GENERAL EQUILIBRIUM IMPACTS OF ENERGY AND POLLUTION TAXES ON CAPITAL ACCUMULATION, GROWTH AND REDISTRIBUTION IN 123 SECTOR MODEL OF UK

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ENERGY AND ENVIRONMENT MODELLING
ECOMOD-ANE-IEIT CONFERENCE, MOSCOW

September 13-14, 2007

THE UNIVERSITY OF HULL

Business School

Motivation:

Impact of Floods in England in July 2007

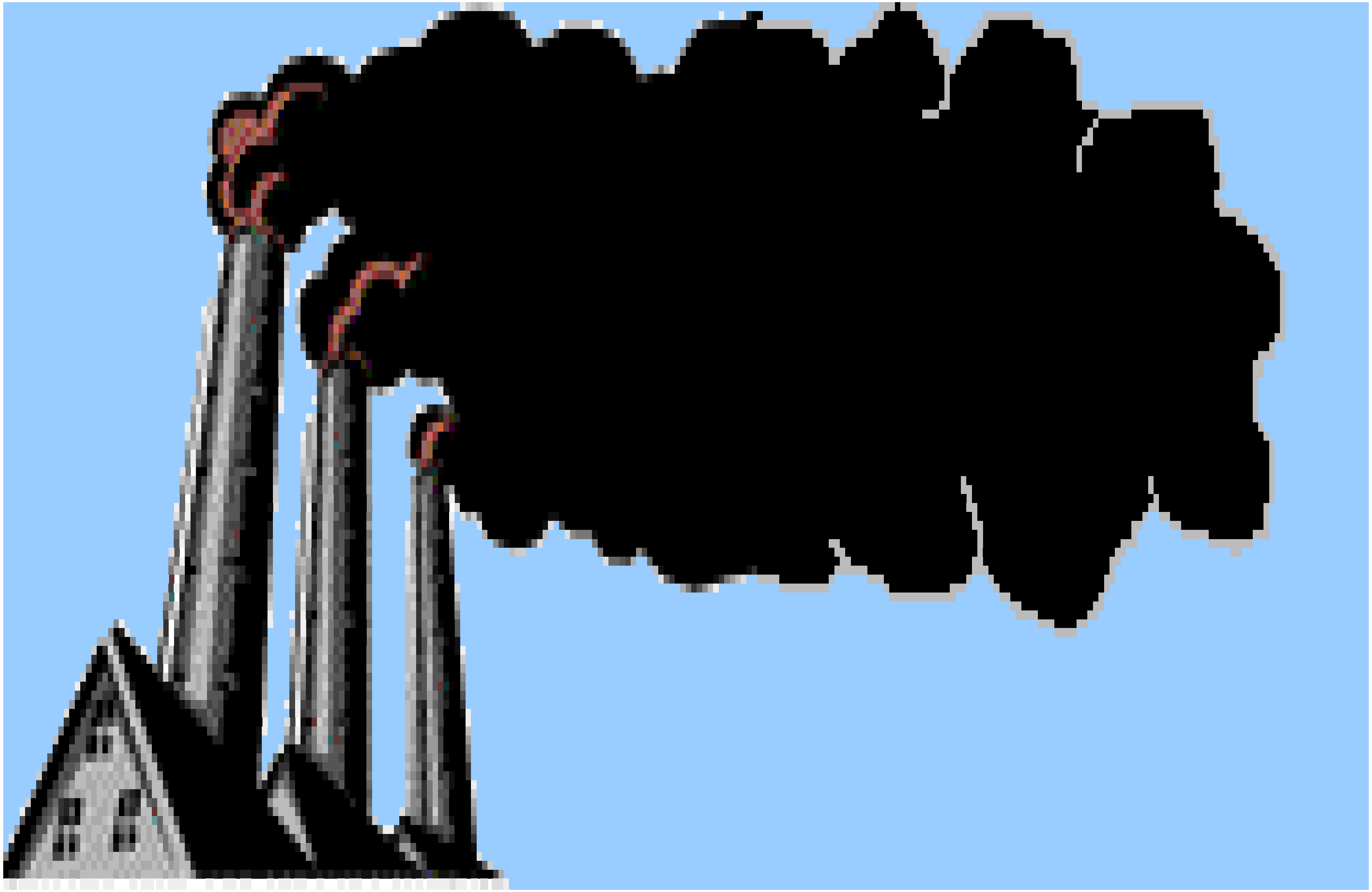
Source: BBC

Impact of Floods in England in July 2007

Impact of Floods in England in July 2007

Impact of Floods in England in July 2007

Pollution as by Product of Production



Electricity Generation and Pollution

Secondary industry: manufacturing

also includes oil refining, energy production, food processing

EASTERN
SECURITY
BEST
QUALITY
neer

Chemical Pollution

Water Pollution

Major Findings of Stern Review (2006)

- Greenhouse gases major causes of global warming

- Rise in the mean global temperature by 2-5 centigrade likely by 2030

- Draughts and floods

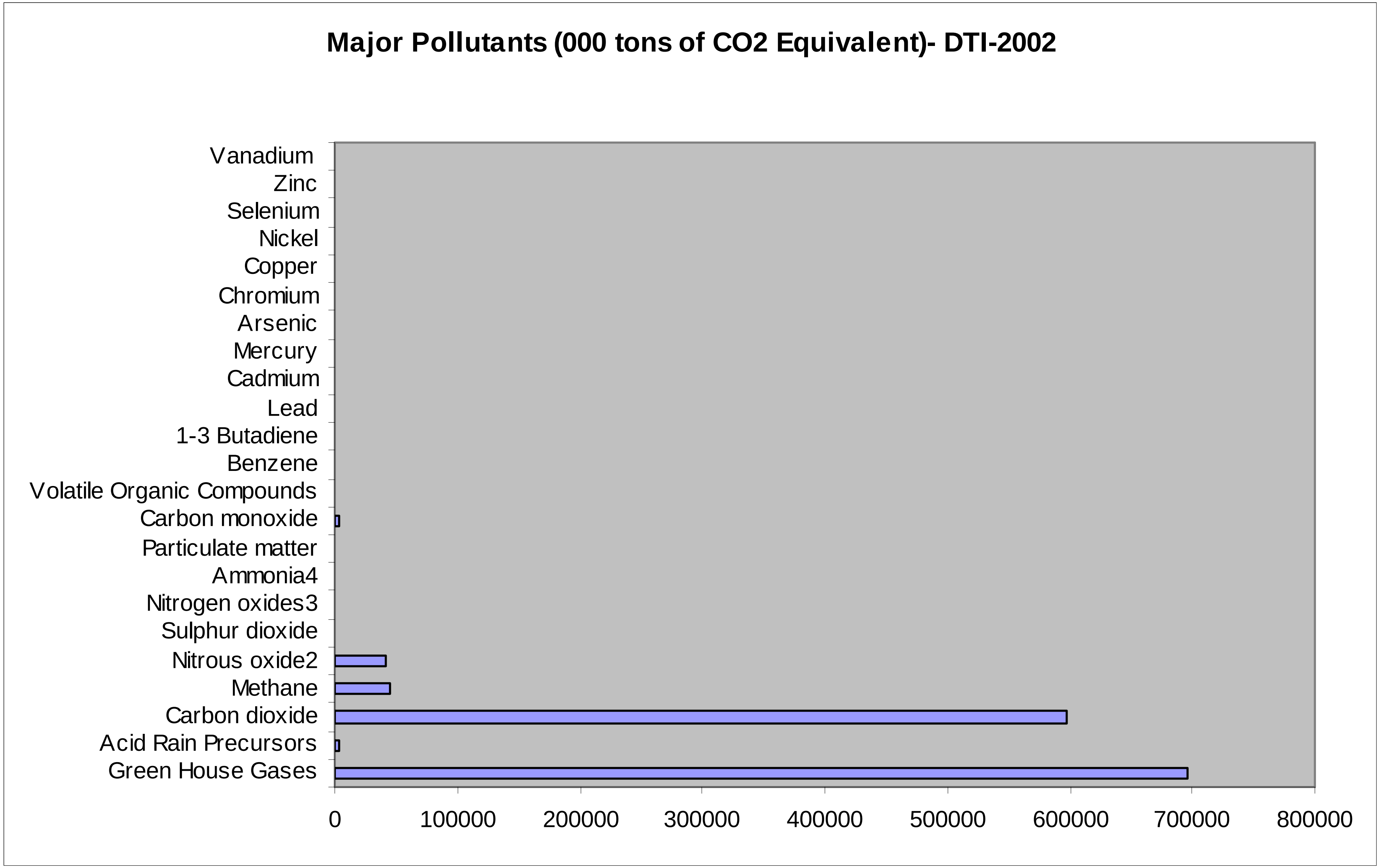
- Oceanic, atmospheric imbalances, melting of Ice Sheets and rise in sea level by 5-12 m

EU and UK Targets: Stern Review (2006)

- Kyoto Agreement
- Eco-Driving: 120 g CO2 per KM by 2012
- Revenue neutral road pricing schemes
- Reducing energy consumption by 80 percent by 2020
- Energy saving buildings
- Ships powered by sun, wind, waves, and fuel cells
- Raising the ratio of renewable to 20 percent of total energy sources by 2020

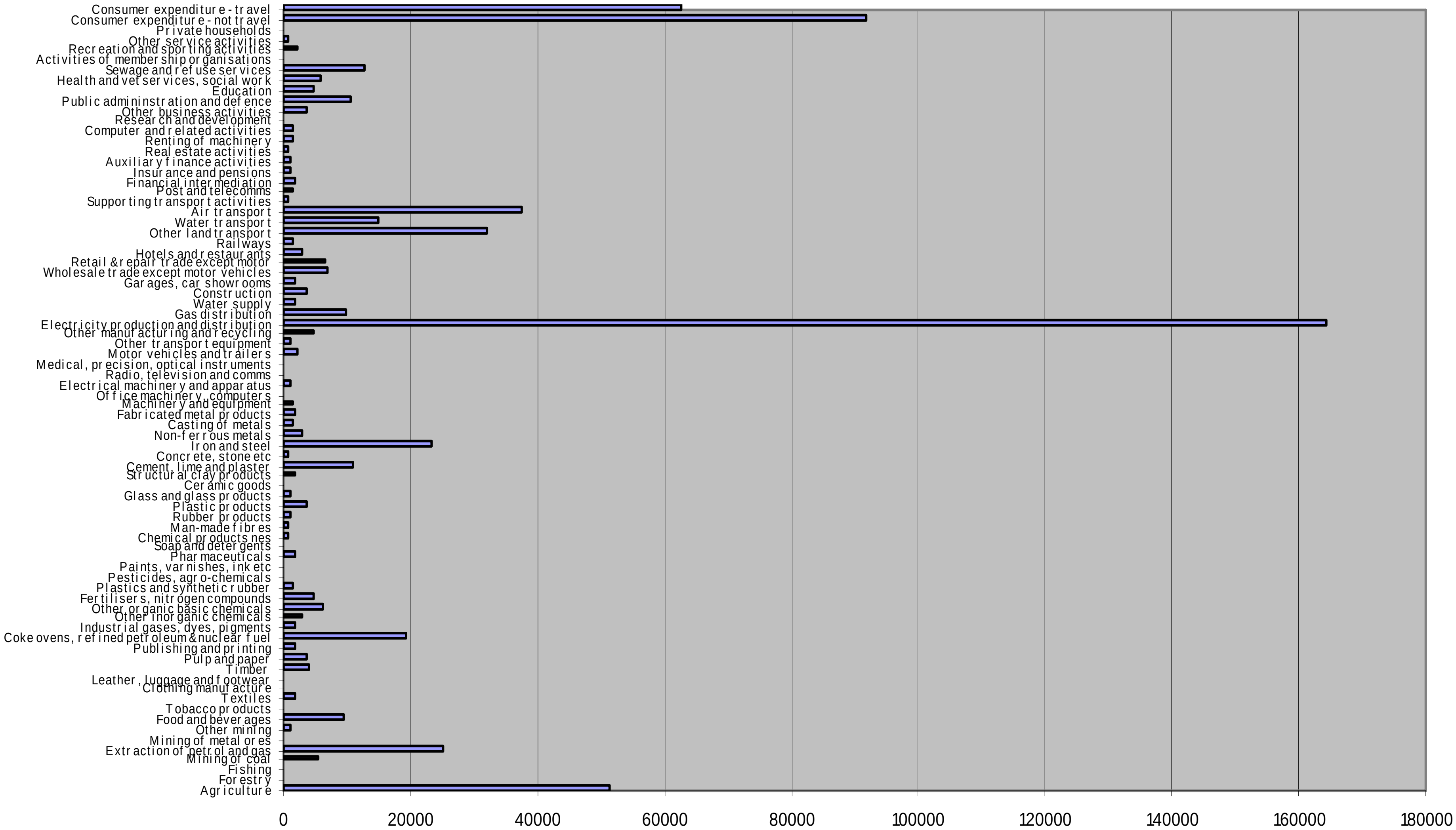
Some Papers in EEM Conference MOSCOW Relating to Pollutions and Solutions

- Camfert and Tabler
- De Miguel Cabeza
- Golub, Strukova dn Lugovoy
- Matsumoto
- Mohora Bayer Dramais and Opese
- Okagawa and Ban
- Umanskaya, Mason and Barbier
- Ricci
- Wissima and Dellink
- Garcia Flecha and Oses Eraso
- HASCHE Barth and Swinder
- Lehr and Cratzat
- Kalinowska, Kremers and Truong
- Karanfil and Ozturk
- Kaul
- Kolovos and Christakos
- Kononova and Churkina
- Kumbaroglu
- Vinhas De Souza and Lysensko



Source: ONS/DTI

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



Source: ONS/DTI

Some Literature on Growth, General Equilibrium, Energy and Environment

How man made factors enhance economic growth:

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)

Multisectoral dynamic real economy models

Auerbach and Kotlikoff (1987), Rutherford (1995), Kehoe, SriNivashan and Whalley (2005). 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

Partial or general equilibrium models with the electricity sector to examine how pollution arises in process of generating energy required for efficient functioning of the economy:

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)

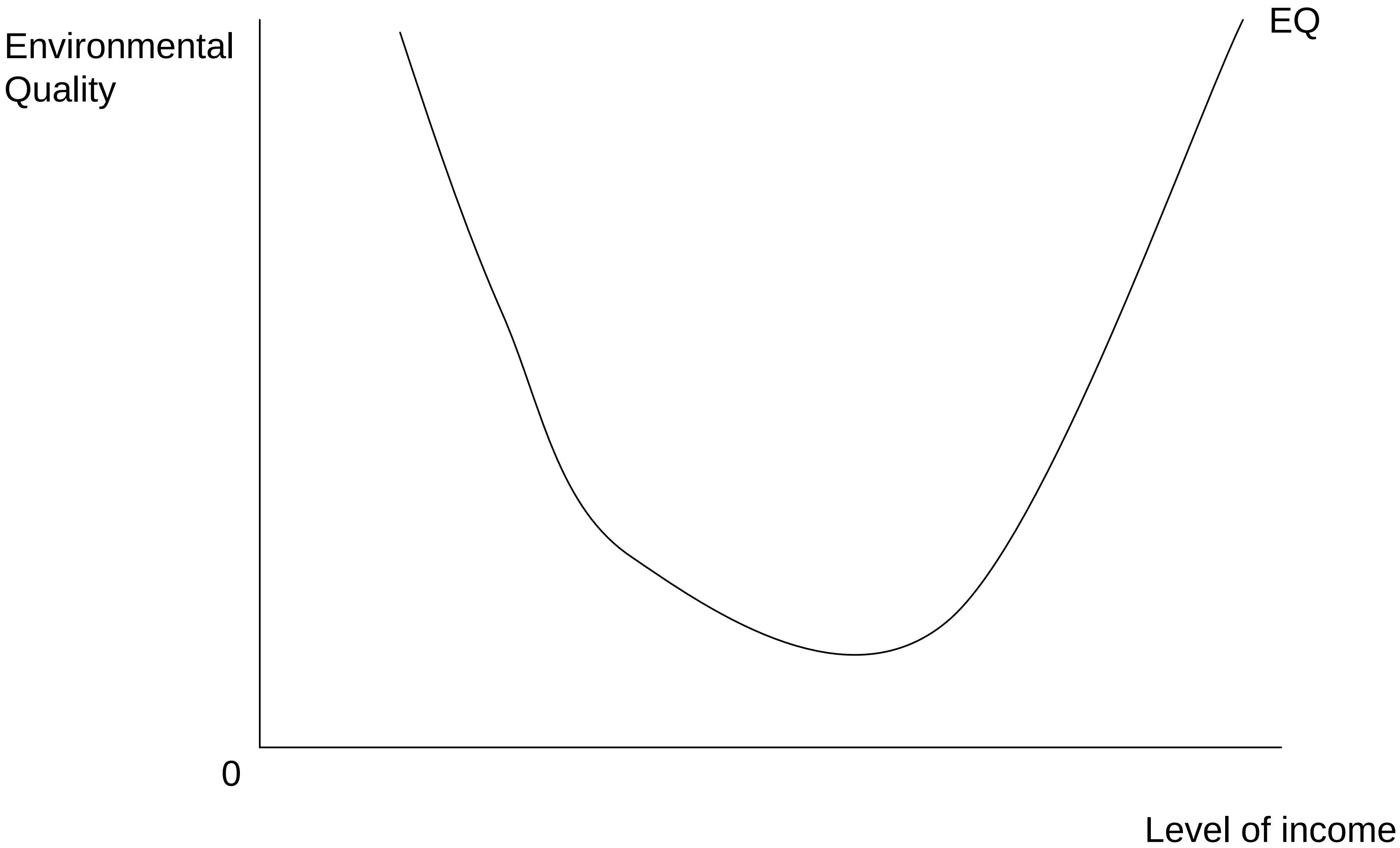
Climate change and burden and dividend sharing from improvement of environment:

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), Proost and Van Regemorter (1992), Rasmussen (2001), Kumbaroglu (2003), Roson (2003) , Uri and Boyd (1996) and Vennemo (1997)

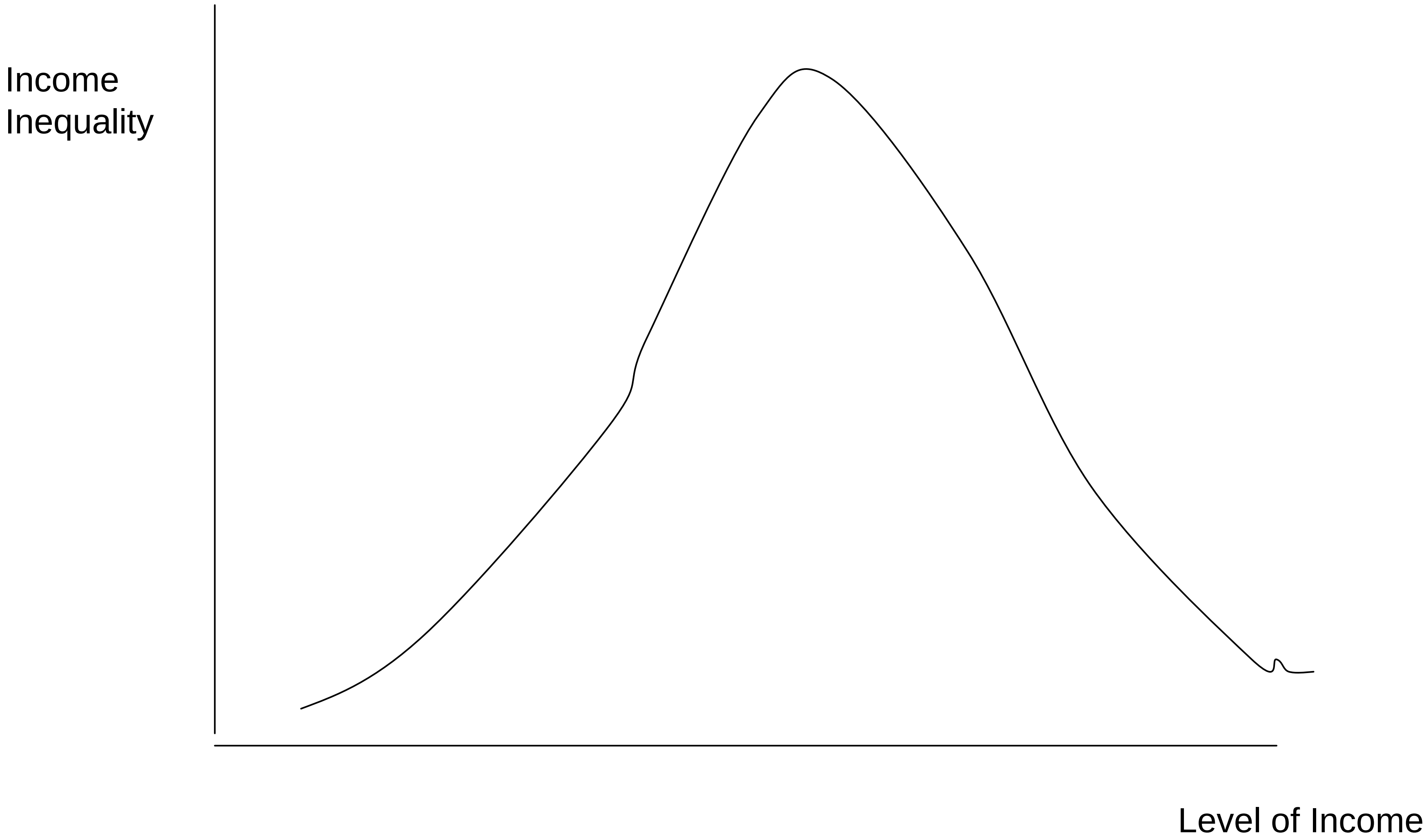
Game Theoretic models: Radner et. al.

DEFRA Report (various years), Kyoto Protocol (1997), Glenn Eagle summit (2005), Stern Report (2006)

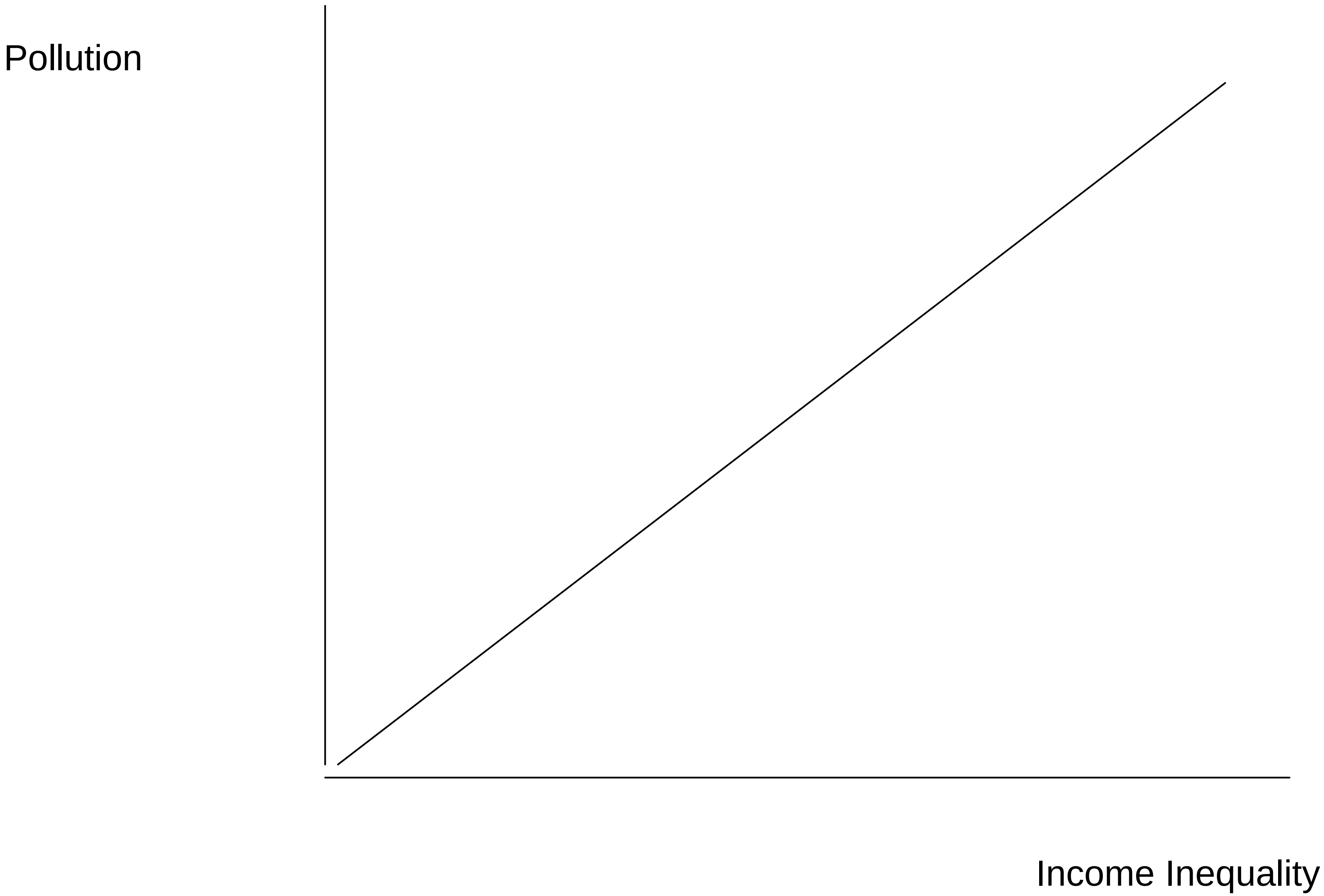
Environmental Quality and Level of Income

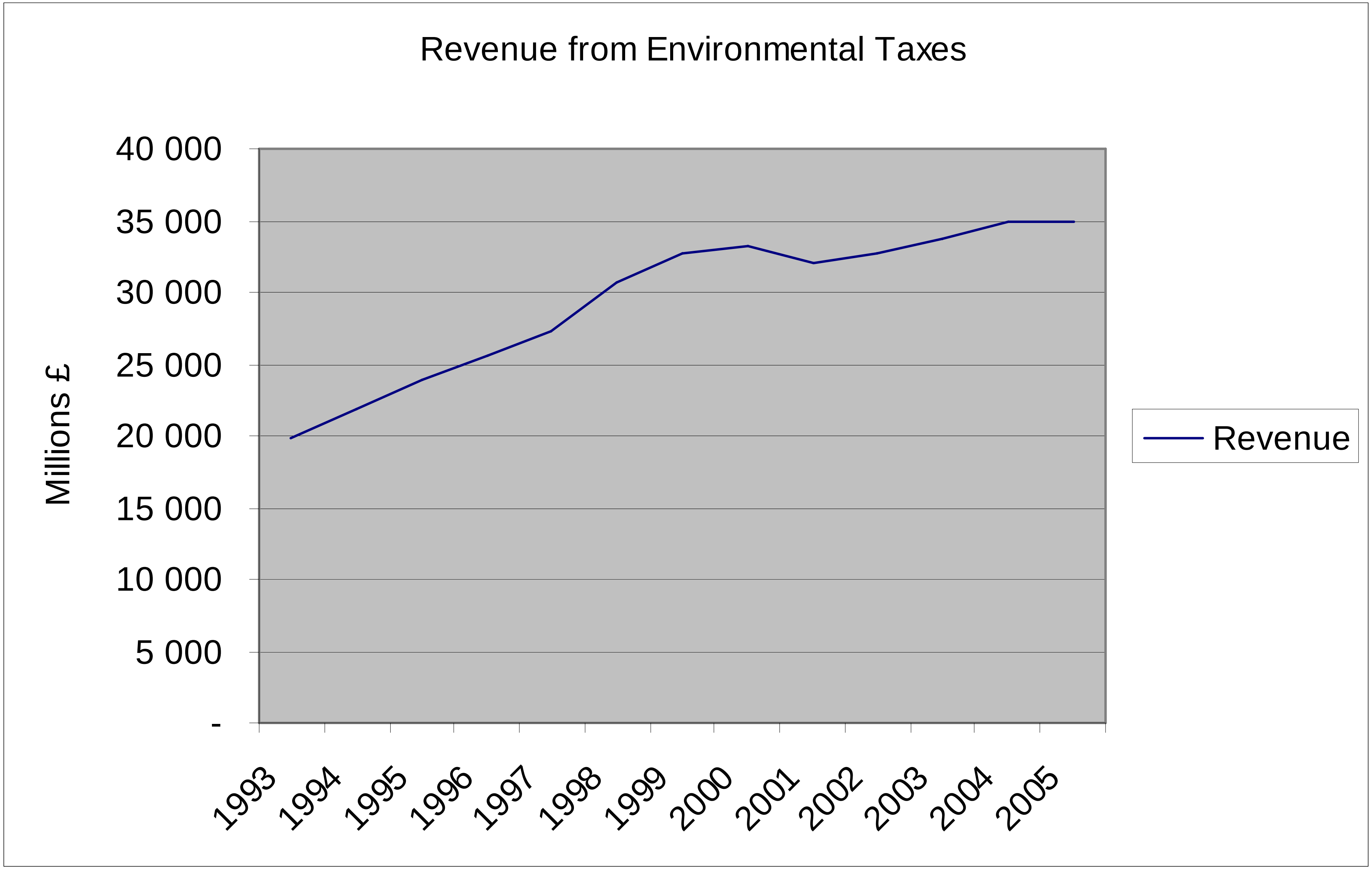


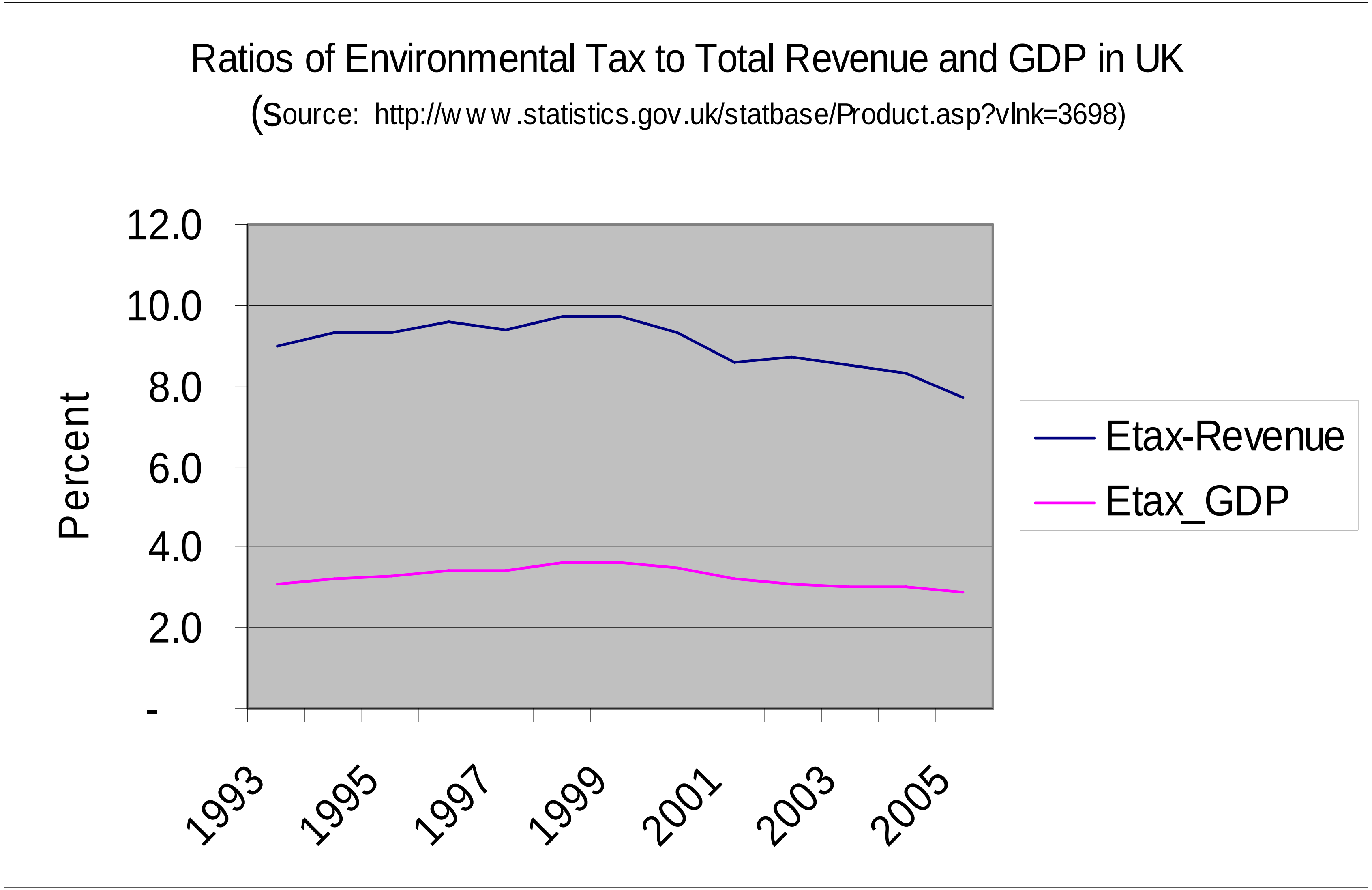
Income Inequality and Level of Income



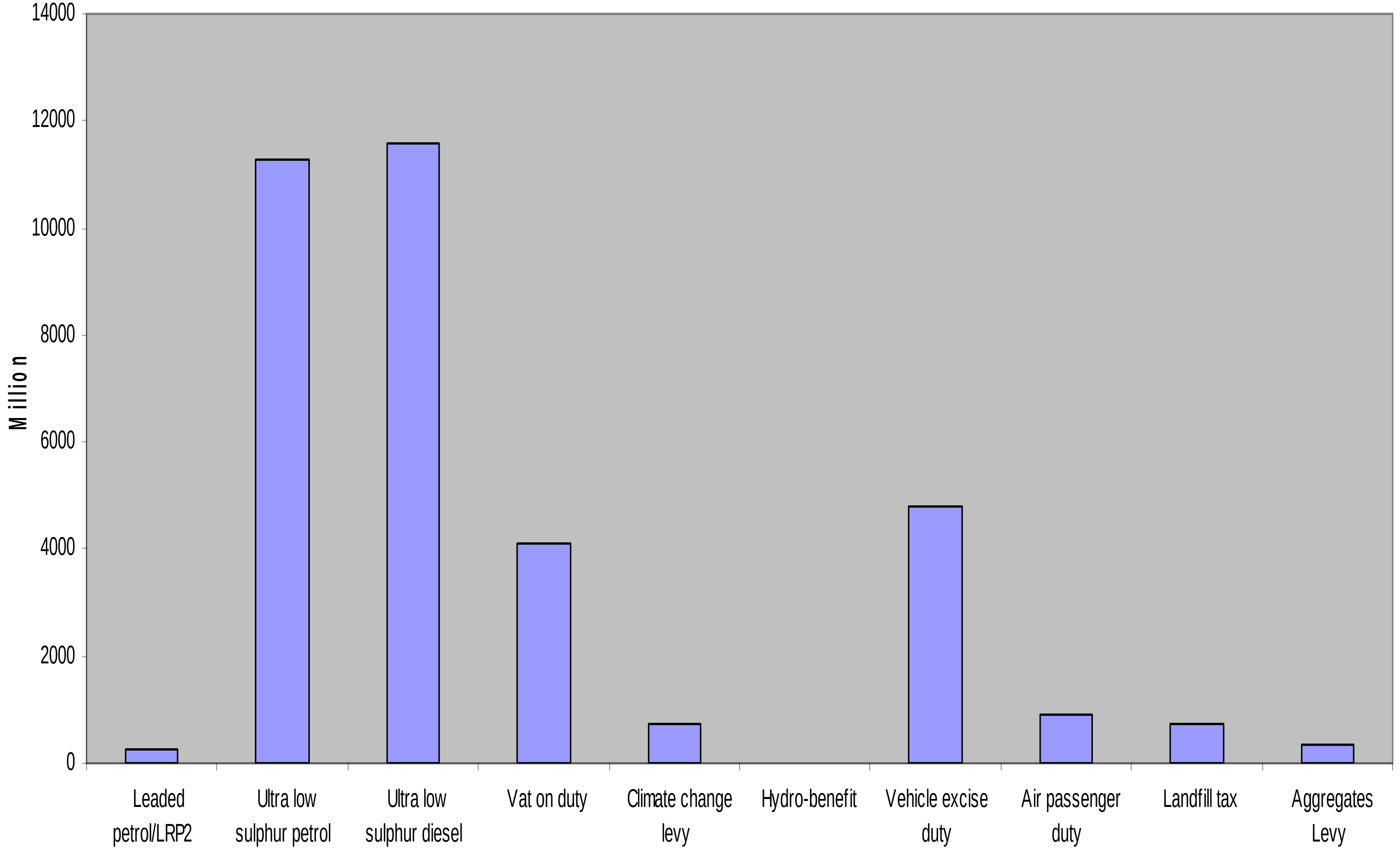
Pollution and Income Inequality




Revenue from Environmental Taxes
Millions £
40 000
35 000
30 000
25 000
20 000
15 000
10 000
5 000
-
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
Revenue


Ratios of Environmental Tax to Total Revenue and GDP in UK
(Source: http://w w w .statistics.gov.uk/statbase/Product.asp?vlnk=3698)
Percent
12.0
10.0
8.0
6.0
4.0
2.0
-
1993
1995
1997
1999
2001
2003
2005
Etax-Revenue
Etax_GDP

Revenue from Environmental Taxes, 2005



Major Arguments for Policy Analysis

- Pollution taxes on the use of capital and labour inputs in production across sectors link the energy, environment and growth of economy.
- Air, water, land pollution is essentially a by-product of processes of production.
- Evolution of economy differs with and without energy and pollution taxes.
- Dynamic micro impacts on output, employment, investment and capital stocks by sectors and households at micro level.
- Dynamic macro impacts on growth and redistribution.
- Environmental taxes slow down the growth of economy.
- Mechanism of pollution control should rely on energy saving or energy efficiency measures than on the energy and environmental taxes.

Environment in Ramsey Model for Optimal Growth

Preference: $$U_0 = \sum_{t=0}^{\infty} \beta^t \ln(C_t) - \sum_{t=0}^{\infty} \theta^t \ln(E_t) \quad 0 < \beta < 1$$

Technology: $$Y_t = AK_t^{\alpha} \qquad 0 < \alpha < 1 \qquad A = 1$$

Emission $$E_t = \varphi Y_t \qquad 0 < \varphi < 1$$

Market clearing: $$C_t + I_t = Y_t \qquad K_0 = K_0 \qquad C_t = Y_t - I_t$$

Accumulation $$K_{t+1} = K_t(1-\delta) + I_t$$

Cost of pollution in production reflected in lower investment

State and control: $$C_t = AK_t^{\alpha} - \phi\{K_{t+1} - K_t(1-\delta)\}$$

$$0 < \phi < 1$$

Ramsey (1928) Cass (1965) Koopman(1965) Uzawa (1965)

Optimal Conditions and Steady State of the Model

$$\underset{K}{Max}\, U_0 = \sum_{t=0}^{\infty} \beta^t \ln\left(K_t^{\alpha} - K_{t+1} + K_t(1-\delta)\right) - \sum_{t=0}^{\infty} \theta^t \varphi K_t^{\alpha}$$

$$\frac{\partial U_t}{\partial C_t}\frac{\partial C_t}{\partial C_{t+1}}\frac{\partial C_{t+1}}{\partial K_{t+1}} = ..-\frac{\beta^t}{C_t}\left(\alpha K_t^{\alpha-1} - 1\right) + \frac{\beta^{t+1}}{C_{t+1}} - \theta\varphi\alpha K_t^{\alpha-1} + .. = 0$$

$$.. = K_{t-1} = K_t = K_{t+1} = .. = \overline{K}$$

$$.. = C_{t-1} = C_t = C_{t+1} = .. = \overline{C}$$

$$\frac{\beta^t}{C_t}\alpha K_t^{\alpha-1} - \theta\varphi\alpha K_t^{\alpha-1} = \frac{\beta^{t+1}}{C_{t+1}} - \frac{\beta^{t+1}(1-\delta)}{C_{t+1}}$$

Pollution reduces output and capital stock in the steady state

$$\overline{K} = \left(\frac{\dfrac{\beta}{\overline{C}} - \dfrac{\beta(1-\delta)}{\overline{C}}}{\alpha\left(\dfrac{\beta}{\overline{C}} - \alpha\theta\varphi\overline{C} \right)} \right)^{\alpha - 1}$$

$$\frac{\partial \overline{K}}{\partial \theta} < 0, \frac{\partial \overline{K}}{\partial \varphi} < 0 \quad \frac{\partial \overline{Y}}{\partial \theta} < 0, \frac{\partial \overline{Y}}{\partial \varphi} < 0$$

Model Structure

Households

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

Subject to

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

Firms

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

Government

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

(4)

Environment

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

Benchmarking

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

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

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

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

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

Theoretical Aspects of General Equilibrium Analysis

Economic system is described by a system of $n(n-1)$ relative prices that clear all goods and factor markets. It is often stated in terms of vectors of prices, demand and supply and excess demand functions for inputs and outputs.

Vector of prices $p = (p_1, p_2, .., .., p_j, .., .., .., p_n)$

Demand for commodities are expressed in terms of the price vector

$X_j^d = X_j^d(p) = X_j^d(p_1, p_2, .., .., p_j, .., .., .., p_n)$

Supply functions defined similarly

$X_j^S = X_j^s(p) = X_j^S(p_1, p_2, .., .., p_j, .., .., .., p_n)$

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

$$E(p) = (E_1(p), E_2(p), .., .., .., E_j(p), .., .., E_n(p)).$$

The general equilibrium is a price vector, p^*, such that

$$p^* \geq 0$$

$$E(p^*) \leq 0$$

$$\text{if} \quad E(p^*) < 0 \quad p^* = 0$$

Brouwer's Fixed Point Theorem

A continuous function from a compact convex set into itself has a fixed point. Prices can be normalised to made their sum equal to one using the homogeneity assumption as

$$S = \left\{ p \Big/ \sum_{i=1}^{n} p_i = 1, p \geq 0 \right\}$$

Consider a set of the excess demand functions evaluated a *p*. Update or adjust this price according to following rules for each of j commodities:

$$\left.\begin{aligned} \overline{p}_j &= p_j \quad if \quad E_j(p) = 0 \\ \overline{p}_j &= p_j + \Delta \quad if \quad E_j(p) > 0 \\ \overline{p}_j &= \max(0, p_j - \Delta_j) \quad if \quad E_j(p) < 0 \end{aligned}\right\} \quad for \quad j = 1,2,..,..,n$$

Here Δ represents a very small positive constant. Following above rule in each iteration find new prices as

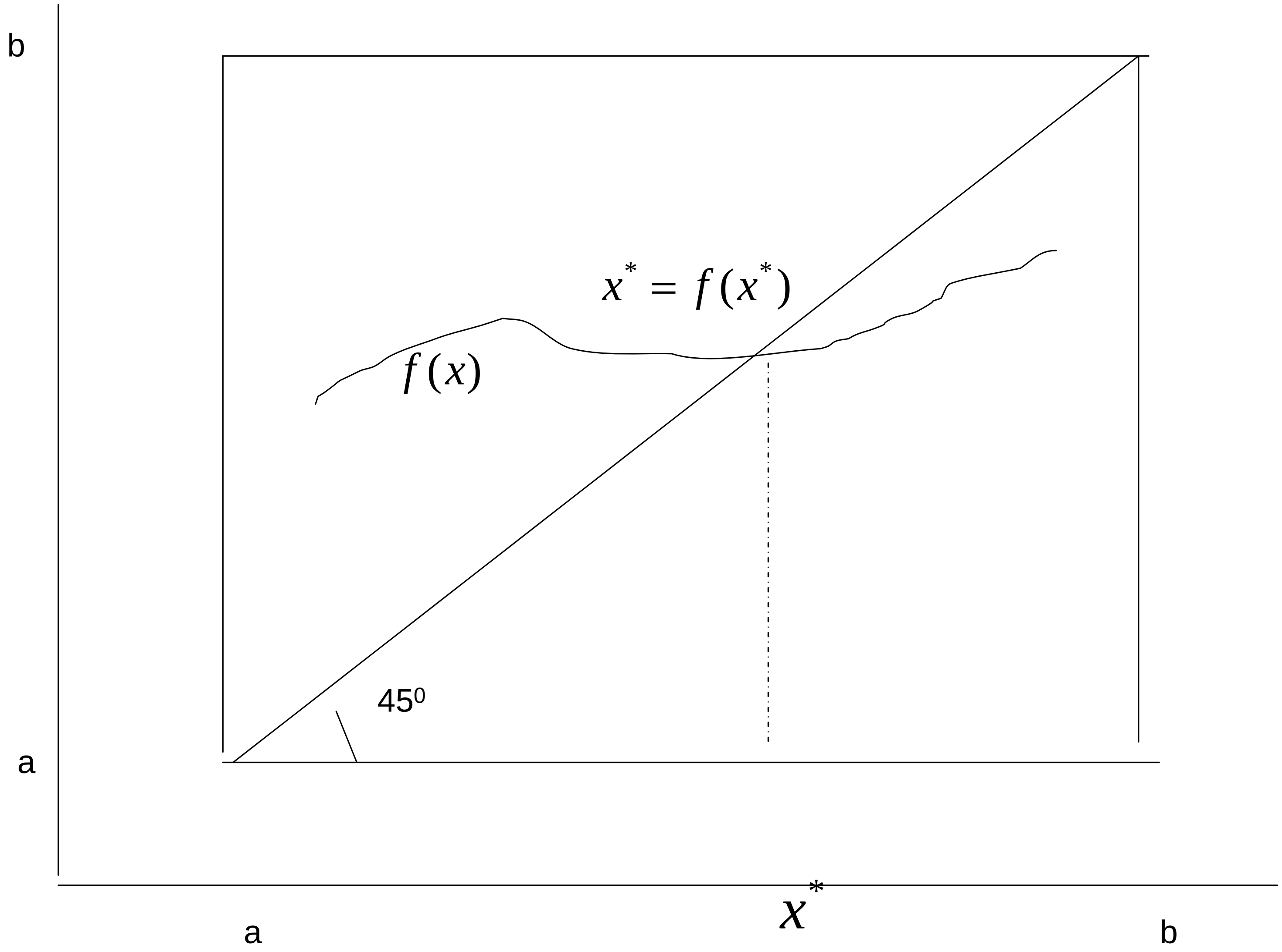
$$p \to E(p) \to \overline{p}$$

$\overline{p}$ remains unchanged if excess demand is zero, $E(p) = 0$; $\overline{p}$ rises if $E(p) > 0$ and $\overline{p}$ falls if $E(p) < 0$ and if $E(p) < 0$ then $p = 0$.

The fixed equilibrium point is found by continuous transformation of the nonempty convex set onto itself

$$p^* \to E(p^*) \to p^*$$

Graphical Illustration of Brouwer fixed point theorem



More explicit proof of the Brouwer't theorem requires use of Sperner's Lemma and Kanster-Kuatowski-Mazzurkeiwiecz (KKM) theorem which can be found at Ross Starr (1997) on fixed point algorithm and convex hull.

Uniqueness of Equilibrium

One approach to establish the uniqueness of the equilibrium is based on evaluation of Jacobian matrix of excess demand functions. Taking *n*th commodity as a numeraire and differentiability of the excess demand functions Jacobian matrix is normalised as following (Hicksian method):

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

The equilibrium is unique if the principal minors of J alternate in sign, its values is positive for even number of rows and columns; and negative for uneven number of rows and columns.

Stability of Equilibrium and Walrasian Auctioneer

Intrilligator (1971) suggests decentralised iterative computation of equilibrium, leading to time paths for quantities and prices. If these time paths eventually converge to equilibrium values then the process is table.

$$x = \left(x_1, x_2, ., .., x_j, .., ., .., x_n\right)$$

$$p = \left(p_1, p_2, ., .., p_j, .., ., .., p_n\right)$$

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

Equilibrium is locally stable if

$$\lim_{t \to \infty} p(t) = p^* \;\; \text{given} \quad \left| p(t_0) - p^* \right| < \delta$$

where t_0 denote the initial starting point and $\left| p(t_0) - p^* \right|$ the Euclidean norm in the price space.

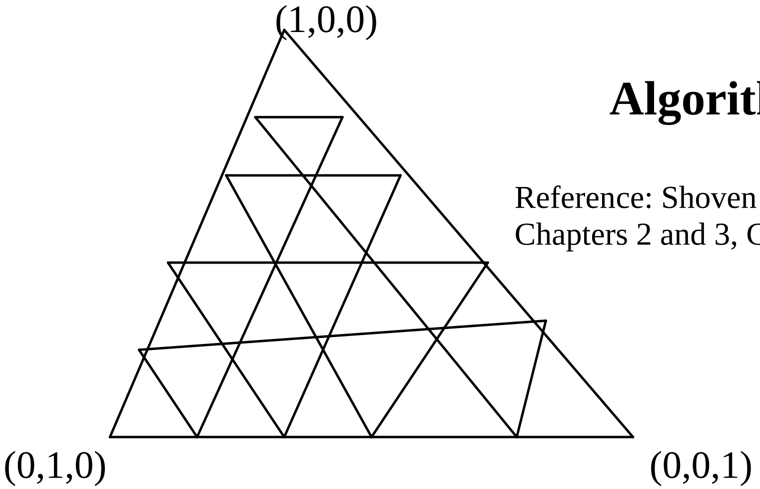
Equilibrium is globally stable if it is reached regardless of any starting point

$$\lim_{t \to \infty} p(t) = p^* \;\; \text{for any} \quad p(t_0)$$

Algorithms to Compute Equilibrium

Reference: Shoven J. B. and J. Whalley (1992) Applying General Equilibrium, Chapters 2 and 3, Cambridge University Press.

Scarf algorithm (triangulation of simplex)



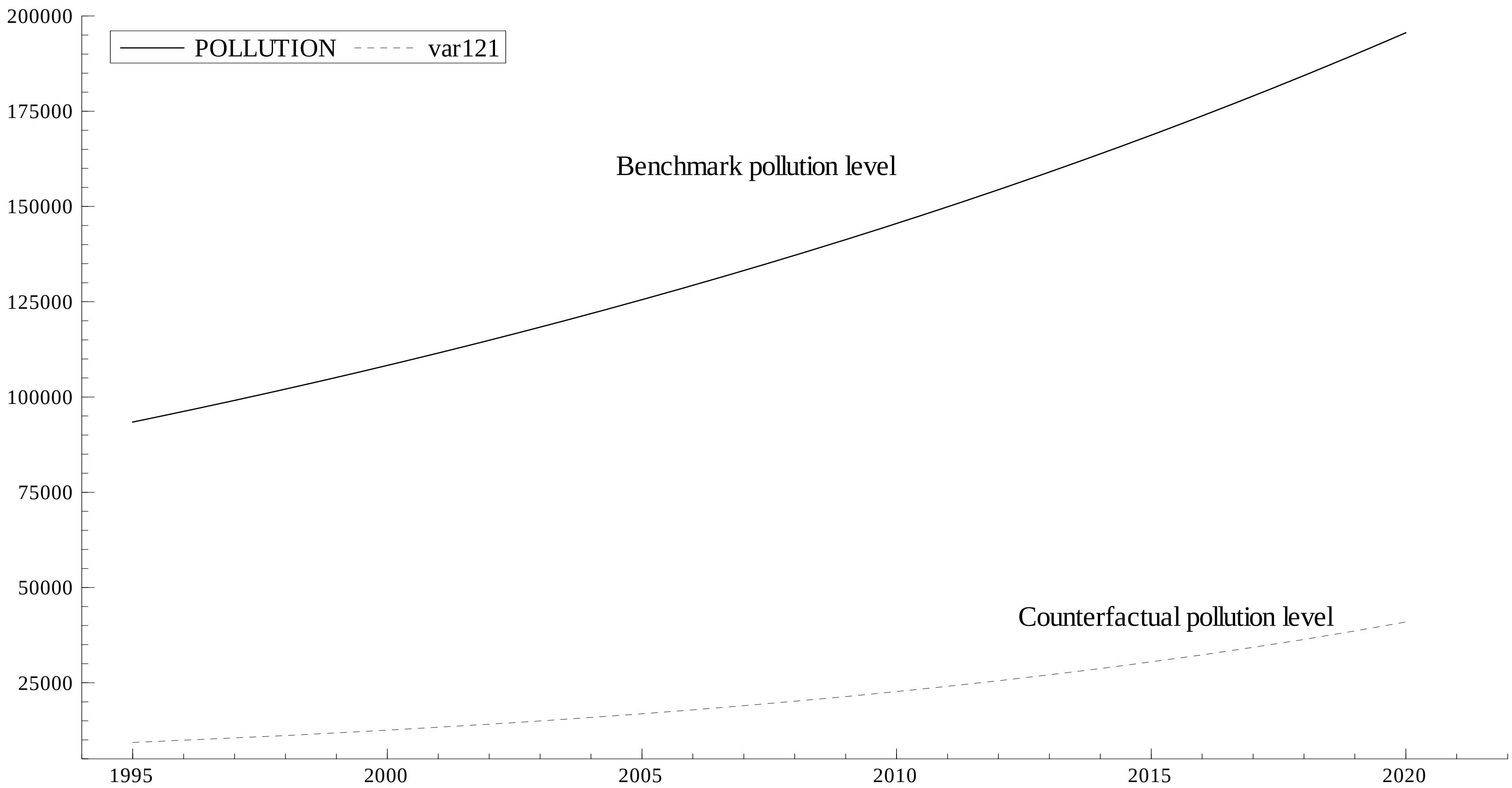
Triangulation of a unit simplex with grid size of 5.

Steps:

1. select an initial simplex and grid size D (5 in above simplex).
2. calculate the labels of vertices of the initial simplex by applying the labelling rule.
3. If the simplex is completely labelled go to step 5 else to step 4.
4. generate a new vertex applying the replacement rule. Determine the label of new vertex.
5. Since the vertex is completely labelled an approximation to competitive equilibrium has been found where the excess demand is less than a selected ε .

Exercise (i) find the co-ordinates for any five sub-simplices (ii) show division of this unit simplex for grid size of 10.

There are many other algorithm to compute equilibrium: Merrill's algorithm, Van der Laan and Talman algorithm, MCP algorithm and Judd algorithms (See Handbooks of Computational Economics, North Holland for details on these).



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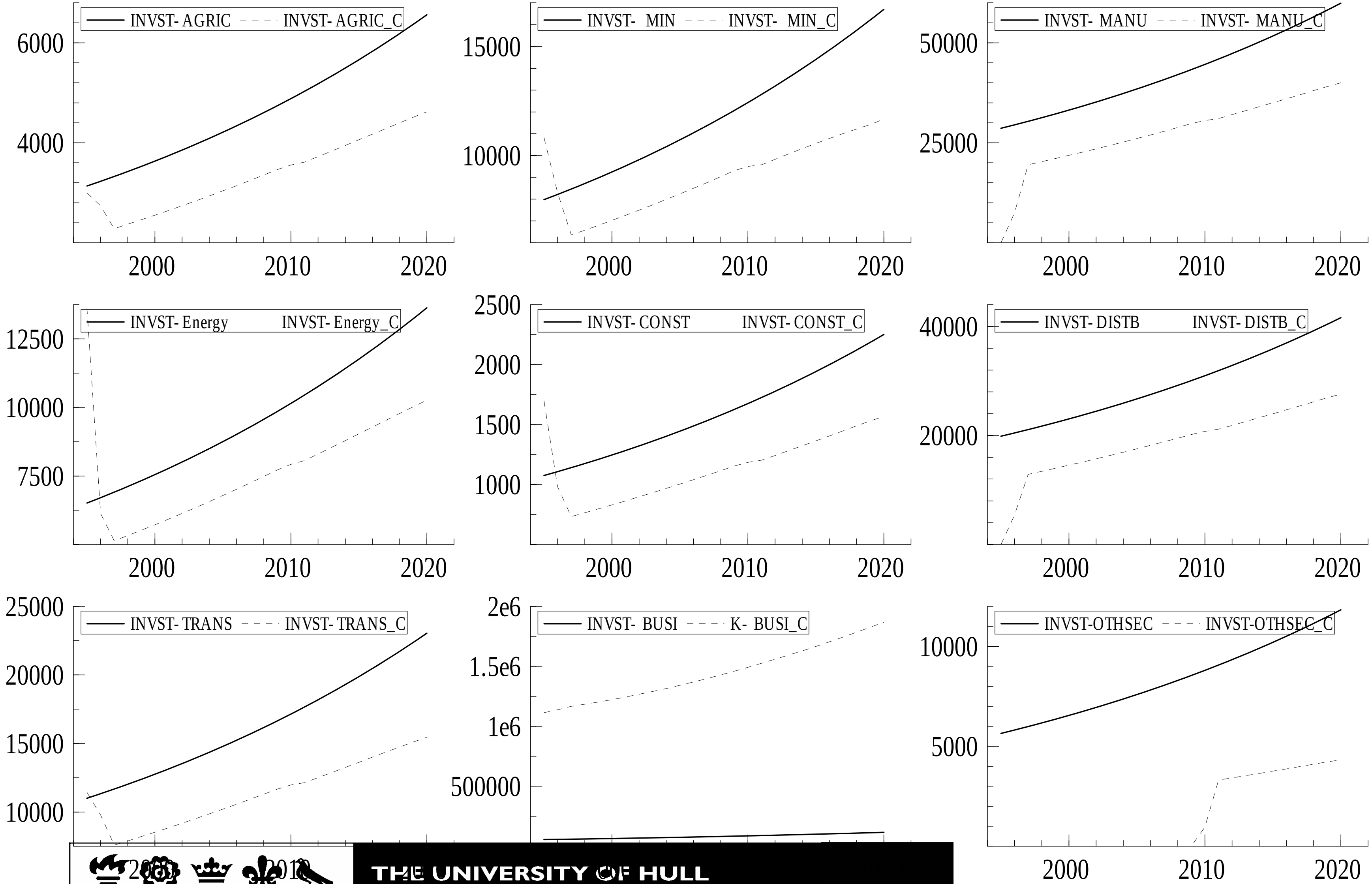
Impact of energy carbon taxes on investment by sectors



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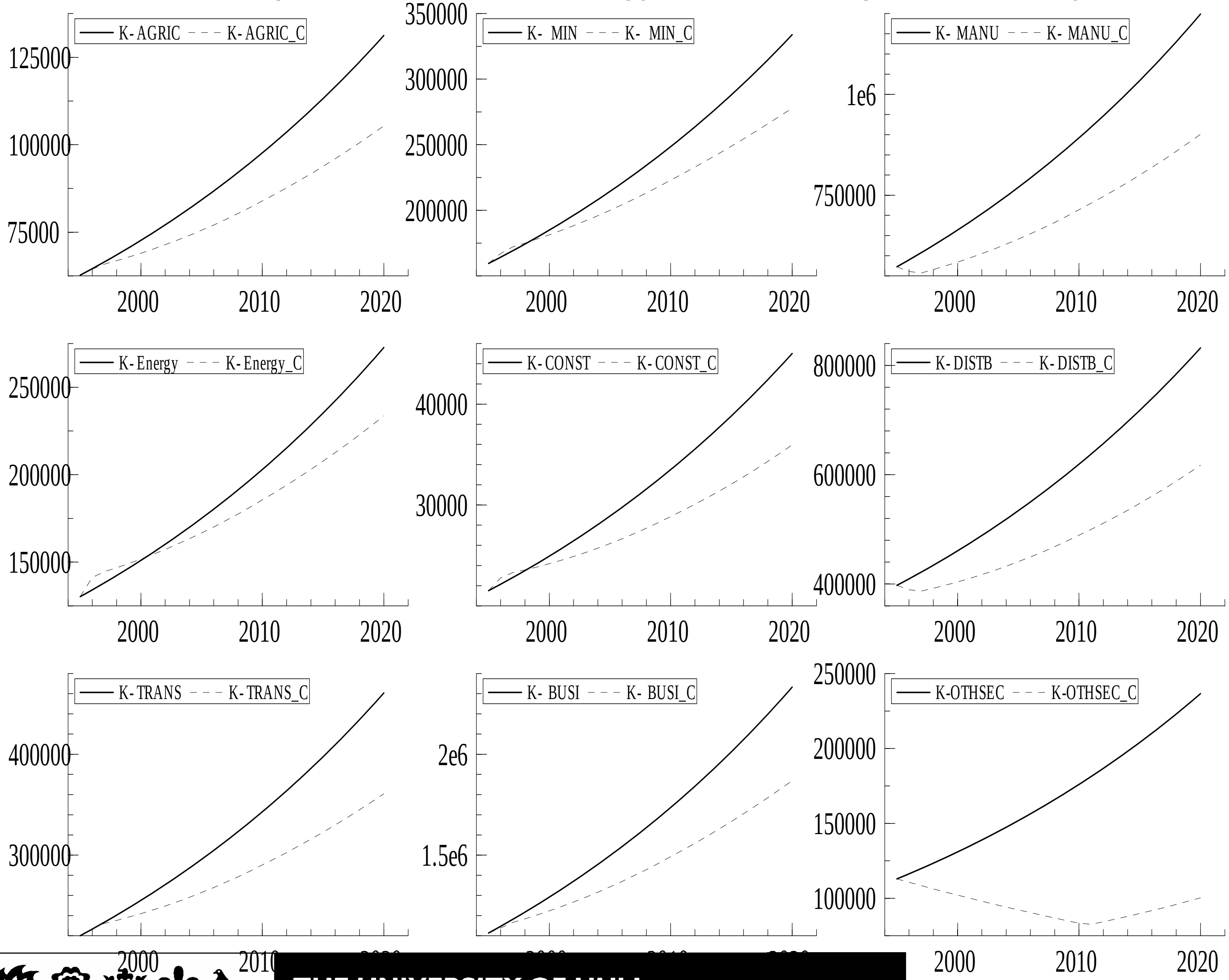
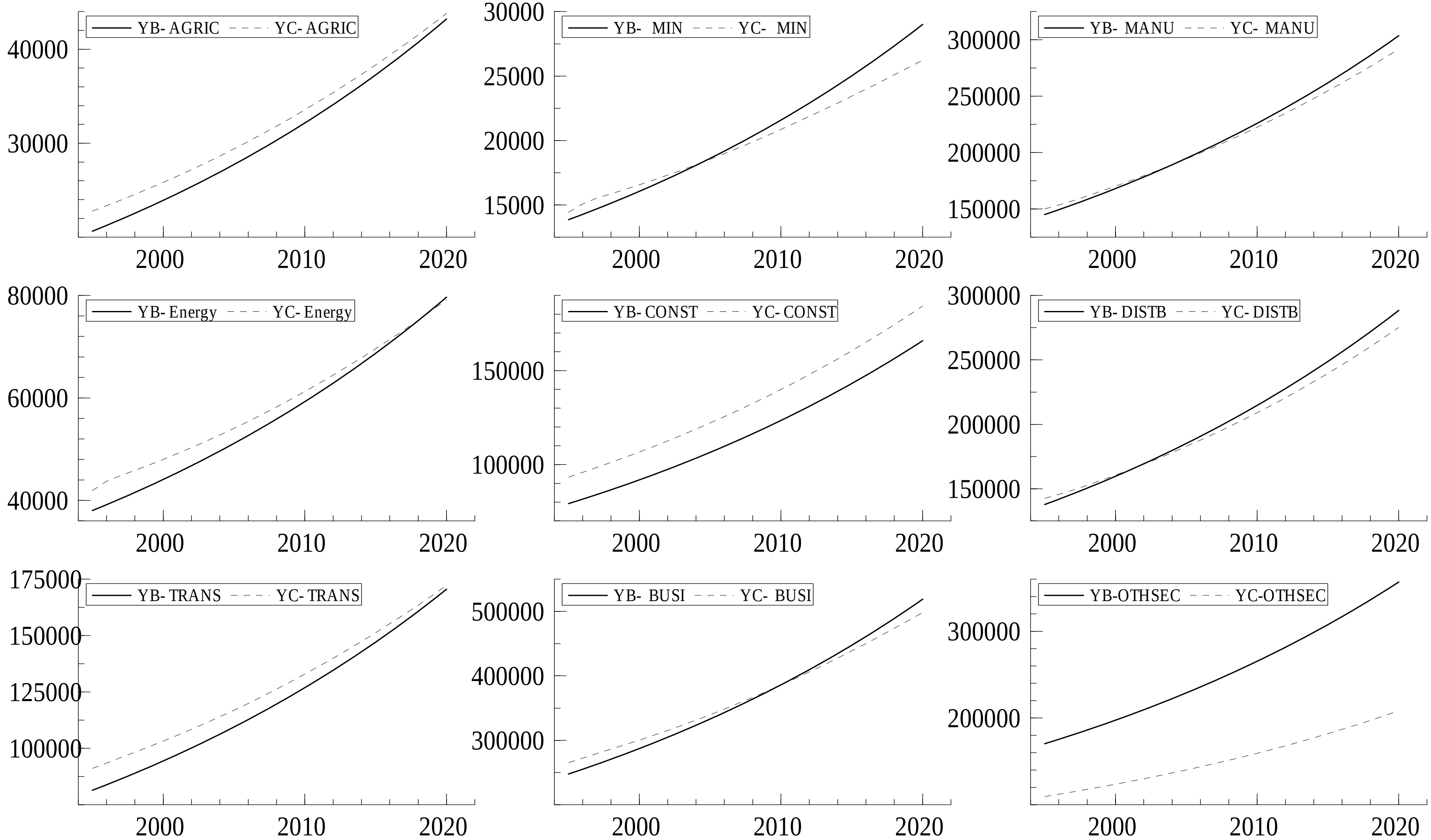
Impact of carbon energy taxes in capital stock by sectors



Impact of carbon energy taxes in the levels of output by sectors



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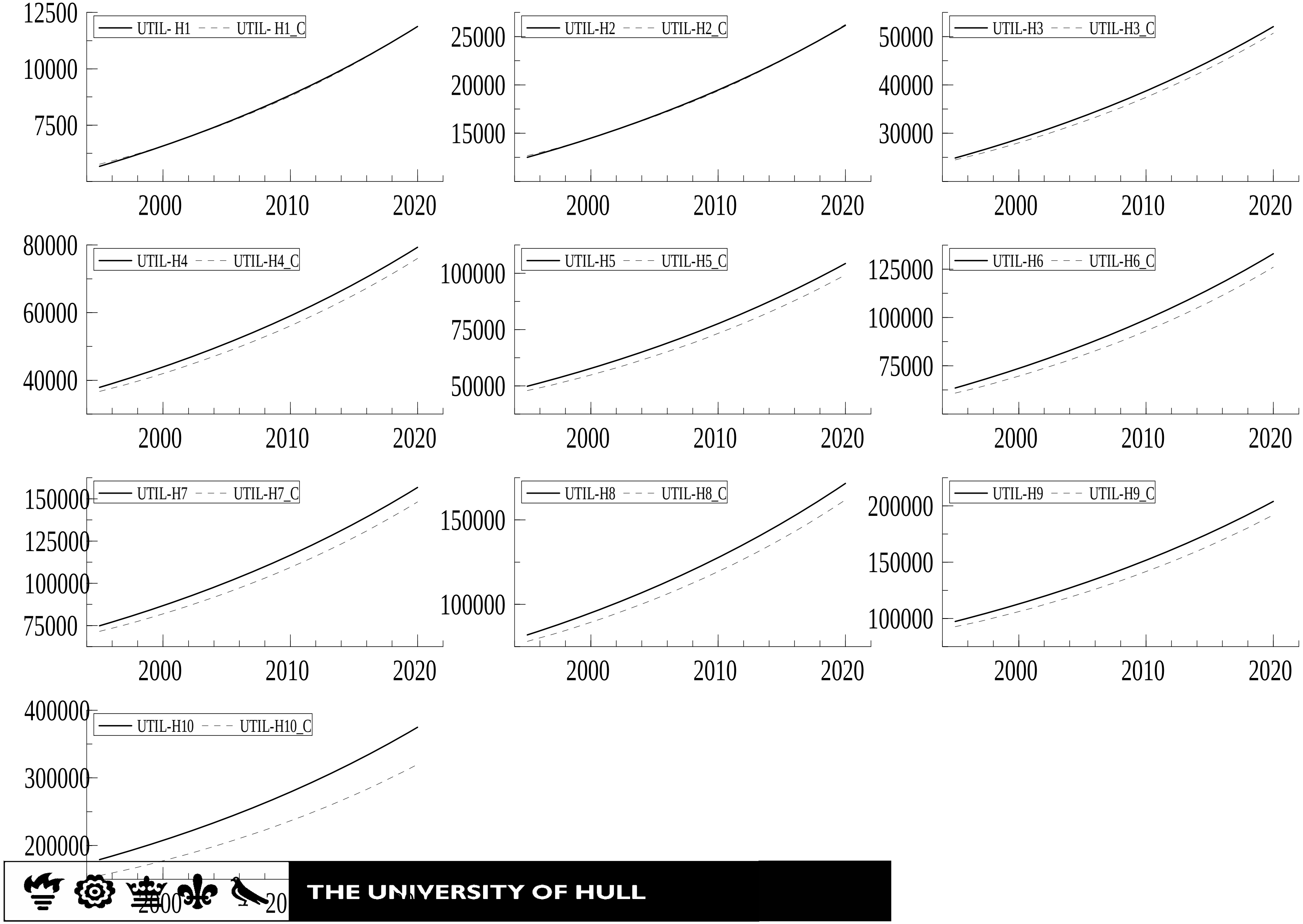
Impact of carbon energy taxes in utility level of households



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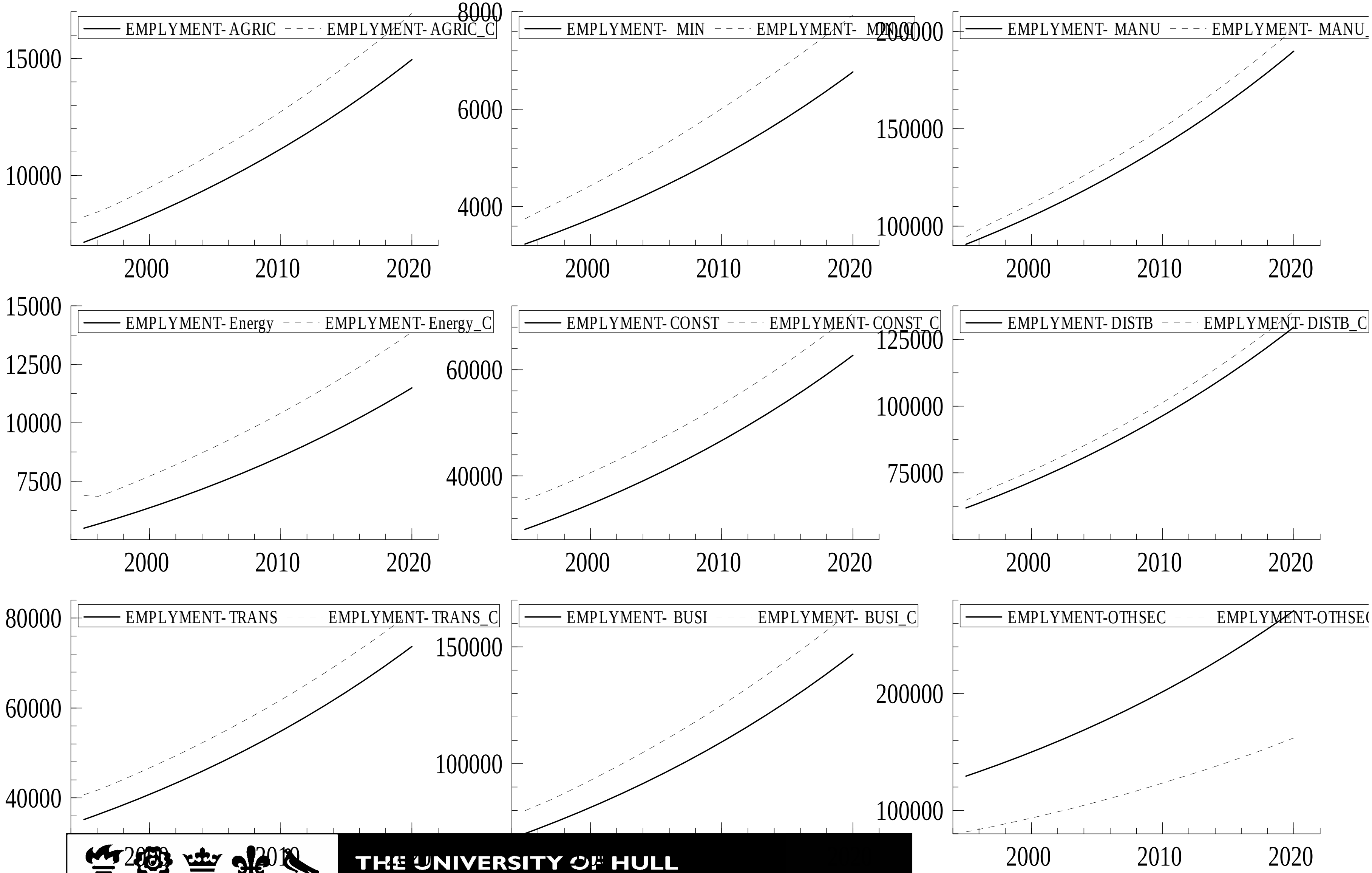
Impact of energy carbon taxes on employment by sectors



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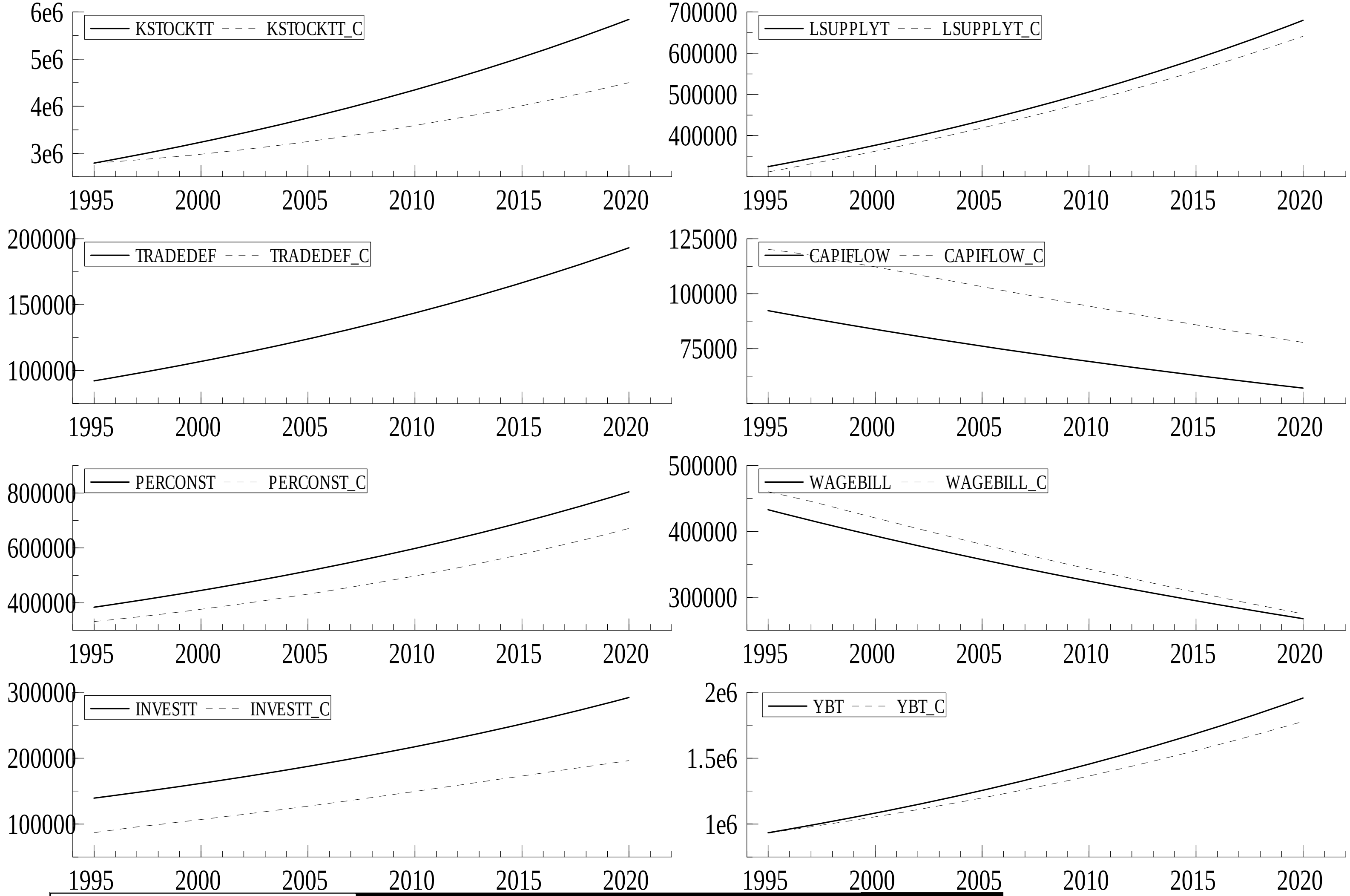
Macroeconomic impacts of carbon energy taxes



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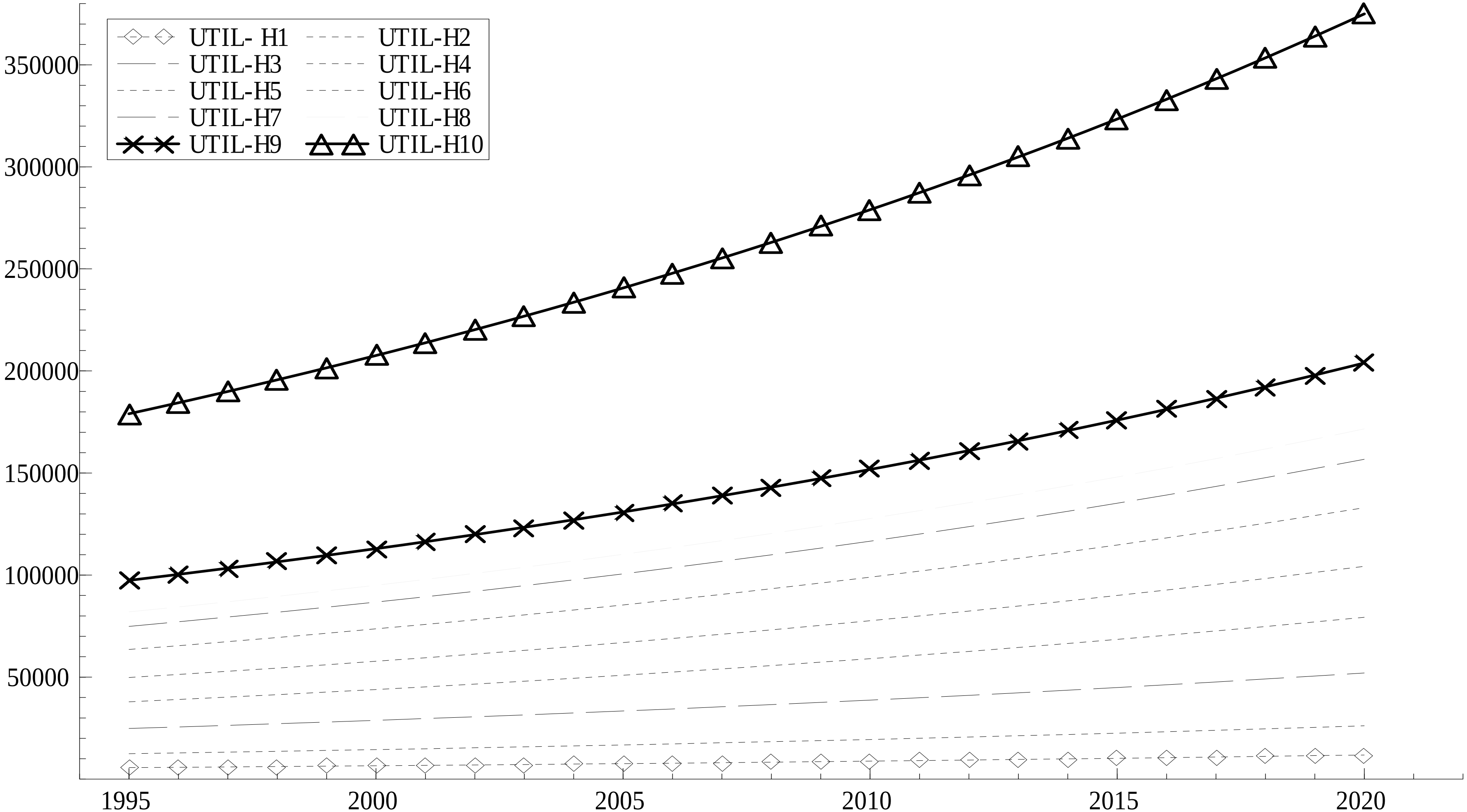
Utility Level of Households in the Benchmark Scenario



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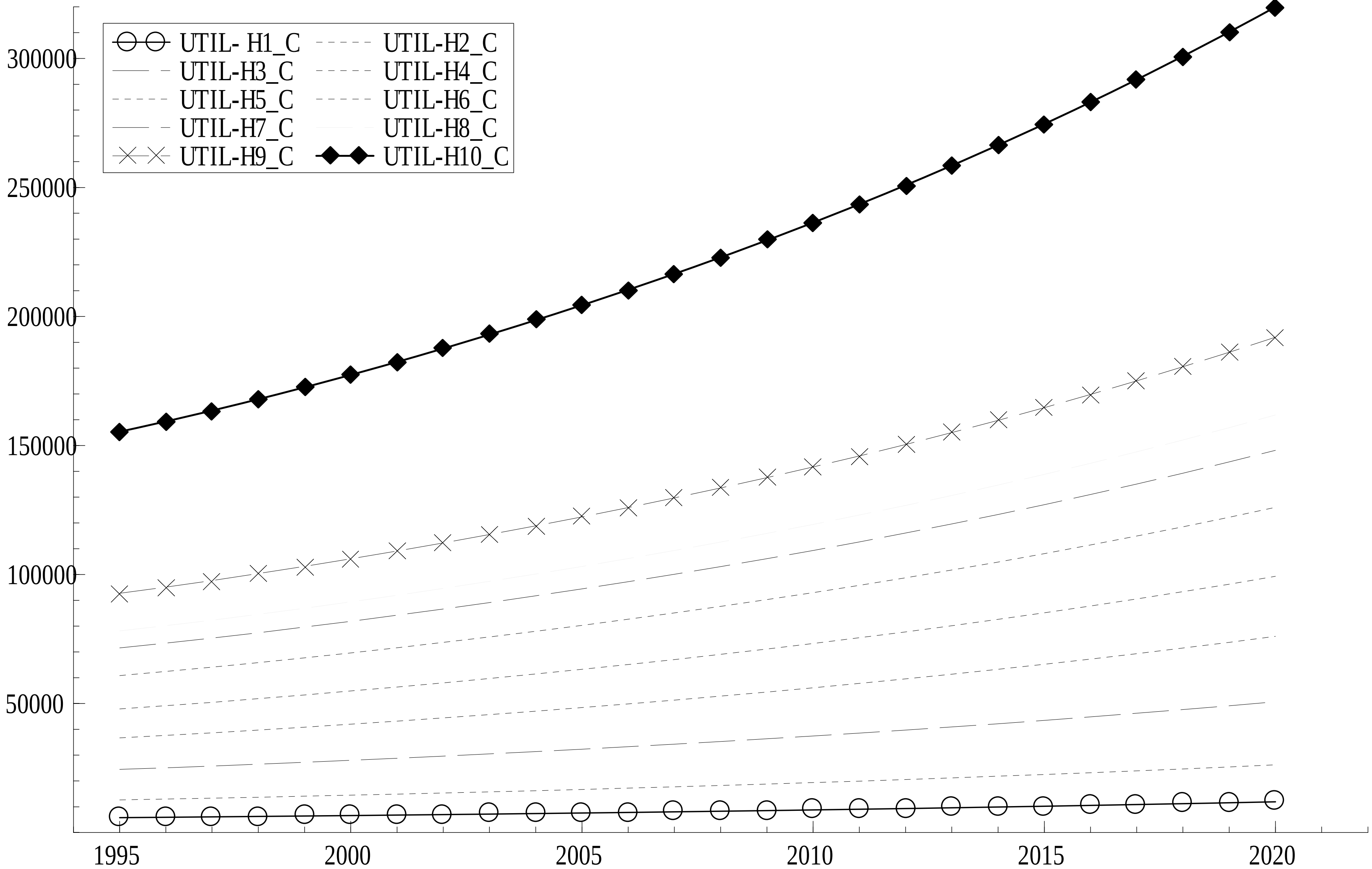
Comparing Utility Level All Households in Counterfactual Scenario



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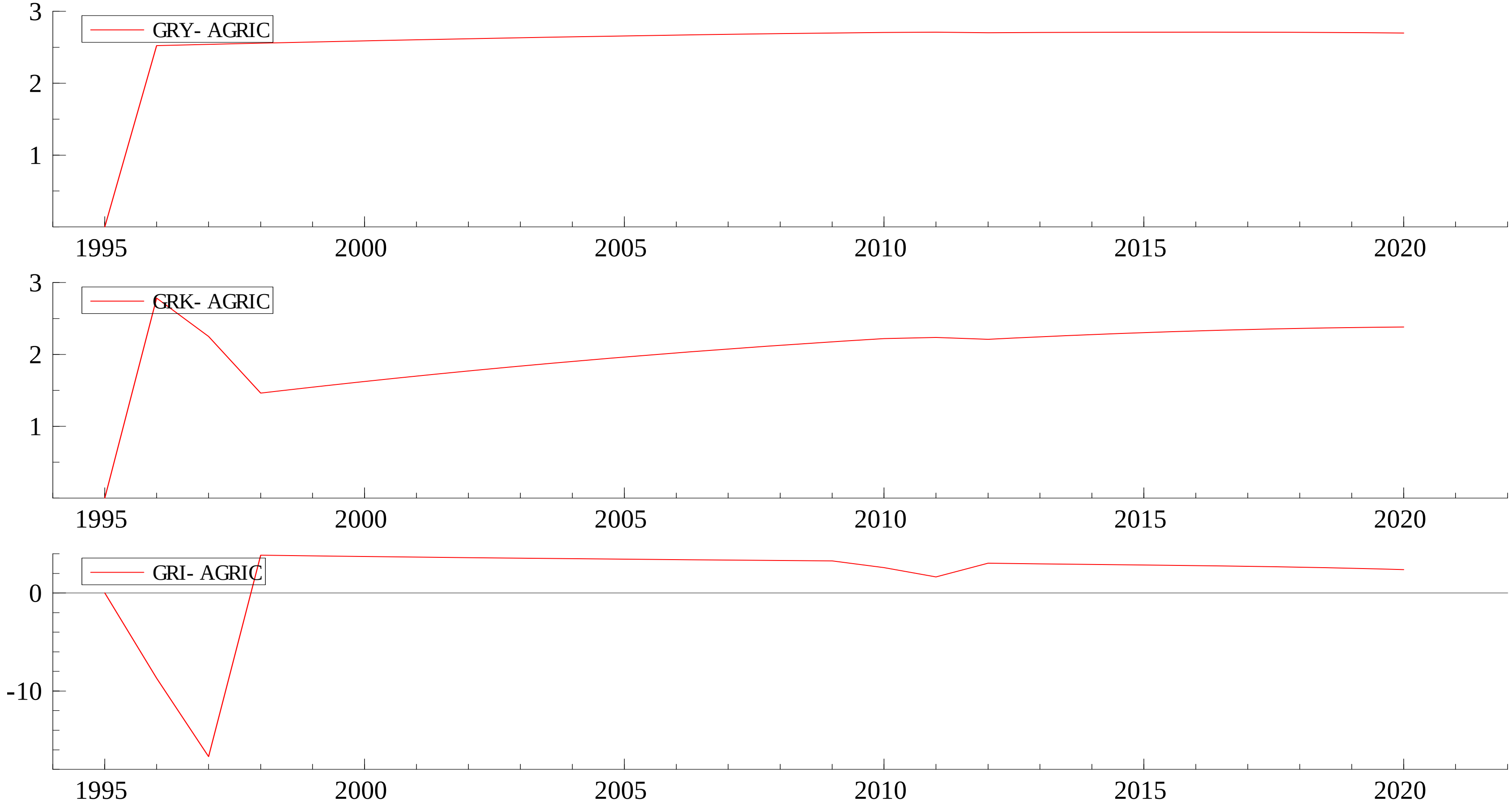
Growth rate of output, investment and capital stock in agriculture.



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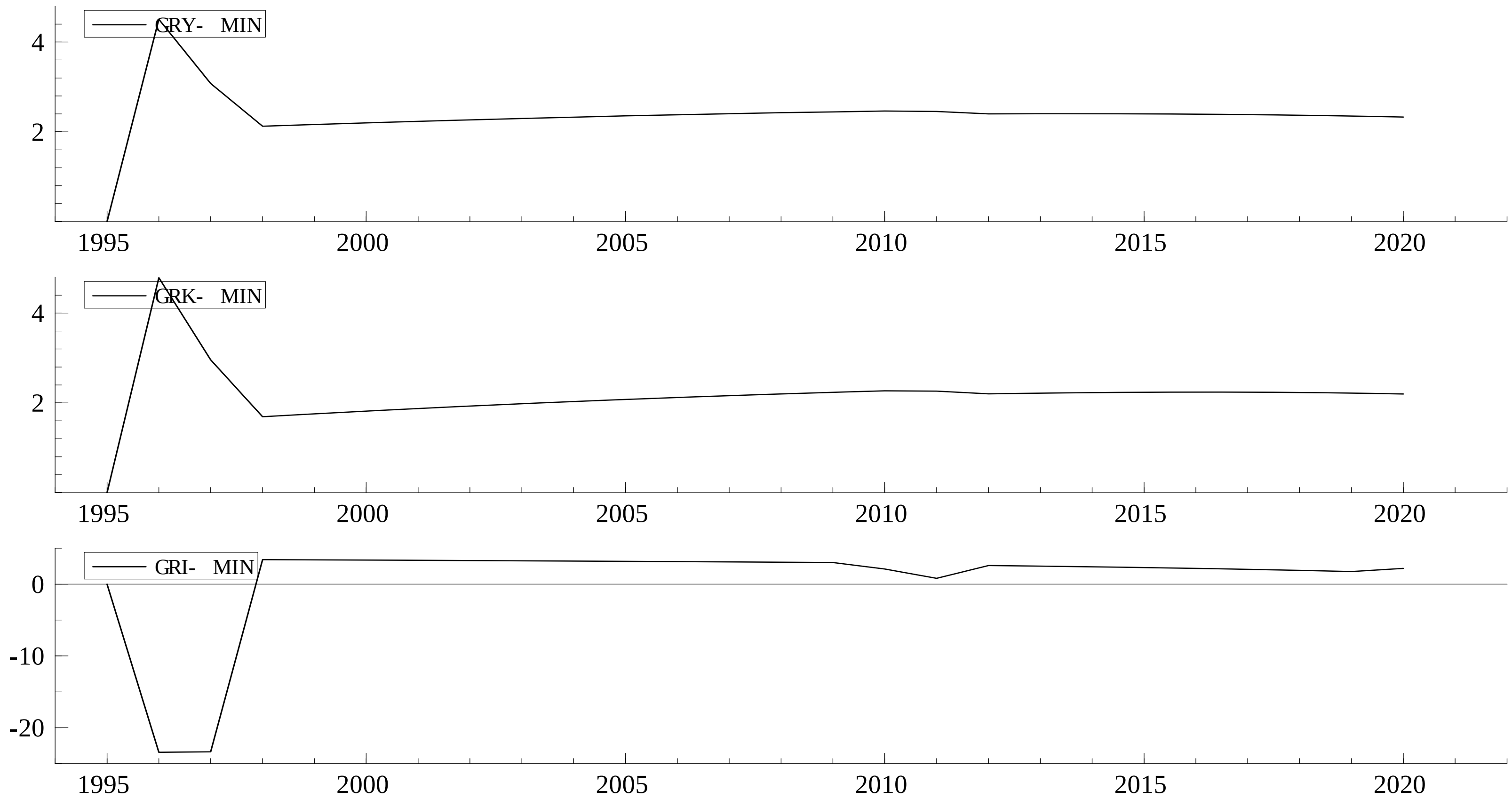
Growth rate of output, investment and capital stock in mining



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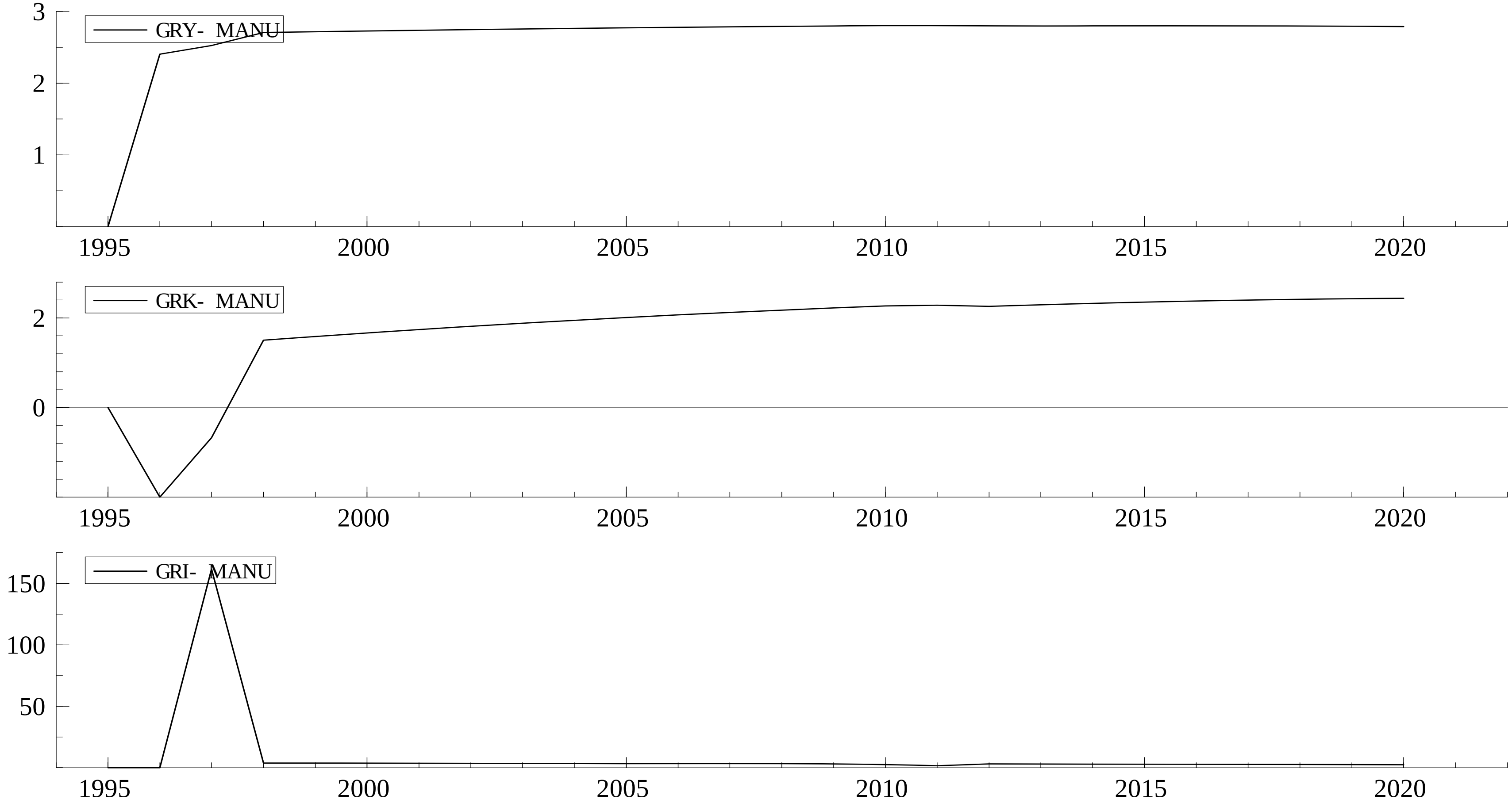
Growth rate of output, investment and capital stock in manufacturing



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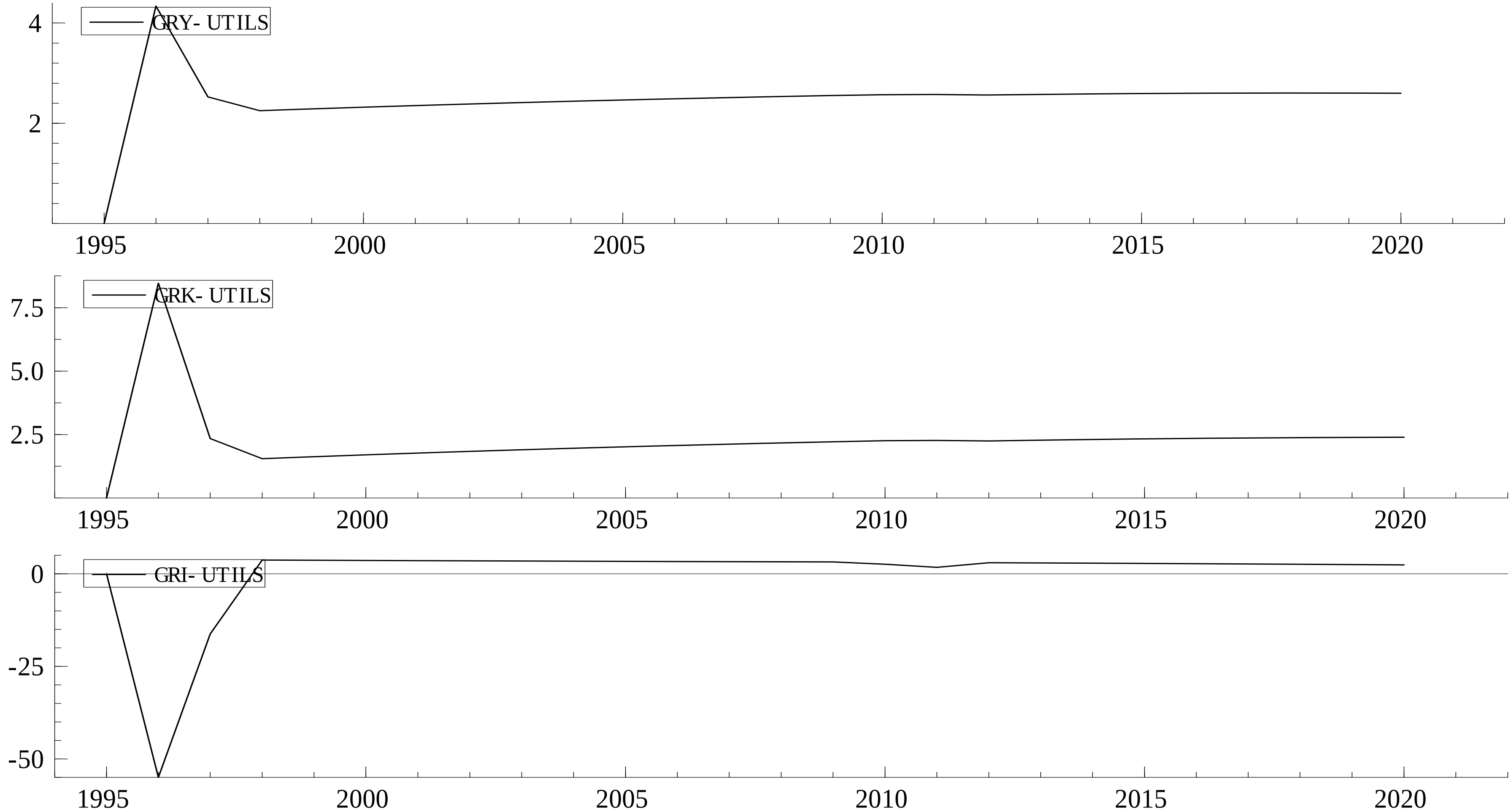
Growth rate of output, investment and capital stock in energy sector



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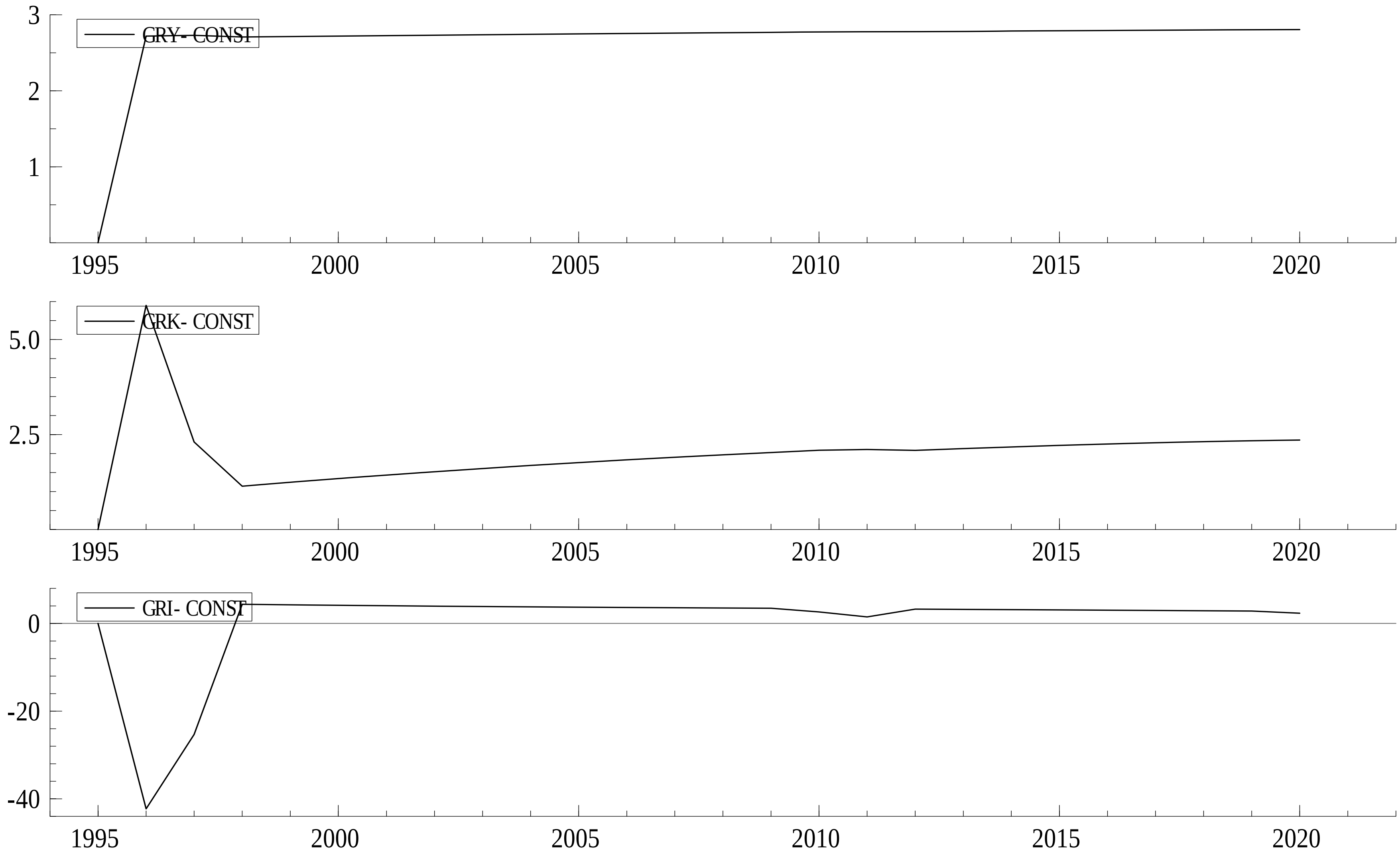
Growth rate of output, investment and capital stock in construction sector



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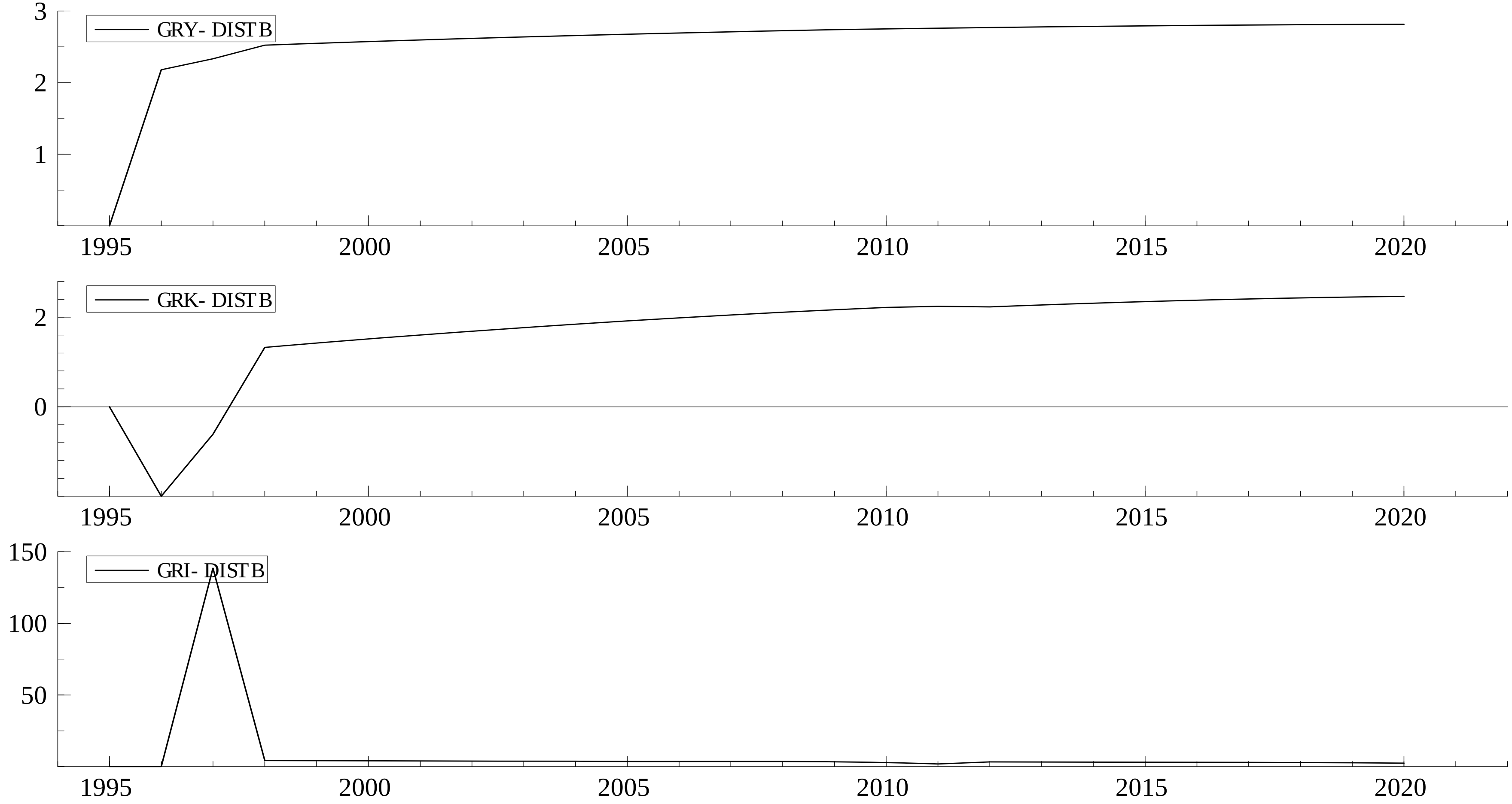
Growth rate of output, investment and capital stock in distribution sector



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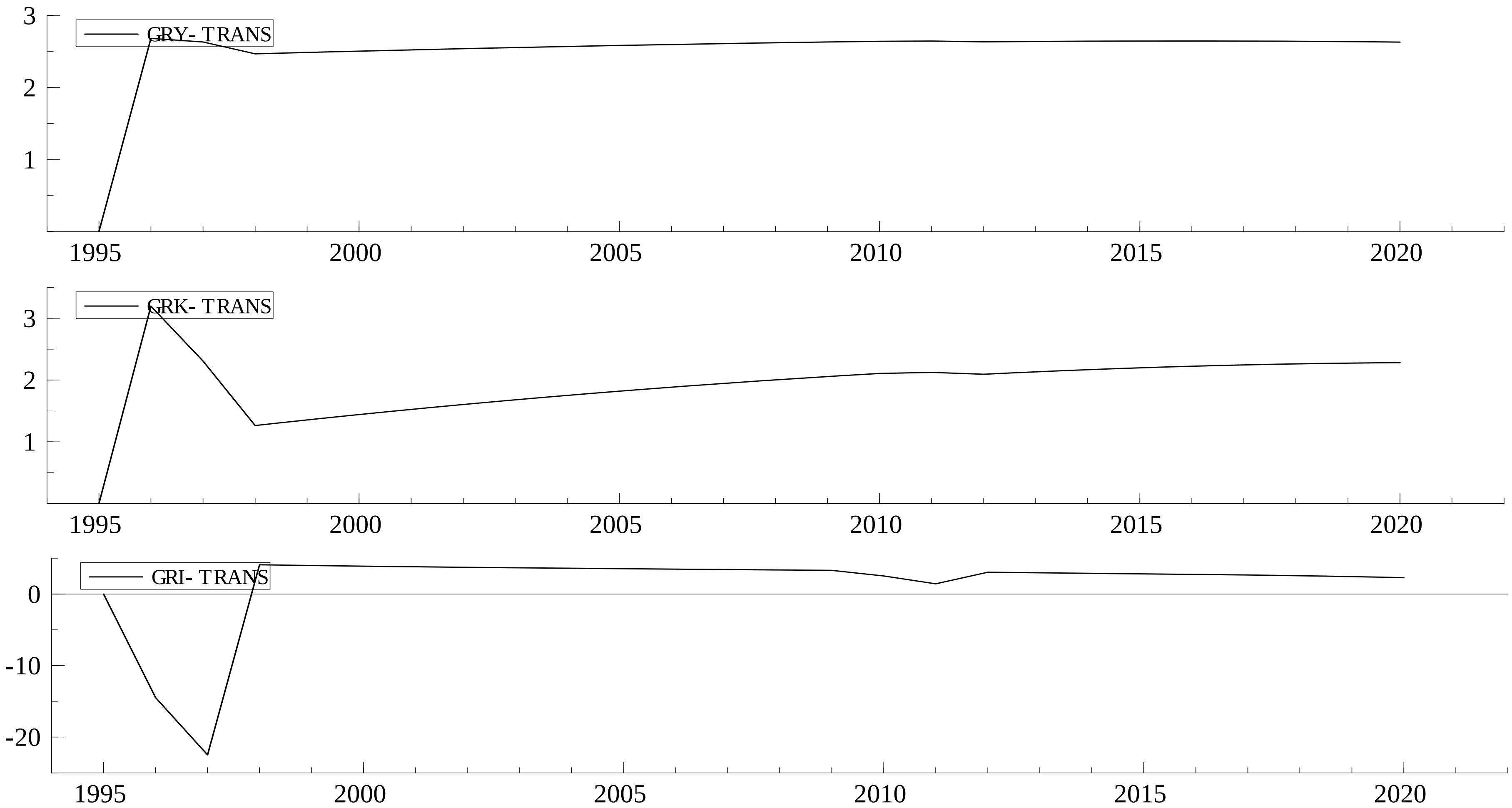
Growth rate of output, investment and capital stock in transport and communication sector



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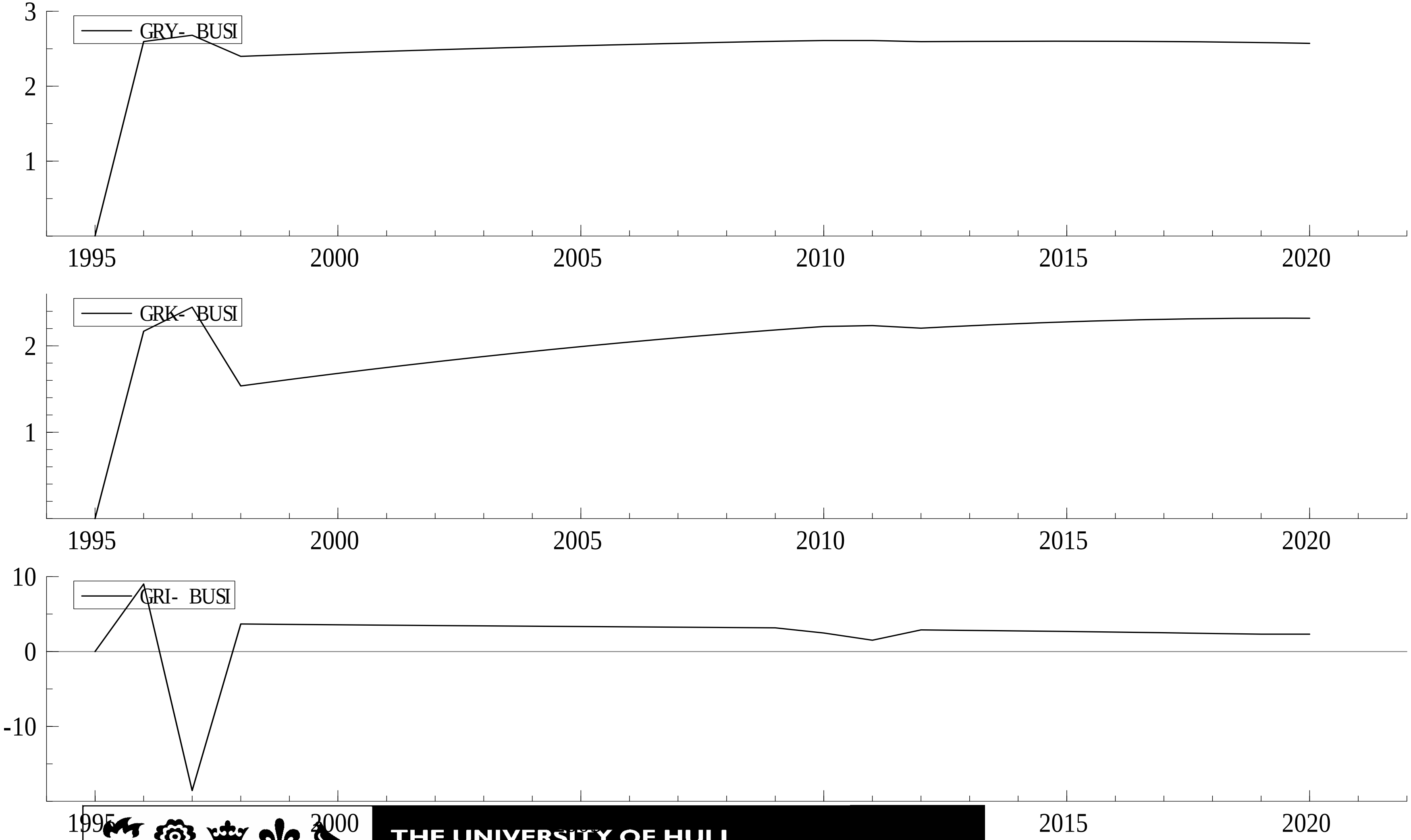
Growth rate of output, investment and capital stock in business sector



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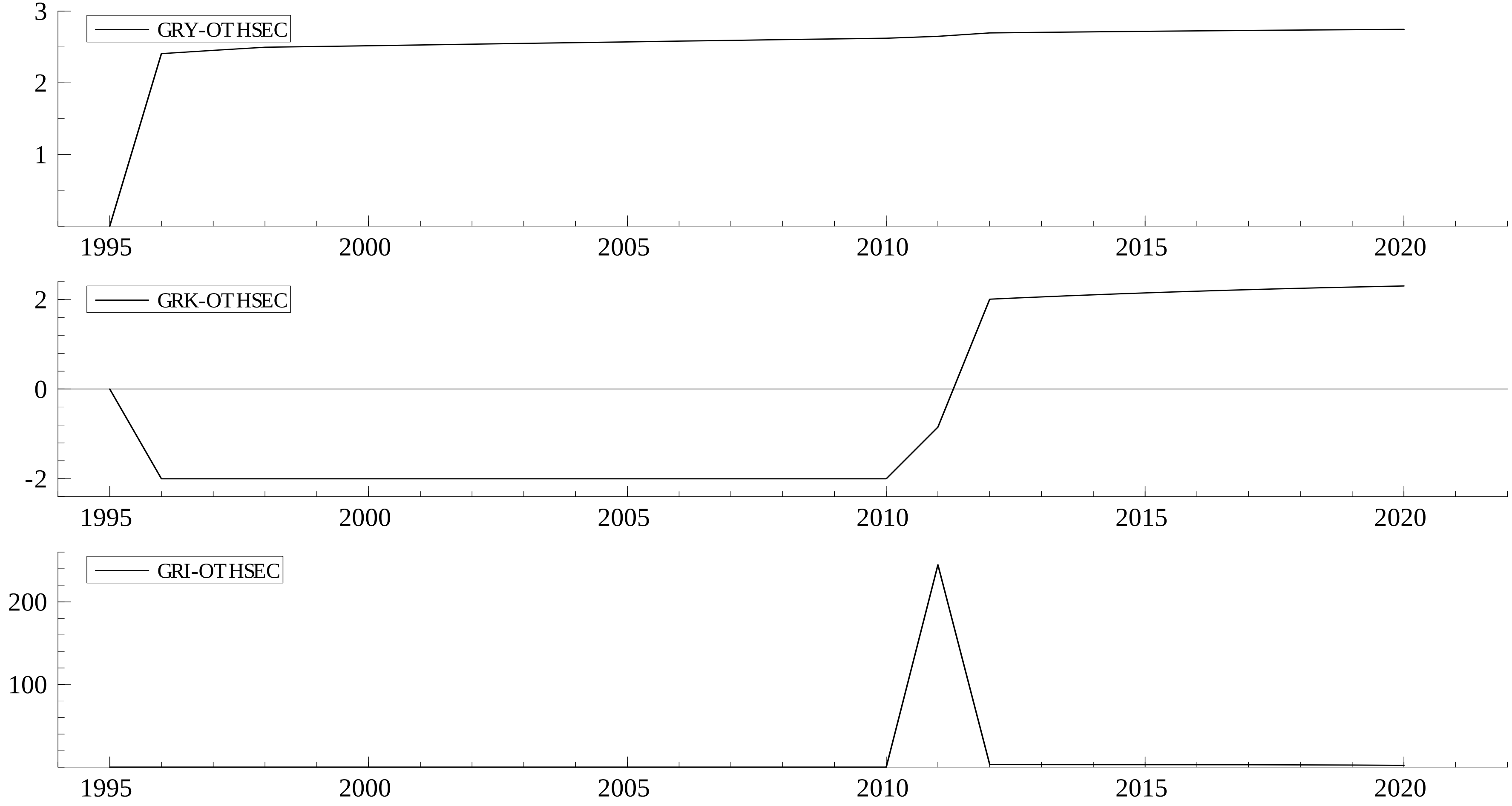
Growth rate of output, investment and capital stock in other sectors



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