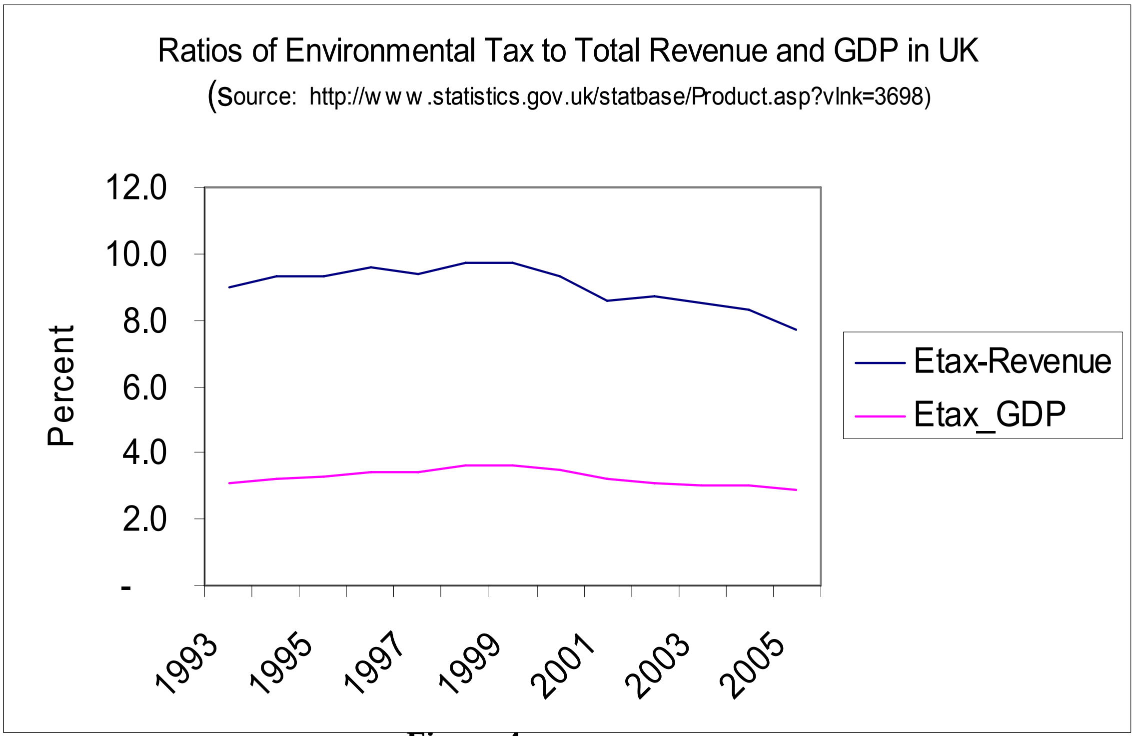
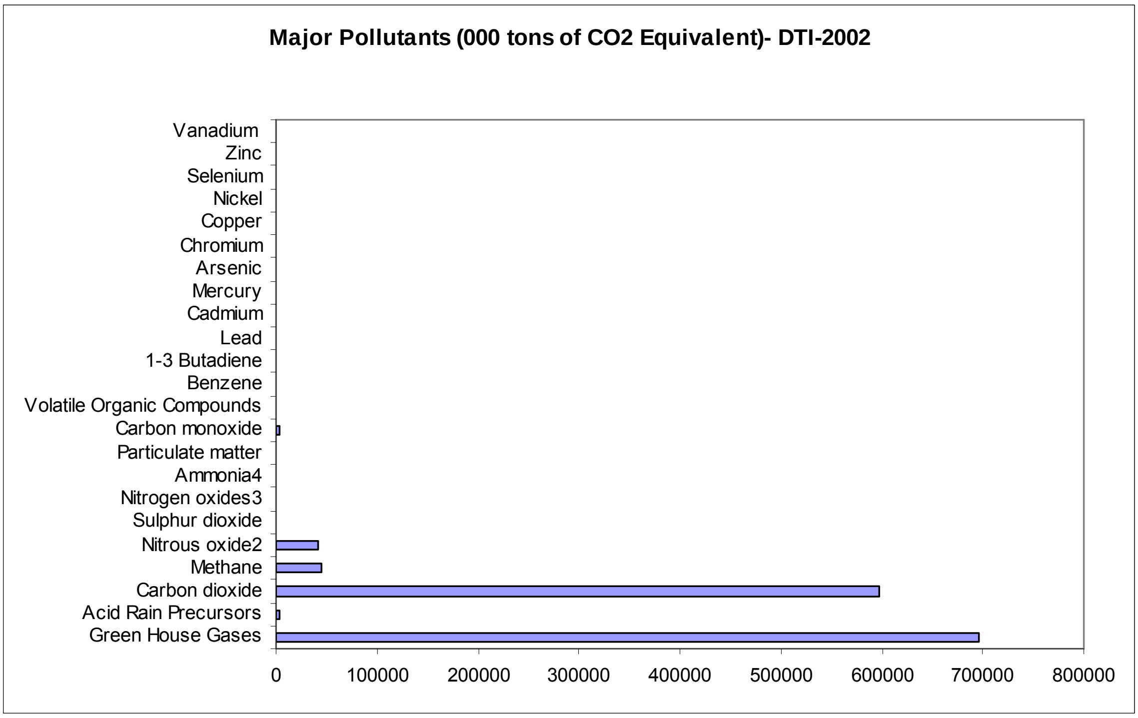


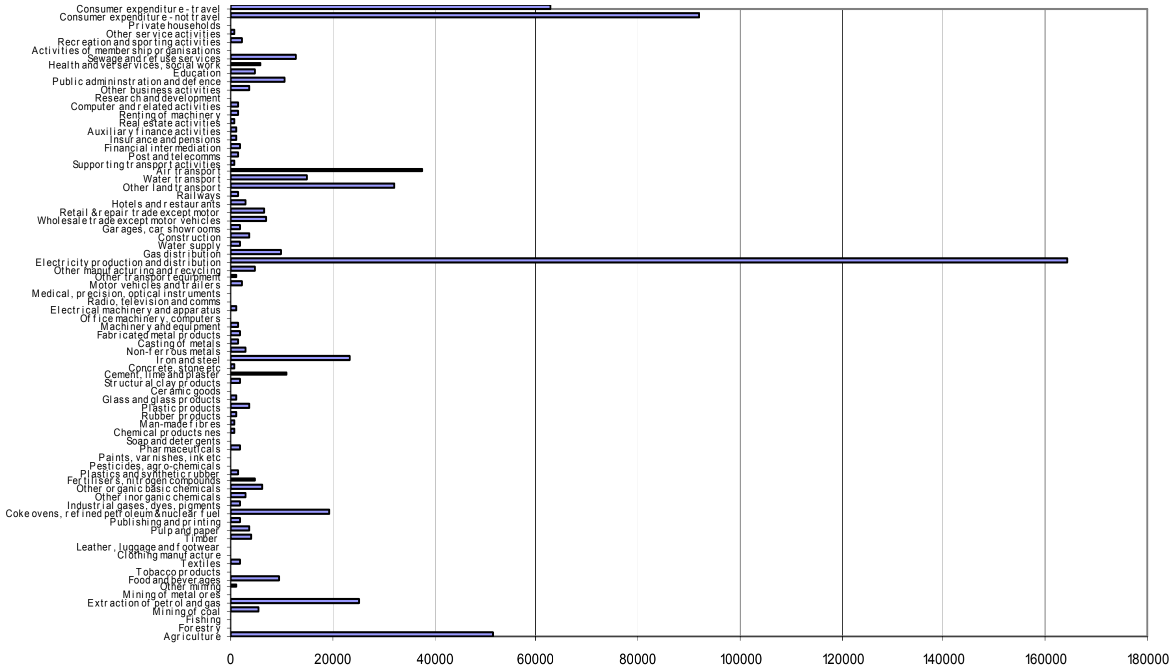
Figure 4.c



Source: DTI, http://www.berr.gov.uk/energy/index.html

Figure 4.d

Green House Gases: Thousands of Tonnes of CO2, DTI-2002
(CO2, CH4, N2O, HFC, PFC, SF6)



Trend of revenue from the energy taxes and share of it in the total revenue and GDP is shown in figures 4a and 4b along with the amount of CO2 and other pollutants generated by the production process in 4c and 4d.

V. General Equilibrium Results: Impact of Capital Accumulation in Growth of Output and Welfare of Households.

Scientifically pollution - carbon dioxide, methane, nitrogen dioxide or nitric oxide, chlorofluorocarabon (CFC)) in solid, liquid or gaseous form or the explosive, oxidizing, irritant, toxic, carcinogenic, corrosive, infectious, teratogenic, mutagenic hazardous solid wastes - is detrimental to human, animal of plant lives. It not only contaminates and adulterates the natural environment and ecological balances locally but has global consequences resulting in the rise of temperature, acid rains, a large Arctic ozone hole ultimately generating a process called the "greenhouse effect". Despite that it is hard to quantify the damage caused by such pollution and putting energy and environmental taxes might be not be a prudent way of controlling such pollution. Using applied general equilibrium models Whalley and Wigle (1991) had estimated consequence of 50 percent reduction in CO2 gases to cause up to 19 percent reduction in GDP, Vennemo (1997) showed carbon taxes to cause fall in the wage rate of up to 5 percent, Kombaroglu (2003) reported them to dampen the growth rate by up to 6 percent, Bohringer, Conrad and Loscel (2003) found negative impacts of such taxes on output, employment and the wage rate, Perroni and Rutherford (1993) how the markets for pollution permits would affect the structure of trade among economies. Findings of this paper are not very different than of those reported above.

Economists have paid little attention to the form of social pollution that affects mainly service industries. Corruption, sleaze, malpractices, breach of fundamental human rights and social values create tensions, anxieties, social conflicts and reduce the creativity and productivity of workers and utility of households though it is very hard to quantify impacts of these externalities.

This section focuses on reporting results from a representative model with nine sectors and ten households for a model horizon on 25 years with particular focus on the impacts of energy carbon taxes on the level and growth rates of capital accumulation, employment, output, investment by sectors, the level of welfare by ten categories of households, and economy wide impacts in terms of key macro economic variables with a numbers of interconnected graphs constructed from the results of the model. More detailed results for 11, 21 and 123 sector versions and scenarios for 50 and 100 years' were computed but not reported due to space limitations[3].

Imposition of extra environmental and energy taxes to reduce the pollution (Fig. 5) affects the behaviour of households and firms. Taxes reduce the profitability of firms, therefore they invest less (Fig. 6) and have less capital stock (Fig. 7) and they produce less (Fig. 8). Taxes depress the real income of households and their levels of utility (Fig. 9) despite working more (Fig. 10). These affect macroeconomic scenarios and allocations (Fig.11) and impact on redistribution (Fig.12a, 12b).

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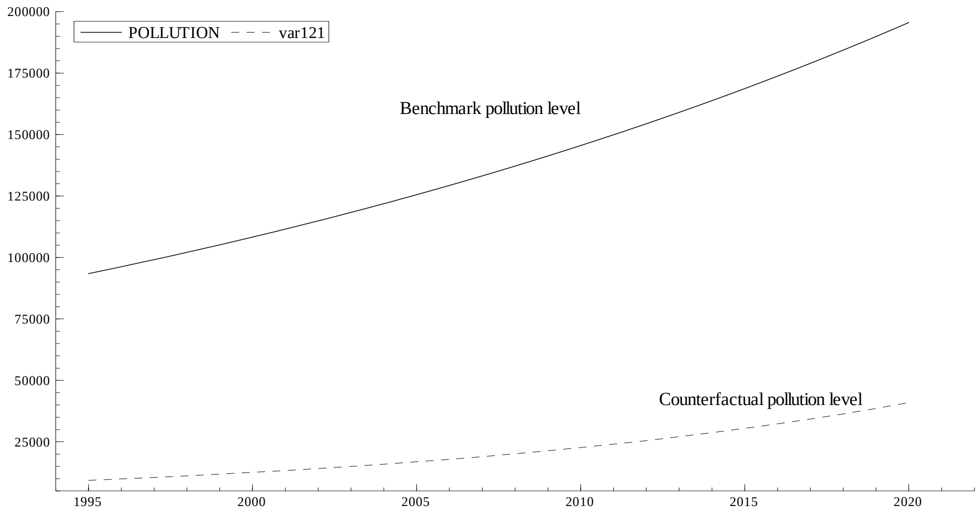
[3] Models were solved using the GAMS/MPSGE software(Rutherford (1995) with its Path solver (Dirkse and Ferris (1997)). More elaborate results are contained in series of excel files as in Tuerck et al (2006) and then the graphs were made using the GiveWin software (Doornik and Hendry (2001).

Figure 5: Level of pollution in the benchmark and counterfactual scenario



There is still a great deal of uncertainty about the optimal rate of carbon tax, as Poterba (1993) puts "even after several years of intense research activity on carbon taxes, global warming".

Figure 6: Impact of energy carbon taxes on investment by sectors

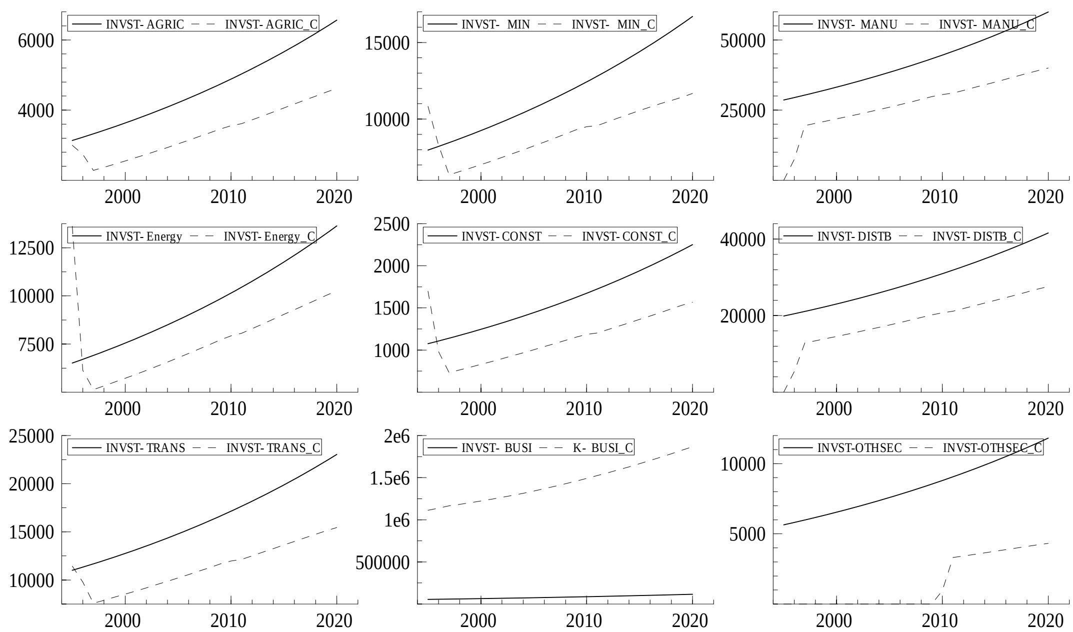


Figure 7: Impact of carbon energy taxes in capital stock by sectors

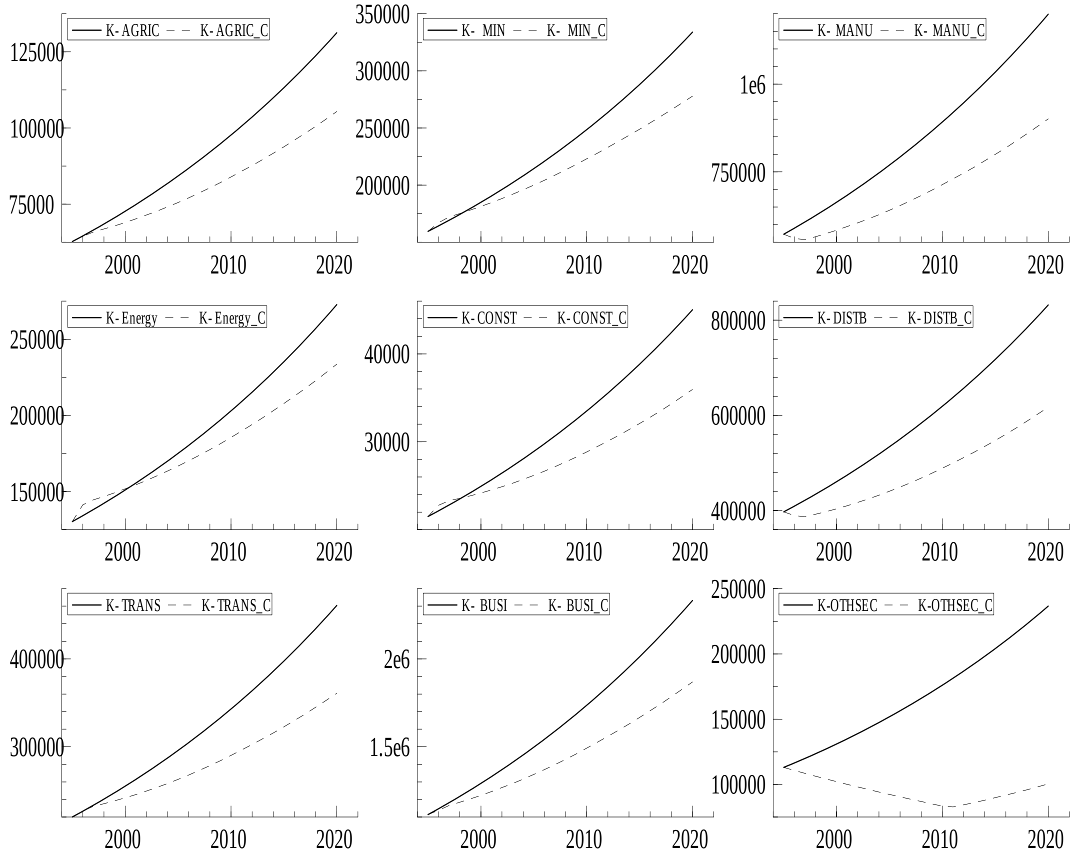


Figure 8: Impact of carbon energy taxes in the levels of output by sectors

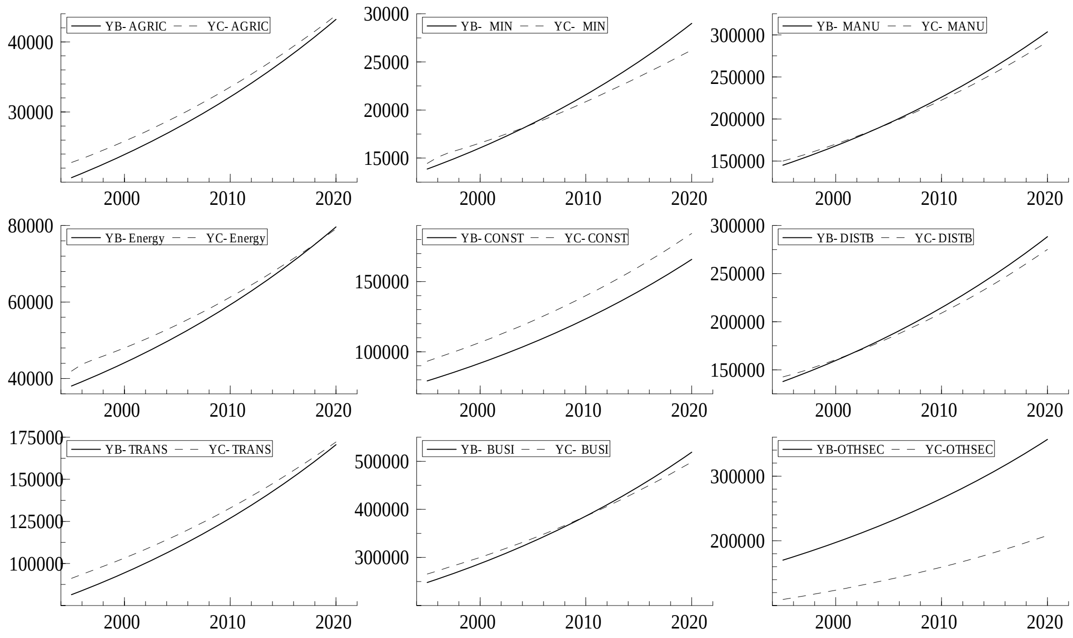


Figure 9: Impact of carbon energy taxes in utility level of households

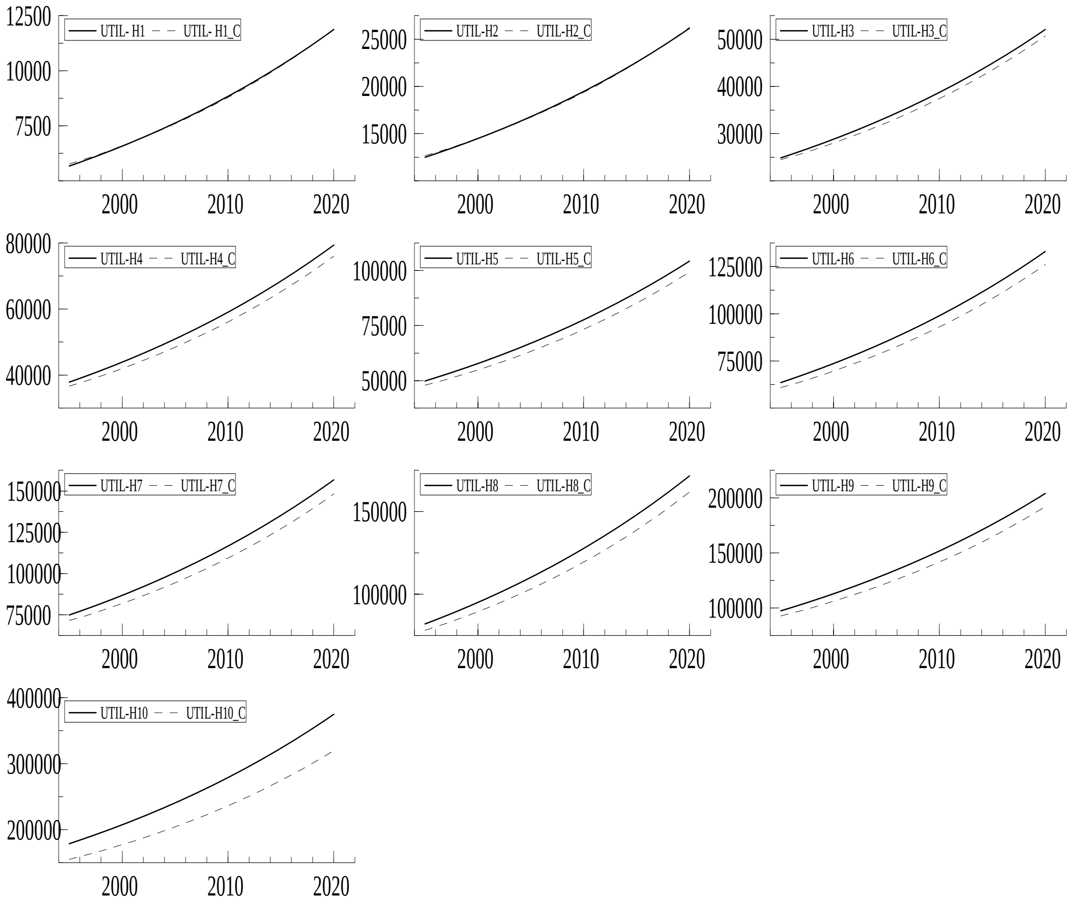


Figure 10: Impact of energy carbon taxes on employment by sectors

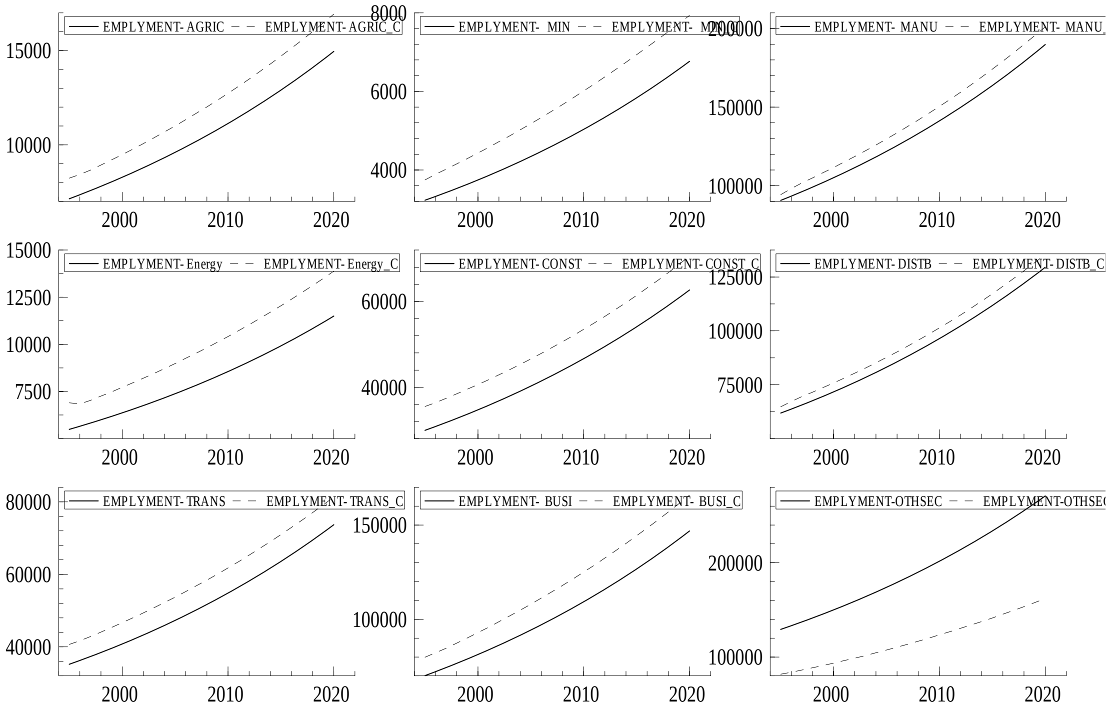


Figure 11: Macroeconomic impacts of carbon energy taxes

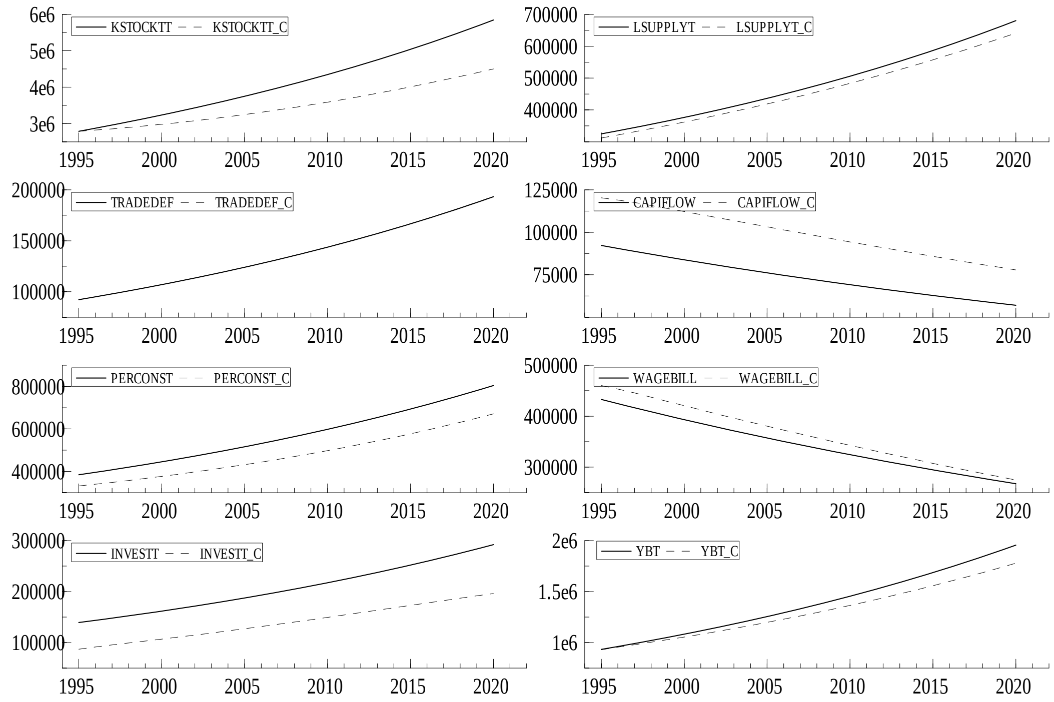


Figure 12a: Utility Level of Households in the Benchmark Scenario

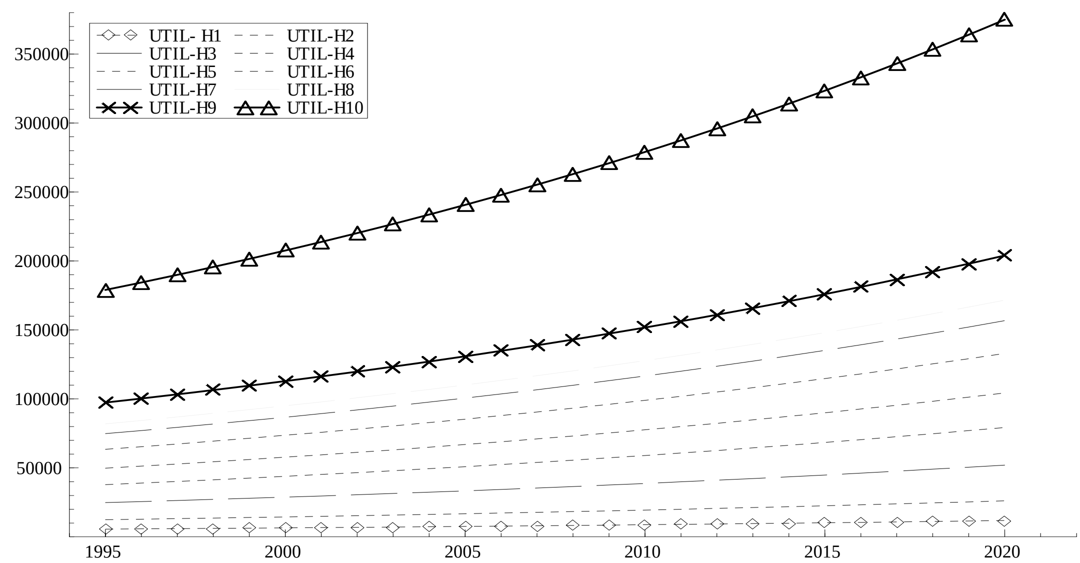
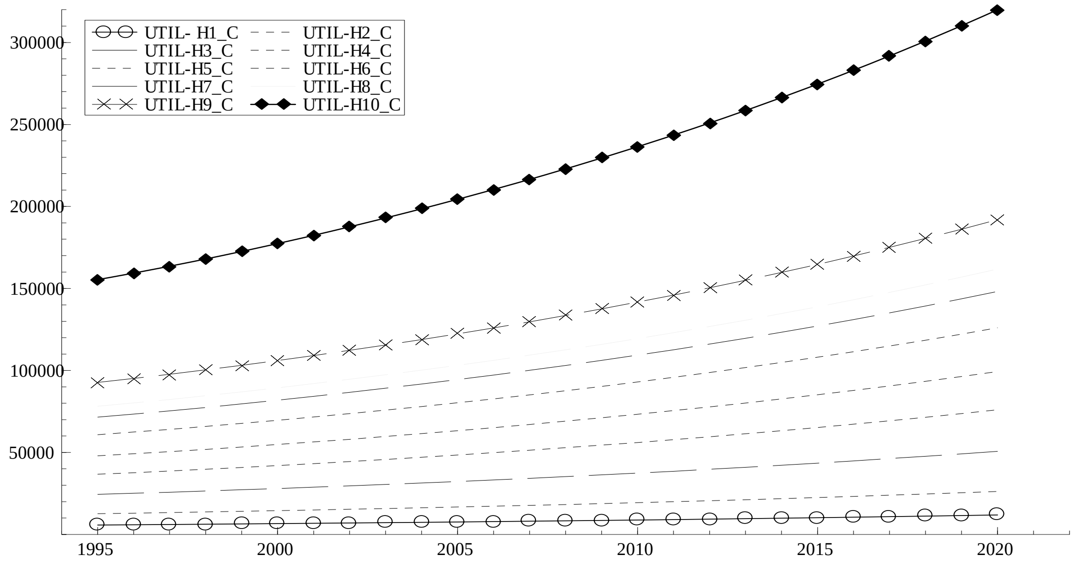


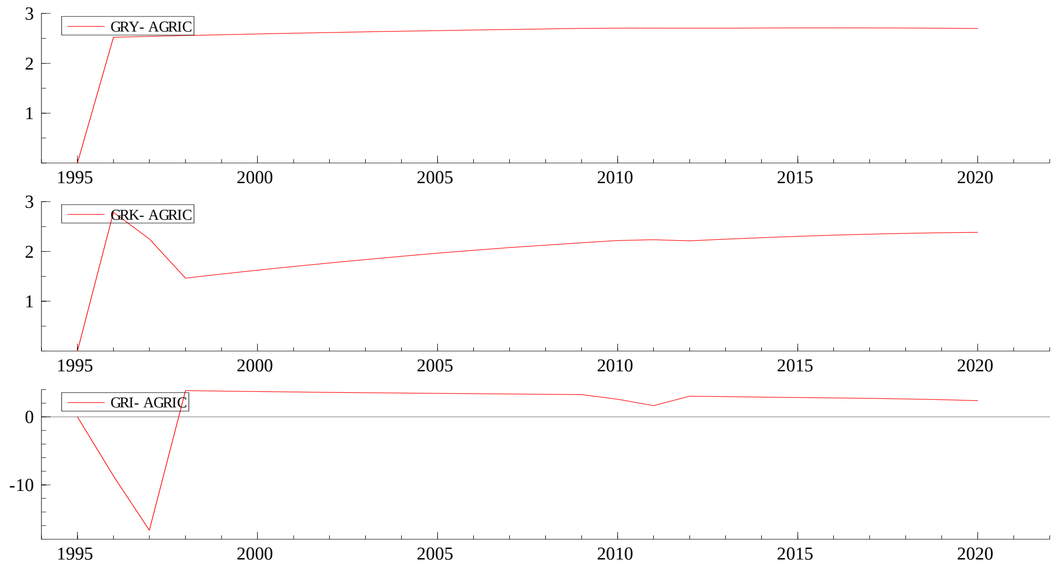
Figure 12b: Comparing Utility Level All Households in Counterfactual Scenario



Impacts of Taxes on Growth of Capital Stock, Output and Investment By Sectors

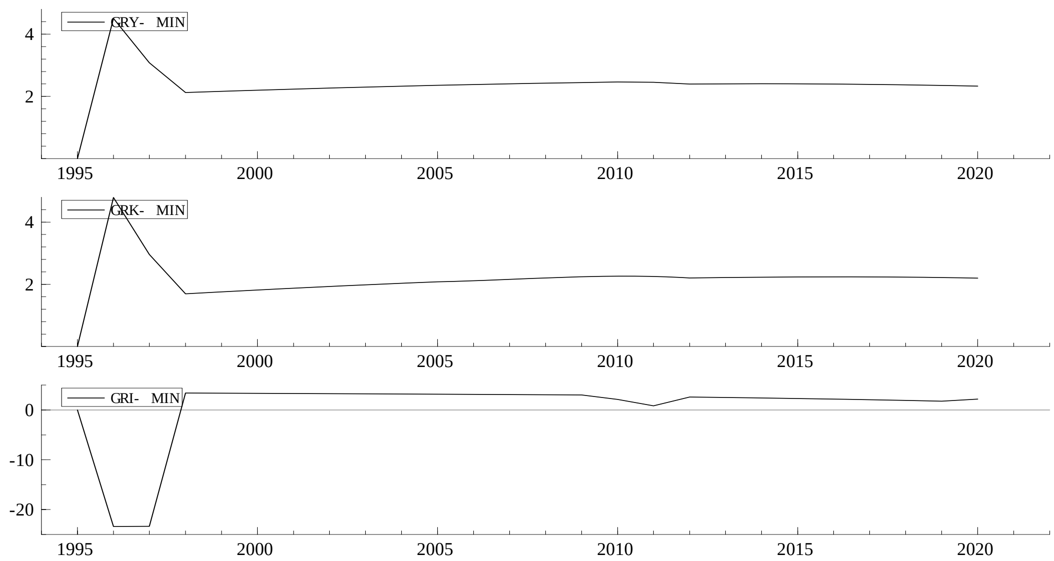
Growth of capital stock, output and investment in the agriculture sector- that includes farms crops, livestock, forestry, and fisheries- is lower than in the benchmark (Fig13) when taxes are imposed in the use of inputs.

Figure 13: Growth rate of output, investment and capital stock in agriculture.



Scientifically it is true that the malpractices in agriculture can generate biomass, organic and inorganic wastes that cause environmental problems and hazards to human and animal health which may result from animal manure and other dejections, animal corpses, residues of plastic, rubber and other petrochemicals, pesticides, pharmaceuticals, papers and wood, mineral fertilizer, scrap tools and agricultural machines. Nitrous oxides generated by these processes can bring respiratory infections, burning of eyes, headache, chest tightening, ground water pollution and inadequate measures taken to control the spread of crop or animal diseases can produce biological hazards. It is questionable, whether extra tax for controlling such pollution in this manner is reasonable as the most of agricultural wastes can be valuable resources if properly recycled with adoption of better agricultural recycling practices. More taxes in input merely deter farmers from spending on better environmentally friendly production technology.

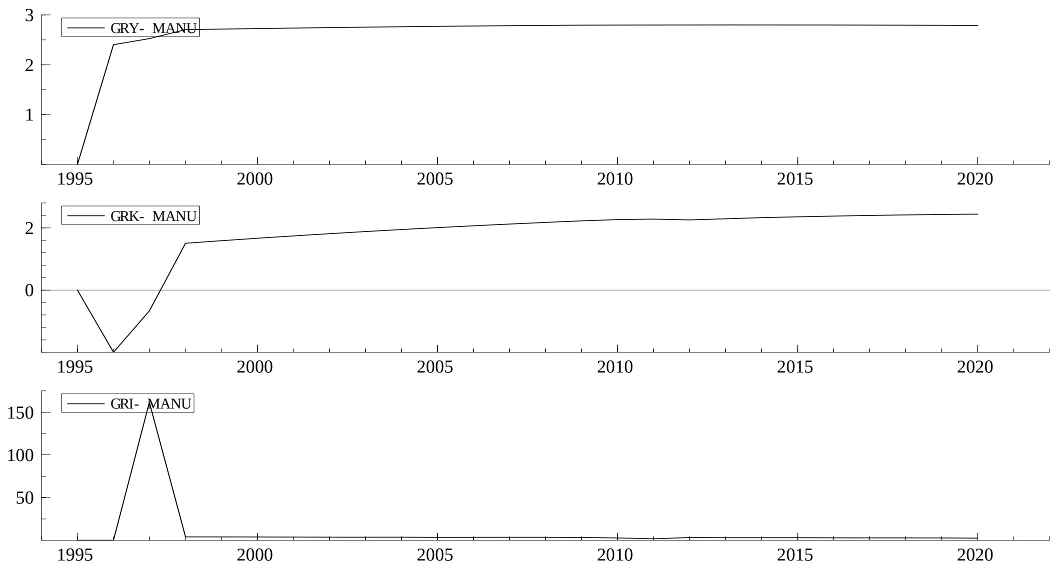
Figure 14: Growth rate of output, investment and capital stock in mining



Extra taxes reduce the growth rate of output, investment and capital stock in the mining sector (Fig 14). It is well understood that pollution emerging from physical and chemical processing of minerals in metal ores extraction as well as other mining and quarrying sector may generate acids and drilling mud, dangerous substances, land deformation which can be minimised by designing dumping sites for sulfidic waste specific materials with proper consideration of climate, hydrogeological conditions to prevent air penetration and water infiltration rather through higher rates of input taxes.

Accumulation of capital stock, output, and investment is affected by extra taxes in the manufacturing sector (Fig.15) relative to the benchmark. At the current state of technology manufacturing is not possible without burning fossil fuels directly from machines operating from burning such fuels or indirectly through use of electricity that is generated through CO2 releasing fossil fuels.

Figure 15: Growth rate of output, investment and capital stock in manufacturing sector

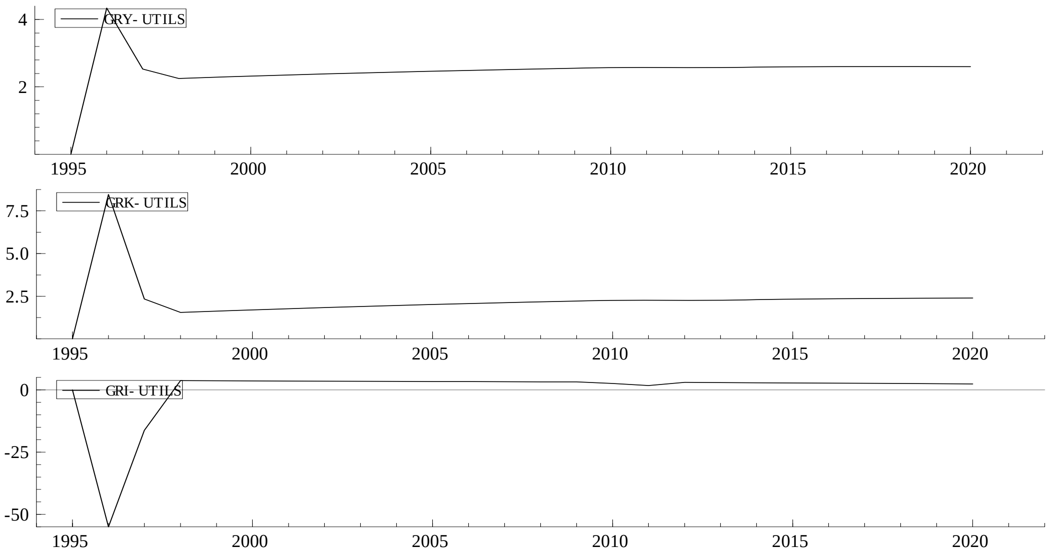


This is evident from a cursory look at the composition of 45 different industries[4] that rely very much on fossil fuels. Despite continuous efforts for adopting more efficient and environmental friendly production technologies over years, production plants of these industries are known for generating pollutants such as CO2, S2 or other hazardous gases as by-products in the production process, ever since the time of industrial revolution. Environmental or energy taxes can only raise the cost of production and lower their motivation to search for better technology.

Growth of capital, output and investment in the energy sector - that includes production and distribution of electricity and gas - are affected negatively by extra input taxes (Fig. 16).

4 such as meat processing, fish and fruit processing, oils and fats, dairy products, grain milling and starch and animal feed, bread, biscuits, etc, sugar, confectionery, other food products, alcoholic beverages, soft drinks and mineral waters, tobacco products, textile fibres, textile weaving, textile finishing, made-up textiles, carpets and rugs, other textiles, knitted goods, wearing apparel and fur products, leather goods, footwear, wood and wood products, pulp, paper and paperboard, paper and paperboard products, printing and publishing, coke ovens, refined petroleum & nuclear fuel, industrial gases and dyes, inorganic chemicals, organic chemicals, fertilisers, plastics & synthetic resins etc, pesticides, paints, varnishes, printing ink etc, pharmaceuticals, soap and toilet preparations, other chemical products, man-made fibres, rubber products, plastic products, glass and glass products ceramic goods, structural clay products, cement, lime and plaster, articles of concrete, stone etc , iron and steel, non-ferrous metals, metal castings, structural metal products, metal boilers and radiators, metal forging, pressing, etc; cutlery, tools etc, other metal products, mechanical power equipment, general purpose machinery, agricultural machinery, machine tools, special purpose machinery, weapons and ammunition, domestic appliances, office machinery & computers, electric motors and generators etc, insulated wire and cable, electrical equipment, electronic components, transmitters for TV, radio and phone receivers for TV and radio, medical and precision instruments, motor vehicles, shipbuilding and repair, other transport equipment, aircraft and spacecraft, furniture, jewellery and related products Sports goods and toys, miscellaneous manufacturing & recycling

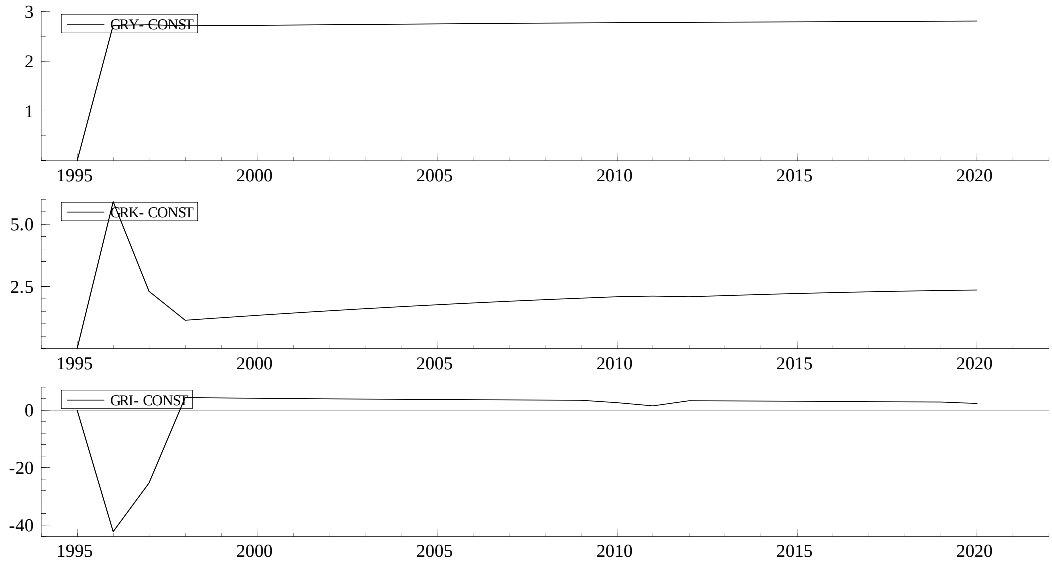
Figure 16: Growth rate of output, investment and capital stock in energy sector



Electricity is generated from coal, oil, gas, wind turbines and nuclear sources. Coal and oil plant generate larger amount of CO2 in atmosphere and the nuclear sources are difficult to build in the beginning and leave plenty of hazardous wastes at the end. If one looks at the current industrial structure of the energy sector, environmentally friendly renewable sources can not fulfil even a fraction of energy demand and this industry is in needs of support for better technology such as carbon tapping, development of hydrogen and other sources of green energy, extra taxes can only cause a setback .

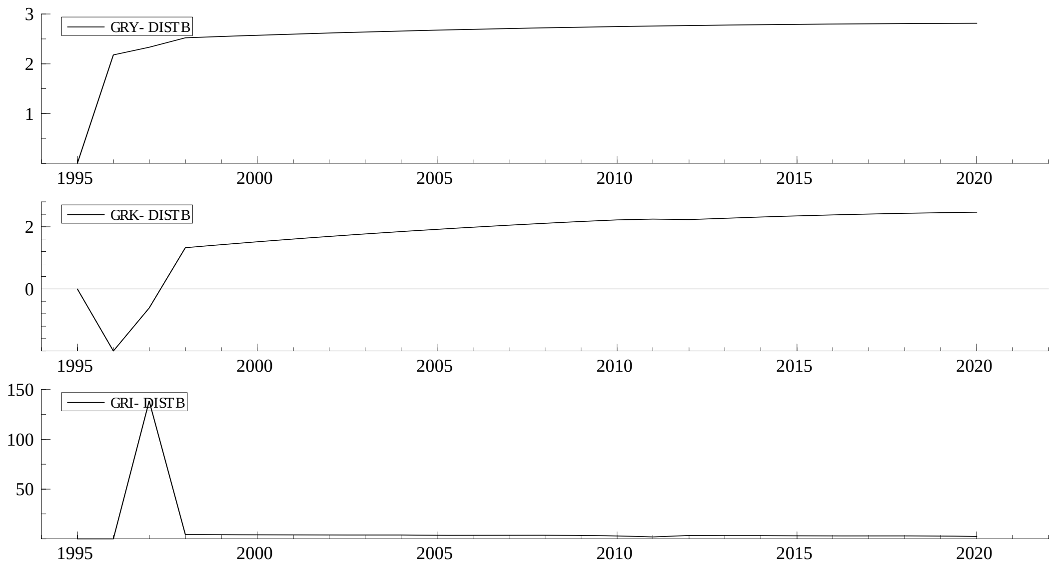
The growth of capital, output and investment in the construction sector is relatively higher than in other sectors (Fig 17) mainly because of higher taxes in the use of input in this sector in the benchmark.

Figure 17: Growth rate of output, investment and capital stock in construction sector



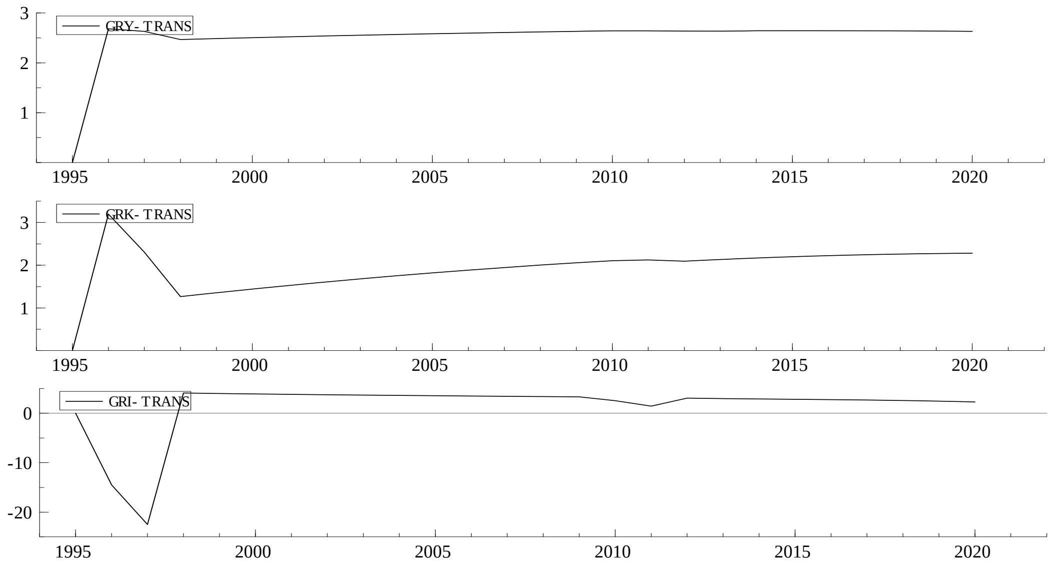
The distribution sector here consists of motor vehicle distribution and repair, automotive fuel retail, wholesale distribution, retail distribution, hotels, catering, pubs etc. Improper scrapping of old vehicles generates solid waste, cold-storages and refrigeration generates CFC and improper treatment of residues at the retail level causes pollution. Again extra taxes slightly lower the growth of output, capital and investment compared to the steady state (Fig 18).

Figure 18: Growth rate of output, investment and capital stock in distribution sector



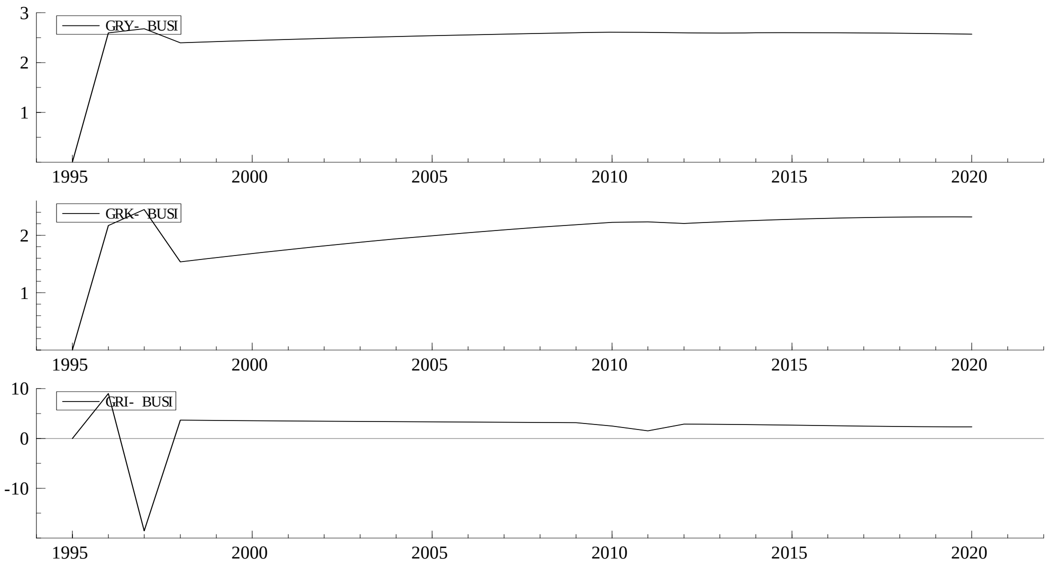
Transport and communication sector comprises of railway transport, other land transport, water transport, air transport, ancillary transport services, postal and courier services and telecommunications generates air, water, noise and land pollutions. Extra environmental taxes raise cost of operating their businesses and depress the growth of capital, output and investment in this sector (Fig 18). Better technology rather than taxes can promote the growth of this sector.

Figure 19: Growth rate of output, investment and capital stock in transport and communication sector



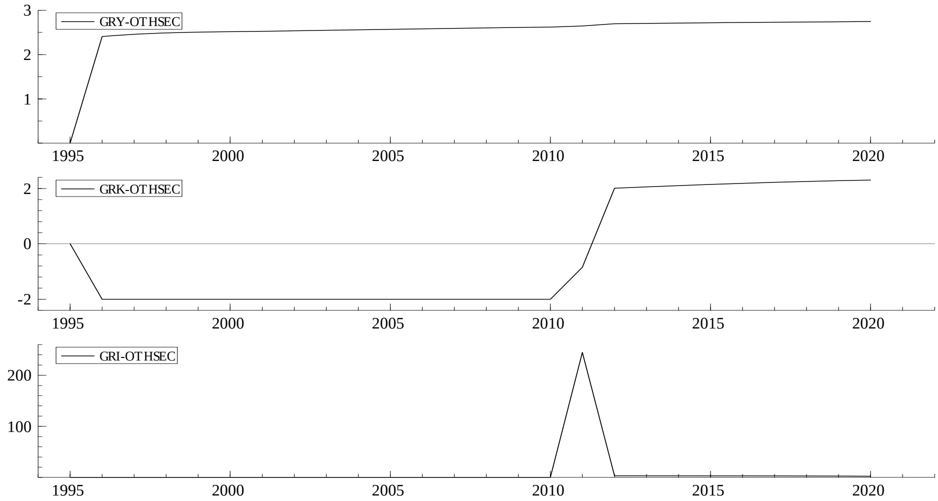
The business service sector represents banking and finance , insurance and pension funds , auxiliary financial services, owning and dealing in real estate, letting of dwellings, estate agent activities, renting of machinery etc, computer services, research and development , legal activities, accountancy services, market research, management consultancy, architectural activities and technical consultancy ,advertising and other business services. Negative externality in this sector may be less visible; intense competition for market often generates rivalry, spam, fraud and unhealthy practices that can put extra costs of providing services. It is difficult for any tax system to prevent such malpractices. Higher rates of taxes reduce its growth compared to the benchmark (Fig. 20).

Figure 20: Growth rate of output, investment and capital stock in business sector



The other services sector includes public administration and defence, education, health and veterinary services, social work activities, membership organisations, recreational services, other service activities, private households with employed persons and sewage and sanitary services. Malpractices in social services sector appear in the form of corruption, sleaze, unfair treatment and breach of fundamental liberties, trust and social values which may cause anxiety and create psychological burden and create an unhealthy environment for workers as well as entrepreneurs in the economy. It requires more creative thinking and putting extra taxes creates disincentives and cannot contribute to higher productivity required for growth prospect of this sector (Fig. 21).

Figure 21: Growth rate of output, investment and capital stock in other sectors



VI. Conclusion

An attempt has been made here to evaluate the economy wide impacts of changes in pollution taxes imposed on use of capital and labour inputs on the capital accumulation, on growth rates of output, employment and investment sectors and income, utility and welfare by households and on the allocation of scarce economic resources across production sectors and among households and the government in the UK economy benchmarking the model to data on income for ten categories of households and production sectors aggregated from 123 sector input-output table or with the disaggregation with 123 sectors of the UK economy. Results demonstrate very important role of investment and saving and capital accumulation process in the evolution of the economy. Insufficient growth rate of capital, caused by higher rate of energy and environmental taxes on use of labour and capital income can slow down the growth rate of output across all sectors and reduce the level of welfare of households. Environment and energy taxes not only slow down the rate of accumulation and growth but also make households worse off than compared to policies in base as usual scenarios. Mechanism for pollution control should rely on other energy saving or energy efficiency measures as well as industry specific and better waste management techniques than relying on energy and environmental taxes to let economy move in the balanced growth path.

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