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Abstract

Production technology is the main driving force of economic growth while upgraded technology reduces carbon emission. This paper investigates the long run relation with short run dynamics using the USA data for the period of 1963 -2007. This paper observes that production technology is the cause of reduction of CO_2 emission only in short run. The impulse response of production technology suggests shortening the patent protection right that might encourage redesigning low carbon production processes to curve down carbon emission with raising income. Continuous change and adaption of production technology is the main driving force for sustainable development.

Keywords: Production Technology, Innovation, Design Patent, Patent Right, Technological Progress, Co-integration, Causality, Carbon Emission, Income, CO_2 Emission, Impulse Response, R&D.

JEL *Classification*: C_{33}, O_{40}, Q_{25}

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CARBON EMISSION AND PRODUCTION TECHNOLOGY: EVIDENCE FROM THE US

Fossil fuel carbon emission generated by the US has been increasing continuously over the long past several decades, while at the same time; the number of technological innovation (design patents) has been increasing rapidly. Figure 1 shows the rising trends of CO_2 emission and design patents representing technological innovations. Per capita carbon emission is also not declining except in mid 1970s (Figure 1C). It shows clear evidence that technological innovation and carbon emission have been increasing steadily over several decades. It contradicts general perception about technology, which plays a crucial role to curve down carbon emission. What is the role of innovation in the context of climate change? Does the rising innovation reduce fossil fuel consumption and thereby carbon emission?

From 1963 - 2007, total carbon emission emitted by the US increased yearly 1.39 percent and per capita carbon emission also raised by 0.39 percent, while the granted design patent grew 4.76 percent. During 1990 -2007 only per capita CO_2 emission growth rate declined by 0.04 percent which is good for the US but less than desired level, while annual growth rate of total fossil fuel carbon emission and design patent increased by 1.14 and 6.86 percent, respectively. Section I of this paper discusses on production design patent and explains a simple theory how it helps to reduce pollution in a growing economy. Section II provides empirical results that growth of production design innovations reduces emission in short run only. In long run, both innovation and emission rise – especially long past innovations (design patents) are the cause of increasing carbon emission in the US. This finding helps to formulate proper economic policy to arrest the rising CO_2 emission.

Truly, recent global climate change challenges to the existing production technology in the world. To tackle the climate change general opinion is the adaption of the green or clean technology. General perception is that developed nations have the clean and green technology that is acquired through innovations which is protected in the name of *patent rights*. It is discussed in details in section I.

Section II uses data from the US Patent and Trademark Office (USPTO) to show the trend of design patents. The US economy dominates in holding the world patents. Definitely the US might have been attempted to innovate green technology to dominate its position over the world economy. Patent registration at the USPTO is high and dominates its position in the world over last several decades. Therefore, it is highly expected that the US should provide efficient technology both in terms of productivity and energy saving innovations. So, as per general believes, the US should be the least polluter in the world. In contrast, the US is on the top of carbon emitters list[1] in the carbon dioxide information analysis centre (CDIAC) of Oak Ridge National Laboratory (ORNL), USA. Why is the US on the top polluters list while it holds the major patents of upgraded production technology? It contradicts general believe that the modern sophisticated upgrading technology helps to *mitigate climate change*. How far is it true?

This paper investigates it thoroughly raising few questions on general perceptions whether developed countries have significant *clean technology* that should have had sufficient potential strength to *mitigate climate change*. Are production technological innovations in the right direction towards the low carbon growth? This study focuses on technology aspects especially for production technology that might be observed in the production design innovations, which help

[1] China and the US are in the top list of total carbon emission. China and the US hold 1st and 2nd position in CO_2 emission in the world in 2007, respectively.

to the production process to be efficient in terms of either productivity or energy saving. Ultimately energy requirement per unit of output will be less for each production design innovation. So, any improvement in production system through certain change in ornamental design of product or production process helps to save energy and reduce emission. Each production design innovation should be energy efficient.

Intuitively technological innovations could be the cause of reduction of carbon emission. Climate change is a *global public good* and acts as a constraint for economic growth. A careful study is necessary to understand the causal relationship between production design innovation and carbon emissions. This paper attempts to investigate the long run equilibrium relationship between production design innovations, economic growth and carbon emissions with short run dynamics. It is important to formulate proper policy for mitigating climate change for the country and the world as a whole. Production technology plays a vital role for the low carbon and green economy.

I. Production Technology

A. Production Design Innovations and Patents

Technological innovation is a vast area but this study mainly concentrates on production design innovation[2] which is the main concern of carbon emission in the production process. General believe is that as number of patent on production design innovation increases, the energy consumption reduces and thereby mitigates climate change. This is important to tackle the global climate change with appropriate policy

[2] Utility innovation is excluded.

and formulate strategy for economic development with rising production design innovations.

'Patent is an important legal document, issued by an authorized government agent, granting the right to exclude anyone else from the production or use of a specific new device, or process' for certain defined years. It is issued, generally, 'to the inventor of the device or process after' a thorough examination focusing "on both the novelty of the claimed item and its potential utility. The right embedded in the patent can be assigned by the inventor to somebody else, usually to his employer, a corporation, and/or sold to or licensed for use by somebody else" (Griliches 1990, p1662). The main purpose of the patent system is 'to encourage invention and technical progress both by providing a temporary monopoly for the inventor and by forcing the early disclosure of the information necessary for the production of this item' or the operation of the new process (Griliches 1990). Thus, patent registration is considered as a proxy for innovation and provides country's technological capabilities (Griliches 1990, Lall 1992, Archibugi and Coco 2004, 2005). So, the patent registration of a country shows the trends in the improvement of technological strength (Tong and Frame 1994).

This paper considers the production design patent (DGPNT) as a proxy of production technology. Production design patent is issued for new, original and ornamental design for an article of manufacture. Market ambitions are the prime mover for new innovations in a matured capitalistic economy (Lall (1992)). The technological progress towards green should be captured in terms of production design patents which must be reflected with less pollution in the efficient production process. Thus, this paper tries to argue that growing production design patent might be the cause of reduction of pollution.

Grossman and Krueger (1991), Komen et al. (1997), Andreoni and Levinson (2001) suggest that environmental quality improves with technological progress. Brunnermeier and Cohen (2003) highlight on the determinants of environmental innovation in the US manufacturing industries. Using a panel of 127 manufacturing industries over the period 1989-2004, Carrion-Flores and Innes (2010) identify bidirectional causal links between environmental innovation and toxic air pollution. Carrion-Flores and Innes (2010) find that environmental innovation is an important driver of reductions in US toxic emissions. During 1987 – 2001 the air pollution (SO_2, NO_2, CO and VOC) generated in the US manufacturing sector declines due to technological advancement (Levinson 2009). Levinson (2009) did not focus on CO_2 emission, which is the main culprit of global warming and climate change that may act as a constraint for further economic growth. Using the US data, this paper investigates the causal linkage among income, production design innovation and carbon emission – a study on the long run relation with short run dynamics.

B. Theoretical background

Production function

Following Solow (1956), considering one- good economy, output is produced by only composite capital, *k*, for a given technology. Production function of this economy (intensive form) is

$$y = f(k),\ f_k > 0 \text{ and } f_{kk} < 0. \qquad (1)$$

The production of the economy, *y*, depends only on composite capital *k*, which also generates pollution as a by-product.

Pollution and Choice of Technology

Pollution is unavoidable and an inherent relation with production process using capital for any available technology. Only technological improvements eliminate pollution. Suppose μ, be the rate of pollution, is a proportion of output. Pollution rate, μ, may be a decreasing (increasing) function of technological improvement. For simplicity, initially this paper assumes constant μ. Pollution is generated directly with production but inversely with available cleaner technology. The pollution flow at each moment is proportional to output production and inverse to the technological availabilities, i.e.,

$$p = \frac{\mu y}{A}, \; 0 < \mu < 1 \tag{2}$$

Where p is the pollution, A is the number of available clean technology in the economy. Higher value of A suggests more available clean technology (Reis 2001) in the economy. Choice of technology depends on availability and accessibility for all. For low value of A choice is limited whereas higher value of A provides more alternatives and freedom of choice for cleaner technology. Basic assumption is that any upgradation in production design in terms of either productivity or energy efficiency is considered as clean technology. It suggests that any production design innovation increases output for given inputs or less inputs are required for given output. Thus, per capita output requires less input. In other words, with production design innovations the input-output ratio decreases and consequently pressure on environment reduces.

Pollution is generated directly with production for a given technology at given time. However, over time a nation moves towards more and more clean technology through continuous upgradation or/and innovation. So, clean technology also changes over time and become cleaner. The innovation outcome depends on the R & D expenditure, physical and human capital. Thus, stock of capital and technological progress jointly determine pollution, p, in long run[3]. The long run relation is (taking log of eq.(2))

$$\ln p = \ln \mu + \ln y - \ln A \tag{3}$$

Steady State

The steady state relationship between the growth rate of pollution, income and technology is derived from eq.(3), (differentiating with respect to time,) i.e.,

$$\frac{\dot{p}}{p} = \frac{\dot{y}}{y} - \frac{\dot{A}}{A} \tag{4}$$

Eq (4) suggests that clean technological progress definitely reduces pollution growth. Let relaxing the assumption of constant, μ, rate of pollution. Pollution proportion of output, μ, (i.e., rate of pollution) may change over time. Let

$$\mu = \mu_0 e^{\theta t} \tag{5}$$

Where μ_0 (>0) initial pollution rate, θ ($\theta < 0, or, > 0$) is a constant and t is time variable. So,

$$\ln \mu = \ln \mu_0 + \theta t \tag{6}$$

Now plug the equ. (6) into equ.(3), we get

$$\ln p = \ln \mu_0 + \theta t + \ln y - \ln A \tag{7}$$

and corresponding steady state relationship will be

$$\frac{\dot{p}}{p} = \theta + \frac{\dot{y}}{y} - \frac{\dot{A}}{A} \tag{8}$$

[3]According to Andreoni and Levinson (2001) the increasing return to scale operates in the abatement technology and reduces pollution.

Theoretically it is clear that pollution growth rate increases with economic growth but clean technological progress in production process reduces pollution in long run. Empirical verification is important in this context. Now we verify its empirical validity using a country specific data.

II. Empirical Strategy

A: Data and Methodology

Data Sources

Patent registration is considered as a proxy for innovation and provides country's technological availabilities. Over time annual patent registration of a country shows the trends in the improvement of technological strength. This paper considers the production design patent (DGPNT) as a proxy of production technology which are supposed to reduce pollution. In this study, it is measured as the number of production design patent[4] (DGPNT) per million populations. Time series data on DGPNT for the period 1963 - 2008 are taken from US patent office website. The corresponding annual time series data on per capita CO_2 emission (PcCO2) (express in metric tons) for the period 1963 -2007 is obtained from Carbon Dioxide Information Analysis Centre[5] (CDIAC), the USA; and per capita real GDP (RGDPCH) are taken from Penn World Table 6.3. Combining these data sets together we compile time series data set for the USA covering the period 1963 - 2007.

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[4]It excludes the utility patents. Total number of design patent is divided by population (in million) to make DGPNT per million populations. This paper is based on the basic assumption that number of patents granted in a year is equivalent to number of innovations occur in that year. Design patent permits its owner to exclude others from making, using, or selling the design for a period of 14 years from the date of patent grant. See the website http://www.uspto.gov/go/taf/us_stat.htm.

[5]This carbon dioxide emission data generates from manufacturing industry, which is appropriate for this study. See, Oak Ridge National Laboratory (ORNL) of the USA, http://www.cdiac.ornl.gov .

Characteristics of Data

We have to investigate the characteristics of data set. The augmented Dickey-Fuller (ADF) and KPSS (Kwiatkowski, D., Phillips, P.C.B., Schmidt, P., and Shin, Y.) unit root test procedures are used here to examine whether data are stationary or non-stationary and then find the co-integration, if any. Co-integration tests is required when all variables are integrated of order one i.e., I(1). All the variables have unit root and thereby they are non-stationary.

Methodology

Engle and Granger (1987) show that if two series are I(1), then Granger causality must exist in at least one direction in I(0) variables. According to Engle and Granger (1987), co-integration shows the long run equilibrium relationship among variables and short run dynamics. In case two series are I(1), a VAR model can be constructed in terms of their first differences with addition of an error correction term to capture the short run dynamics with long run equilibrium relation. This is the Vector Error Correction Model (VECM), which is a statistical technique that helps to detect the nature of relationship in long run and short run dynamics among variables in a time series data set. Let the stochastic (or random disturbance) term (ν) is added to the co-integrating equation (3) to form the econometrics model

$$PcCO2_t = \lambda_1 DGPNT_t + \lambda_2\, RGDPCH_t + \nu_t \qquad (9)$$

and Vector Error Correction (VEC) [or more specifically a VAR with error correction term] is

$$\Delta X_t = \Omega \Delta X_{t-i} + \eta EC_{t-1} + \varepsilon_t \qquad (10)$$

Where X_t is the vector of difference of variables, EC is is the error correction term derived from the long run co- integrating relationship

[$EC_t = \left(PcCO2_t - \hat{\lambda}_1 DGPNT_t - \hat{\lambda}_2 RGDPCH_t \right)$]. Ω is the coefficient matrix, η, ε_t are the coefficients of error correction terms and random error terms, respectively.

B: Empirical Analysis

Preliminary results

Preliminary observations are summarised in Table 1, which shows decade wise average annual growth rate of income, carbon emission and production design patents (i.e., the proxy of the production technology). Over all DGPNT growth rate is 4.76 percent during 1963-2007 whereas RGDPCH and PcCO2 growth rates are 2.24 and 0.39 percent, respectively. The critical decade was 1970s in which growth rates of RGDPCH and PcCO2 decreased but DGPNT growth rate declined drastically, it was negative i.e., -0.3 percent. In 1980s, the US economy improved marginally with emission after global recession in 1981-82 following the oil crisis in 1970s; whereas the growth rate of DGPNT increased sharply in 1980s (4.34 percent) and reached at the pick (6.08 percent) in the last decade (1990s) of the 20^{th} century. As soon as technology sharply increased in 1980s and consequently PcCO2 growth rate declined drastically, it was negative growth rate, i.e., -0.38 percent in 1980s. Figure 2 provides its graphical presentation of decadal growth of RGDPCH, PcCO2 and DGPNT. The primary observations suggest that there is a strong relationship between PcCO2, RGDPCH and DGPNT. Economic growth theory also supports it.

Basic findings

Let us analyse the characteristics of data. Panel A of Table 2 presents the results of ADF and KPSS test for DGPNT, RGDPCH and PcCO2. Both ADF and KPSS unit root test results suggest that all three variables are non-stationary and integrated of order 1, i.e., I(1). The, Phillips-Perron (PP) and Ng-Perron (NP) unit root tests also support I(1). Following Johansen's maximum likelihood approach statistically significant one co-integrating vector is identified using Trace (LR) statistic (see, panel B of Table 2). On the basis of such results this paper concludes that PcCO2, DGPNT and RGDPCH are co-integrated. The estimated long run equilibrium relation or co-integration relation is

$$Ln\,PcCO2_t - 0.169\,Ln\,DGPNT_t - 2.819\,Ln\,RGDPCH_t = 0 \qquad (11)$$

This estimated long run equilibrium relationship suggests that both income and production design innovation raise emission level in the USA. So, in long run production technological innovation level increases carbon emission level instead of reduction that contradicts our general perception and theoretical base (see, equation (8)). In long run production design innovations are bad for the environment.

It is more important for the growth rate rather than level. In terms of growth rate definitely technological progress reduces emission growth.

Analyse

Let r_t, r_t^* and r_t^o denote the growth rate of RGDPCH, DGPNT and PcCO2, respectively. From Table 3, on the basis of statistical significance, the estimated equations can be written as, $r_t = 0.08 r_{t-3}^* + \varepsilon_{1t}$, $r_t^* = \varepsilon_{2t}$ and $r_t^o = -0.068\, r_{t-1}^* - 0.437\, r_{t-2} + 0.077\, r_{t-3}^* + \varepsilon_{3t}$ where ε_{1t}, ε_{2t} and ε_{3t} are white noise error terms with zero expectations. These equations take specific form depending on the statistical significance of individual parameters of VECM. Thus, change of technological innovation has reached a stage of stationary, fluctuating randomly around zero and if any divergence that leads away from equilibrium.

It should be noted that r_t^o is a non-linear function of r_t^*, in this study, specifically r_t^o is inversely related to r_{t-1}^* but directly related to r_{t-3}^*. This implies that any shock in r_{t-1}^* will be the cause of corresponding negative shock in r_t^o but any shock in r_{t-3}^* will be the cause of corresponding positive impact on r_t^o. From this estimated equation it is clear that change of innovation in last year (r_{t-1}^*) reduces change of emission at current year (r_t^o) but long past innovation, r_{t-3}^*, raises current emission (r_t^o). Any positive change in technological innovation r_{t-1}^* in current past is the cause of reduction in the emission growth rate in current year, r_t^o. Hence, there is causality running from technological innovation to emission. It should be mentioned that r_{t-1}^* suggests some time is required to diffuse and installation of the new techniques. More importantly, if the new technological innovation is introduced in the economy, there will be a corresponding reduction in the emission growth rate. Long past technology growth (r_{t-3}^*) which provided technology at that time *t-3* become old now and that generates more pollution (r_t^o) if we use it now. Long past technology is the cause of increase emission.

It is observed that income growth effect is negative on emission growth. Past income growth, r_{t-2}, inversely affects current emission growth, r_t^o. It suggests that economic growth directly stimulates to reduce emission growth[6]. Here, income growth is the cause of emission de-growth.

[6] This is the income effect on emission.

Lastly, change of income level (income growth), r_t, depends on the older production design innovation growth, r^*_{t-3}. It is true because of the costlier new technology compare to older one and the majority of the mass adopt the old technology relatively at lower price. Hence, the direction of causality is from technological progress to income growth in the USA during 1963 - 2007. This provides the evidence on the basic assumption regarding technological progress driving economic growth. It is also true that growth of production design innovation affects that of income and emission within a certain time span.

From VECM it is also clear that growth of DGPNT is purely exogenous and independent variable ($r^*_t = \varepsilon_{2t}$) which is unaffected by other variables in this model. Since change of technological innovation is not governed by an autoregressive effect, there is no persistent effect of any change of emission and/or income on technological innovation.

This study observes a specific kind of causality running from technological progress to emission in the USA during 1963 - 2007. Thus, this finding suggests that rapid technological (innovations) progress in the USA helps to reduce CO_2 emission growth in short run. The production design innovation is the central force that causes economic growth as well as de-growth of carbon emission in short run.

C: Forecast Error Impulse Response

Finally, this paper forecasts error impulse responses for future period using VECM. Using the forecasts technique, this paper highlights on the error impulse responses of the concern variables[7]. The impulse response analysis quantifies the reaction of every single variable in the model on an exogenous shock to the model. The impulse

[7] Paper also investigates the response of production design innovation to CO_2 emission.

response analysis is a tool for inspecting the inter-relation of the model variables. Two special cases of shocks could be identified: the single equation shock and the joint equation shock where the shock mirrors the residual covariance structure. In the first case paper investigates forecast error impulse responses, in the latter orthogonalized impulse responses. The reaction is measured for every variable a certain time after shocking the system.

The impulse response analysis is a tool for inspecting the inter-relation of PcCO2, DGPNT and RGDPCH. Figure 3 shows the forecast error impulse responses for 20 years. Column wise figures (in Fig. 3) show the forecast error impulse responses of PcCO2, DGPNT and RGDPCH on all three variables, respectively. For example, figures of the 2^{nd} column provide the impact of DGPNT on all three variables (PcCO2, DGPNT and RGDPCH). The central figure (in Fig 3) shows that DGPNT forecasts on its own impulse response. It also suggests that after 10 years impulse response of DGPNT stabilizes. For the corresponding period, PcCO2 and RGDPCH impulses also stabilize. From this finding this study might suggest to reduce patent protection right from its current specified years. Reduction of the period of patent right encourages the producers to take initiative for rapid innovations or redesigns the production process. Quick adoption of patents definitely helps to reduce carbon emission. This may stimulate to innovate for better and efficient alternative technology to curve down carbon emissions and thereby global warming. So, only the change in production technology is the root cause of reduction of carbon emission with maintaining economic growth.

III. Conclusion

This paper focuses on the technological growth aspects especially for innovations in production technology which is observed in the production design innovation. The paper provides evidence that the long run relation with short run dynamics between carbon emission, production design innovations and economic growth.

This paper shows that production design innovations raise carbon emission in long run, which contradicts the general perception. This finding suggests that progress in production technology reduce PcCO2 growth in short run and production design innovation is the central force that causes income growth as well as emission reduction which is highly desirable. This study also observes a specific kind of causality running from production design innovation to CO_2 emission in the USA during 1963 - 2007.

The impulse response system also supports that carbon emission is heavily reduced in the channel of income growth. The impulse responses of production design patents suggest shortening the patent protection right that might encourage innovating or redesign production processes that definitely reduce emission in short run. So, policy makers should give more emphasis on R & D related to production design innovation which helps to curve down emission with raising income.

It will be more focused if the data are available for sector or industry specific and more representative countries. More research is required in this direction.

References

- Andreoni, J., and A. Levinson. 2001. "The simple analytics of the Environmental Kuznets curve". *Journal of Public Economics,* 80: 269-286.

- Archibugi, D., and A. Coco. 2005. "Measuring technological capabilities at the country level: A Survey and a manu for choice". *Research Policy,* 34: 175 – 194.
- Archibugi, D., and A. Coco. 2004. "A New Indicator of Technological Capabilities for Developed and Developing Countries (ArCo)". *World Development*, 32(4): 629-654.
- Brunnermeier, S. B., and M. A. Cohen.., 2003. "Determinants of environmental innovation in US manufacturing industries". *Journal of Environmental Economics and Management*, 45: 278-293.
- Carrion-Flores, C. E., and R. Innes. 2010. "Environmental innovation and environmental performance". *Journal of Environmental Economics and Management*, 59: 27-42.
- Engle, R.F., and C.W.J. Granger. 1987. "Cointegration and error correction: Representation, estimation and testing". *Econometrica,* 55: 251-276.
- Griliches, Zvi. 1990. "Patent Statistics as Economic Indicators: A Survey". *Journal of Economic Literature*, 28 (4): 1661 -1707.
- Grossman, G.M., and A. B. Krueger. 1991. "Environmental impacts of the North American Free Trade Agreement". *NBER. Working Paper* 3914.
- Johansen, S. 1988. "Statistical analysis of cointegration vectors". *Journal of Economic Dynamics and Control*, 12: 231-254.
- Komen, R., S. Gerking, and H. Folmer. 1997. "Income and environmental R&D: empirical evidence from OECD countries". *Environment and Development Economics,* 2: 505–515.
- Kwiatkowski, D., P. C. B. Phillips, P. Schmidt, and Y. Shin. 1992. "Testing the Null Hypothesis of Stationarity Against the Alternative of a Unit Root". *Journal of Econometrics,* 54: 159- 178.
- Lall, Sanjaya. 1992. "Technological capabilities and Industrialization". *World Development*, 20(2): 165 – 186.
- Levinson, Arik. 2009. "Technology, International Trade, and Pollution from US Manufacturing". *American Economic Review*, 99(5): 2177 -2192.
- Reis, A. B. 2001. "Endogenous Growth and the Possibility of Eliminating Pollution". *Journal of Environmental Economics and Management*, 42: 360 - 373.

- Solow, R. M. 1956. "A Contribution to the Theory of Economic Growth". *Quarterly Journal of Economics,* 70(1): 65-94.

Table 1: Decade-wise Average Growth rate of Income (RGDPCH), CO_2 Emission (PcCO2) and production design patent (DGPNT) in the USA

Decade	PcCO2	RGDPCH	DGPNT
1963-69	3.18	3.69	1.96
1970-79	0.28	2.40	-0.30
1980-89	-0.38	2.29	4.34
1990-99	0.23	2.08	6.08
2000-07	-0.63	1.11	4.04
1963-07	0.39	2.24	4.76

Figure 2: Decade-wise Average Growth rates of income, emission and production design patent in the USA

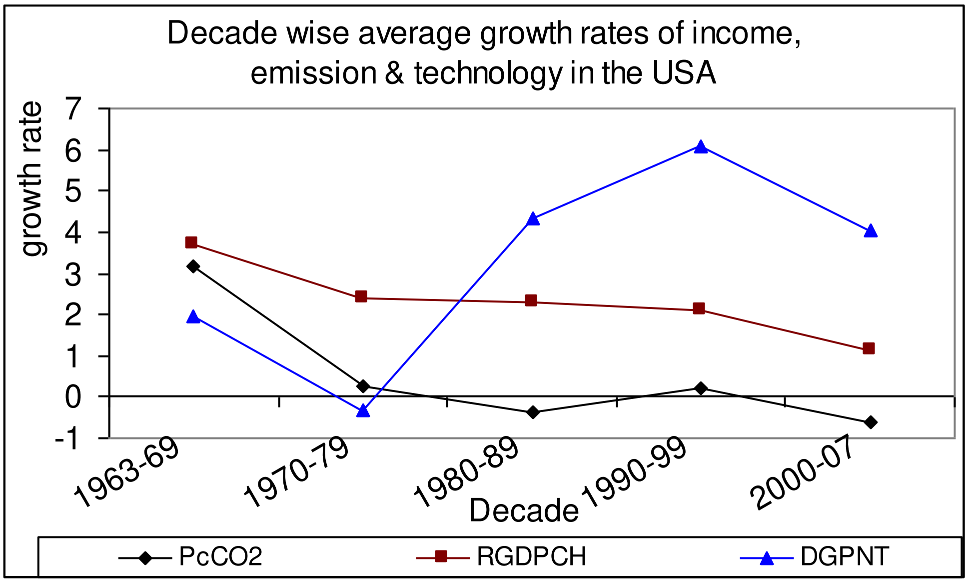


Table 2: Results of Unit root and co-integration test

A: Unit root test			
	ADF		KPSS
Variables	Level	1st Difference	Trend Stationary
lnCO2	-3.15	-4.91***	0.1515**
ln GDPNT	-2.19	-5.304***	0.2301***
ln RGDPCH	-0.86	-5.13**	0.1526**

B: Co-integration Test					
		Eigen value	LR	Critical value 5%	Critical value 1%
H_o: r = 0	H_1: $r \geq 1$	0.435	44.408**	42.44	48.45
H_o: r = 1	H_1: $r \geq 2$	0.299	19.856	25.32	30.45

Note: (i) Critical Values (for trend stationary) at 1% and 5% significance level are 0.216 and 0.146, respectively. (ii) '***' and '**' indicate significance at 1% and 5% level, respectively.

(a) All three variables follow integration of order one, i.e., I(1).
(b) LR test indicates that there is one co-integrating equation at 5% significance level.

Table 3: Results of Vector Error Correction Model

Estimated Co integration relation			
	ln PcCO2	ln DGPNT	ln RGDPCH
Cointigrating vector	1	**-0.169** (-2.597)	**-2.819** (-4.66)
Loading coefficients			
Variables	D(ln $PcCO_2$)	D(ln DGPNT)	D(ln RGDPCH)
Error Correction	**-0.233***** (-2.93)	0.366 (0.768)	0.083 (1.277)
VAR			
Variables	D(ln $PcCO_2$)	D(ln DGPNT)	D(ln RGDPCH)
D(L$PcCO_2$(-1))	-0.027 (-0.164)	-1.215 (-1.24)	0.03 (0.226)
D(LDGPNT(-1))	**-0.068**** (-2.31)	-0.157 (-0.89)	-0.03 (-1.24)
D(LRGDPCH(-1))	0.087 (0.37)	1.487 (1.053)	0.285 (1.49)
D(L$PcCO_2$(-2))	0.035 (0.219)	0.171 (0.18)	-0.034 (-0.265)
D(LDGPNT(-2))	-0.010 (-0.283)	-0.179 (-0.863)	-0.011 (-0.385)
D(LRGDPCH(-2))	**-0.437**** (-2.299)	1.073 (0.94)	-0.081 (-0.521)
D(L$PcCO_2$(-3))	0.243 (1.6)	1.147 (1.26)	0.004 (0.033)
D(LDGPNT(-3))	**0.077**** (2.278)	0.056 (0.28)	**0.08***** (2.91)
D(LRGDPCH(-3))	-0.39 (-1.94)	0.17 (0.14)	-0.011 (-0.065)
Deterministic term			
Constant	**-5.999***** (-2.934)	9.394 (0.767)	2.15 (1.293)
Trend (t)	**-0.016***** (-2.97)	0.028 (0.832)	0.006 (1.244)

Note: (i) Figures in parentheses are t-values. (ii) '***', '**' and '*' indicate significance at 1%, 5% and 10% level, respectively.

Figure 1: Trends of design patents, total and per capita CO_2 emission

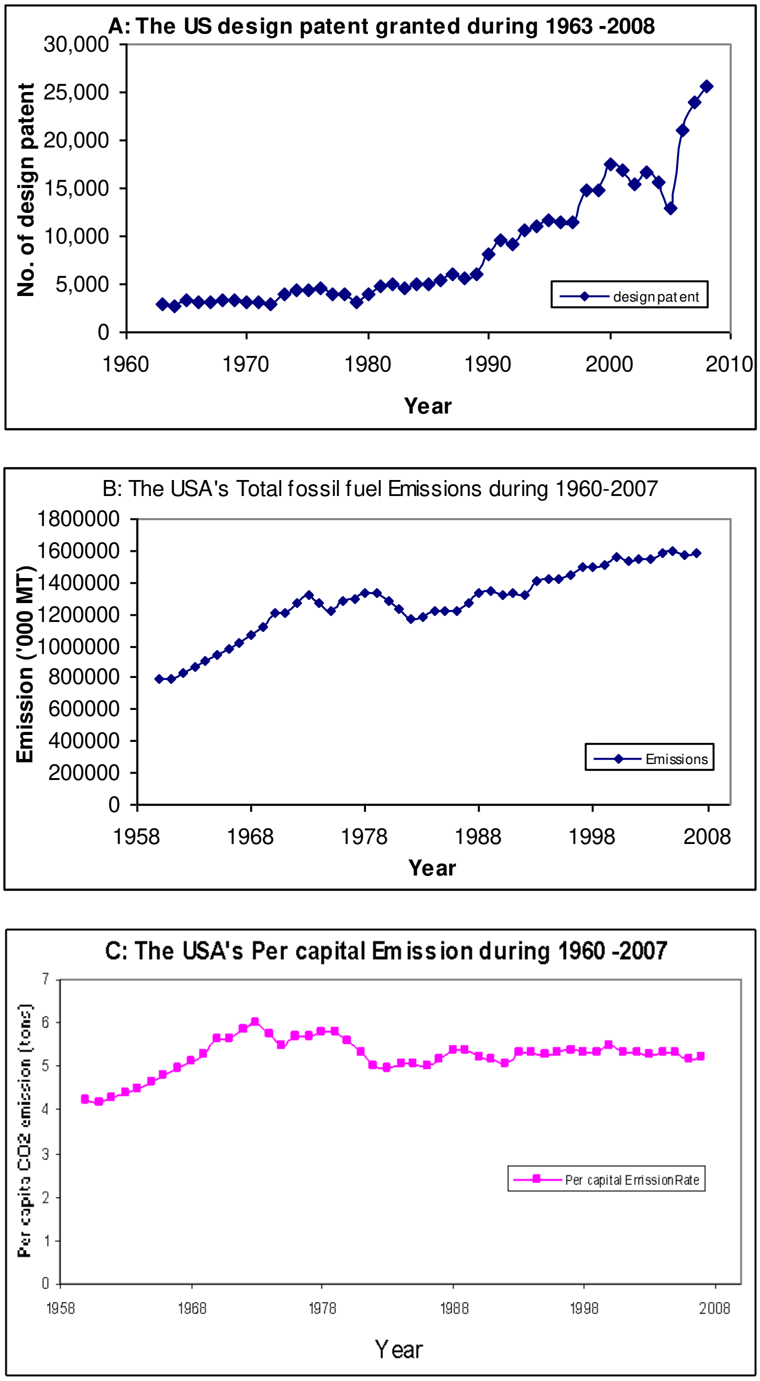
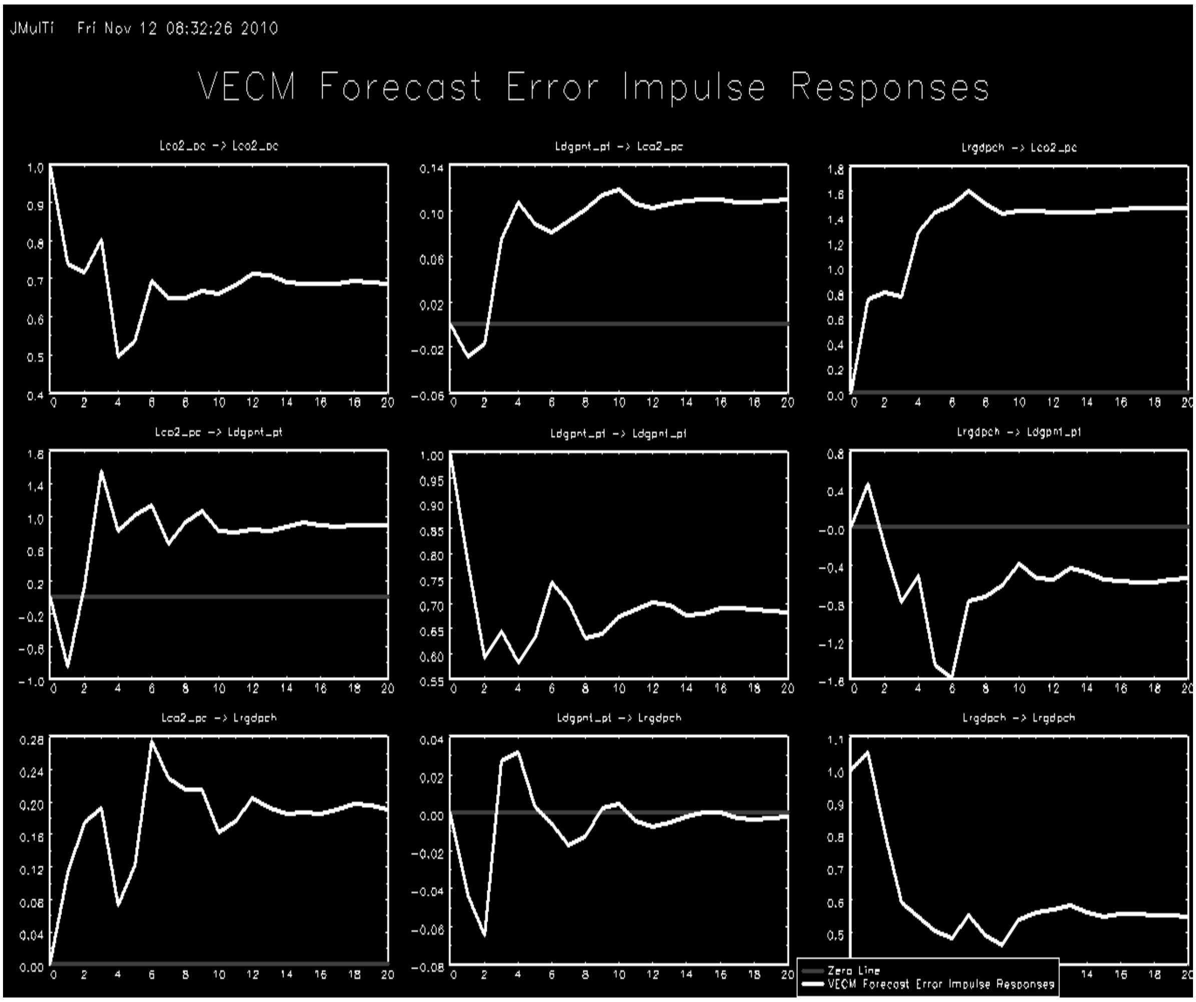
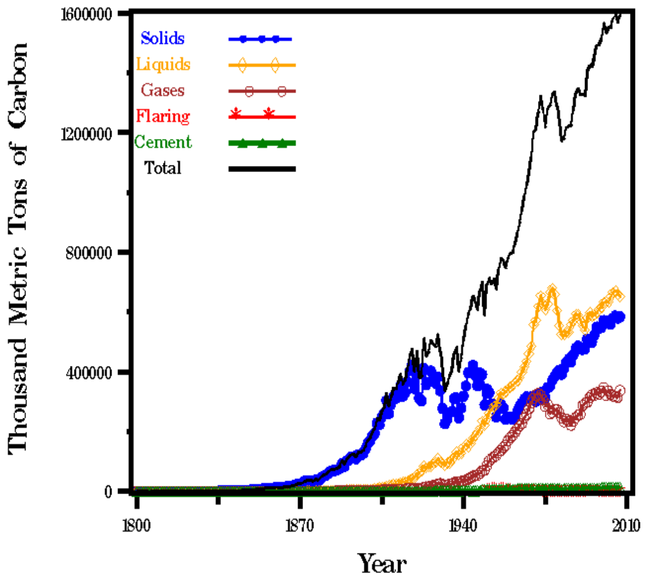


Figure 3: VECM Forecast Error Impulse Responses



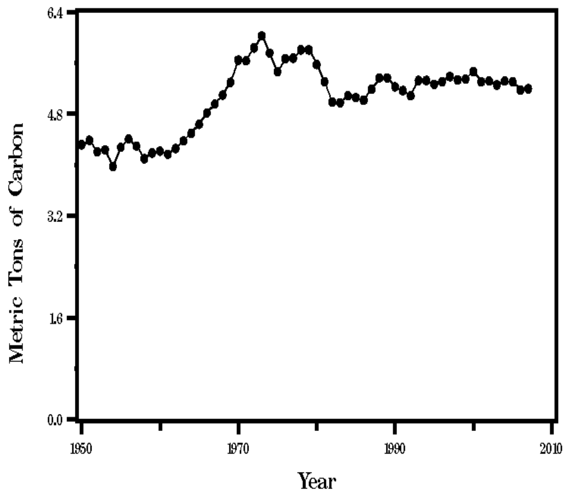
Appendix

Fig.A1: The US emitted total CO_2 emission and decompositions during 1800 -2007



Source: CDIAC, ORNL

Fig. A2: The US emitted per capita CO_2 emission during 1960 -2007



Source: CDIAC, ORNL