Warming and Dimming: An Econometric Assessment of Climate Change

Global warming is a serious concern for policy in the present context. In this research, we explore the different effects of carbon dioxide and aerosols upon that process. Carbon dioxide is known to have a deleterious effect upon climate. Before now, political action taken to fight global warming has aimed mainly at reducing the emission of carbon dioxide. Nobel prize winning chemist Paul Crutzen has proposed an alternative and highly controversial way of fighting global warming: He has suggested decreasing the amount of solar radiation reaching the surface of the earth by artificially increasing the level of aerosols in the stratosphere. By increasing pollution, more solar radiation is directly reflected back into space and the surface of the earth receives less energy and hence there is less warming.

We perform a policy analysis to determine the impact of this new and controversial proposal. Our research suggests an important attenuating effect arising from the role of aerosols. This research uses econometric methods to provide a preliminary assessment of the effect of increasing the level of aerosols in the stratosphere for the purpose of inducing “global dimming”.

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are all students at the University of Oxford. As a team they participated in this year Econometric Game about global warming and dimming. Just like last year Oxford again won the title of best econometricians of Europe with their case solution. This article is a summary of their winning case. All of the authors are in the M.Phil and D.Phil in economics at the university of Oxford.

Discussion of the model

We seek a concise model of the relationship between temperature and other climatic determinants in order to perform long-run temperature forecasting for different scenarios. The underlying idea of the model considered here is that of an energy balance which holds on the surface of the earth: Incoming energy equals outgoing energy.

Incoming energy is measured by incoming solar radiation (RAD_t) and infrared radiation that has been reflected back on earth by greenhouse gases in the atmosphere. In this model greenhouse gases are represented by the levels of carbon dioxide (COO_t) and water vapour (VAP_t) in the atmosphere. This incoming energy is either absorbed or reflected back into space. Absorbed energy either evaporates or induces infrared radiation. The former is measured by the amount of precipitation (PRE_t) and the latter by the temperature on the surface ($TEMP_t$). Modelling of temperature is complicated by the feedback mechanism called the ‘greenhouse effect’: Emitted infrared radiation (temperature) is reflected back upon earth. Simultaneously, increased temperature enhances greenhouse effects by increasing the vapour content of the atmosphere: this increases the reflection of emitted infrared radiation back to the earth’s surface.

This highly stylized model leads to the energy balance equation:

$$RAD_t + COO_t + VAP_t = TEMP_t + PRE_t.$$

In order to implement Crutzen’s proposal we have to look at the determinants of incoming solar radiation. Of the emitted solar radiation, only a fraction reaches the surface of the earth. Some radiation is reflected by clouds (CLD_t) and by aerosols. This attenuating effect through “dimming” has a cooling effect.

The ultimate goal of this modelling exercise is to identify separately the effects of CO_2 and aerosols upon temperature. We do this by imputing aerosols and then decomposing radiation into effects due to clouds and effects due to aerosols.

The Data

Figure 1 plots the data series in levels. Two aspects of the data plots are worth noting. First, seasonality is apparent, particularly in COO_t, PRE_t and CLD_t. Secondly, trending behaviour is apparent in COO_t and RAD_t, with a split trend in the latter. Although PRE_t and CLD_t may appear stationary, they have time-varying means. It is preferable to allow for the potential that some of the series are integrated in order to exploit their co-movements (Juselius, 2007), and this is our strategy.

Estimation Procedure

A cointegrated vector-autoregressive model is estimated; cointegrating vectors are then identified and fixed using their super-consistency property (Johansen, 1995). The resulting simultaneous-equations model is reduced to a parsimonious form using Autometrics (Doornik, 2006).[1] This model is reported in Section 4.1 for temperature alone.

Estimation Results

The unrestricted vector-autoregressive model was run with two lags, seasonal dummies and a restricted constant. The trace test (Johansen, 1995) suggested a rank of four for the system, although the theoretical discussion in section 2 provides justification for only two cointegrating vectors: the energy balance and the greenhouse feedback effect between temperature and water vapour. Given the slightly negatively autocorrelated nature of the data, testing may suggest more cointegration than actually exists; furthermore, imposing a rank of two leaves the next largest root at just 0.46, suggesting no more unit roots in the system. Thus we take a rank of two, and the cointegrating vectors are:

$$CI_{1,t} = temp_t - 0.274coo_t - 0.406rad_t + 1.086pre_t - 0.986vap_t, \quad (1)$$

$$CI_{2,t} = temp_t - 0.405vap_t, \quad (2)$$

where lower case denotes variables in logarithms. The first cointegrating vector (1) represents the energy balance; the second cointegrating vector (2) represents the positive feedback from higher temperature levels into an increased greenhouse effect. All coefficients have the expected sign.[2] These cointegrating vectors enter all six equations in the vector-autoregressive model; here simply the temperature equation is presented:

$$\Delta temp_t = -0.188CI_{1,t-1} - \underset{(0.064)}{1.365}CI_{2,t-1} - \underset{(0.271)}{0.855}\Delta cld_{t-1} - \underset{(0.275)}{0.611}\Delta cld_{t-2} + \varepsilon_t. \quad (3)$$

AR $F(7, 423) = 0.838$ [0.557]
Heteroscedasticity $F(16, 413) = 1.078$ [0.378]
ARCH $F(7, 416) = 2.454$ [0.018]*
Heteroscedasticity-X $F(44, 385) = 0.886$ [0.580]
Normality $\chi^2(2) = 3.905$ [0.142]
RESET $F(1, 429) = 1.986$ [0.160]

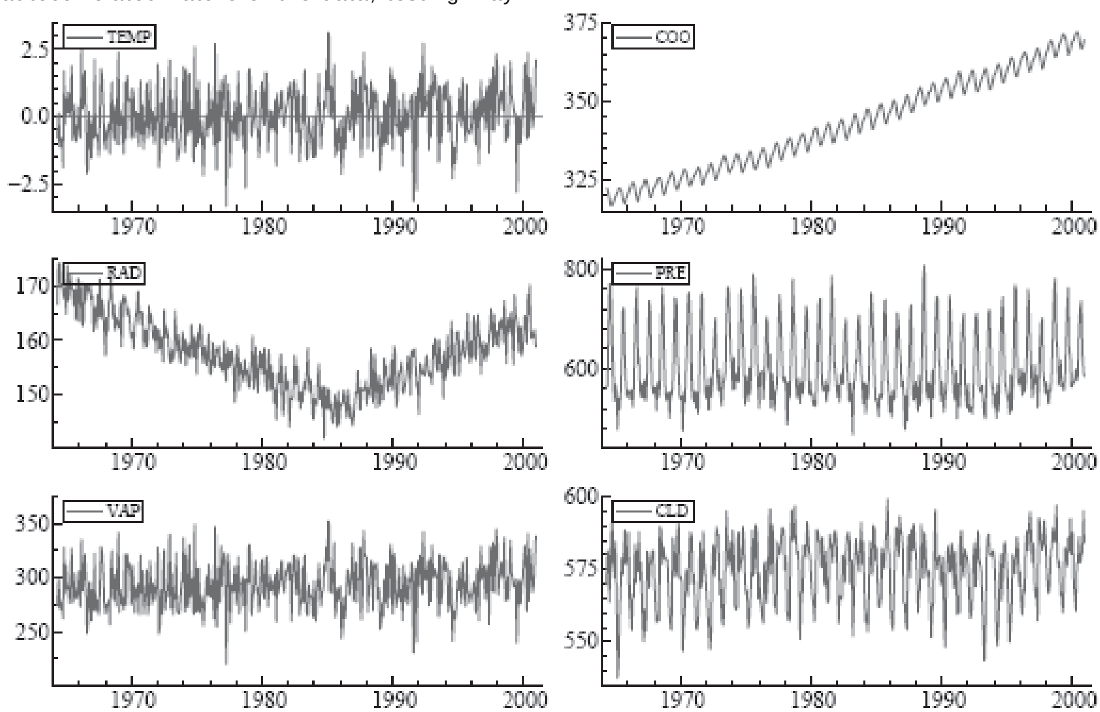

Figure 1: Plot of the data series in levels

[1] See also Hendry and Krolzig (2001).

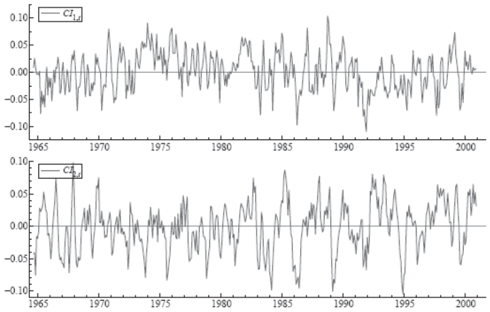

Figure 2: Plots of the cointegrating vectors estimated.

The model passes all misspecification tests at a 1% level of significance. The model output is plotted in Figure 3; the residuals appear normal, and the fitted values match actual values well. From (3), temperature responds to disequilibrium in the energy balance cointegrating vector as would be expected: if there is excess incoming energy (represented by above equilibrium values of coo_{t-1}, rad_{t-1} or vap_{t-1}), temperature increases. The coefficients on the second cointegrating vector correctly reflect positive feedback of temperature on the greenhouse effect.

Aerosols

We now extend the model to incorporate the effect of aerosols. Aerosols are known to contribute to global climate conditions. Unfortunately, very little data on aerosols is available. Although there are many potential proxies for aerosols, these are all highly correlated with other variables of interest, most notably carbon emissions and radiation. Instead of using proxies, we construct a measure of aerosols by exploiting recent scientific research. This allows us to identify the global cooling effect of aerosols separately from the effects of the other variables in the energy balance.

A Measure of Aerosols

New research based on cloud and aerosol observations from NASA's Terra satellite demonstrate that the presence of aerosols in the air over the Atlantic Ocean leads to increased cloud coverage and changes in precipitation patterns (see Khain, Pokrovsky and Sednev, 1999). Based on this scientific evidence, we model cloud coverage as follows:

$$cld_t = \alpha_1 + \alpha_2 pre_t + \alpha_3 aer_t * pre_t + \text{Seasonal Dummies} + \varepsilon_t, \qquad (4)$$

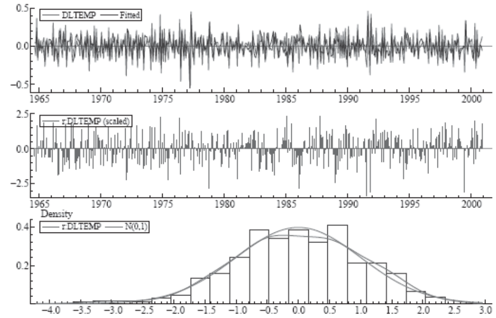

Figure 3: Plotted Model Output.

where aer_t denotes the unobserved level of aerosols at time t. The interaction of aerosols with precipitation reflects the changing relationship between cloud coverage and precipitation due to variation in aerosols. As aerosols are unobserved we model pre_t with a time-varying coefficient and impute the effect of aerosols from variation in this coefficient.

The equation we estimate is as follows:

$$cld_t = \alpha_1 + (\alpha_2 + \beta_1 * TIME + \beta_2 * TIME^2) pre_t + \text{Seasonal Dummies} + \varepsilon_t. \qquad (5)$$

Figure 4 shows imputed and predicted levels of aerosols, with the level of aerosols normalised to zero in May 1964.[3] The hump shape reflects the successful implementation of policies aiming to reduce air pollution.

Policy Experiments

We investigate the global dimming effect of aerosols by looking at temperature changes up to the year 2012 under two different scenarios. In case I, aerosols follow their trend and continue to decrease as shown in Figure 4. In case II, (the Crutzen scenario) aerosols increase. We choose to examine the effect of an increase in aerosols of the same magnitude as the increase observed between 1964 and 1990, when aerosols reached their peak.[4] Imputed aerosols are used to model radiation which affects temperature as described in the econometric model above.

The above model is used to forecast forwards recursively all variables, except radiation, up to April 2012. Radiation is modelled separately and is assumed to depend on aerosols, clouds and seasonal dummies. Figure 5 shows the predicted level of radiation in the two cases. In case I aerosols are decreasing and hence radiation increases. In case II aerosols increase resulting in a reduction in radiation.

[2] Without arbitrary identifying restrictions, the cointegrating vectors cannot be jointly identified in the system. The restrictions imposed are motivated by considering each vector in isolation in the system, imposing just-identifying restrictions on the other cointegrating vector.

[3] The level of aerosols is not identified. However inter-temporal variation in the level of aerosols is sufficient to separate the effect of aerosols from the effects of the other variables.

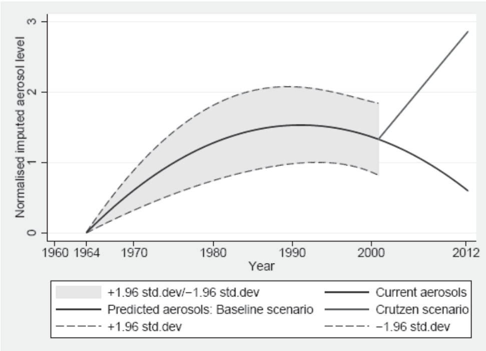

Figure 4: Imputed and predicted aerosols, relative to May 1964. The area between the dotted lines reflects the 95% confidence region around the predictions, relative to the initial level of zero in May 1964.

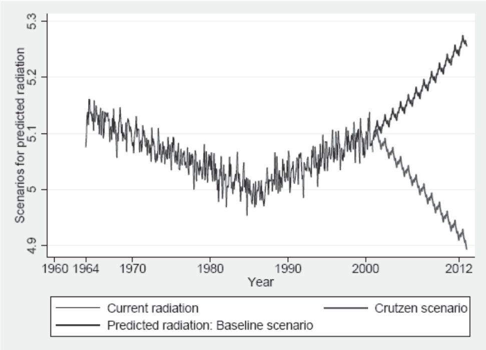

Figure 5: Radiation forecasts under the two scenarios.

The forecasted temperature increase under the two scenarios is shown in Figure 6. In both cases, temperature increases. However, the rate of increase is lower under the Crutzen scenario than under the alternative scenario where aerosols continue to decease at the current rate. In Dec 2012, the temperature increase is 1.065 degrees centigrade under the first scenario, and 0.879 degrees centigrade under the Crutzen scenario.

Conclusion

Based upon our policy experiments, we conclude that aerosols have a substantial impact upon the long-run development of temperature. Using our stylized model, one could recommend artificially increasing aerosol levels in the stratosphere, as suggested by Professor Crutzen. Of course, this ignores any other impacts of this drastic measure upon climate development. What we achieve with this model is to show that increased reflectivity of the cloud layer helps in reducing global warming. One might hope that there are better ways to increase the reflectivity of the cloud cover than pumping small particle pollution into the strato-

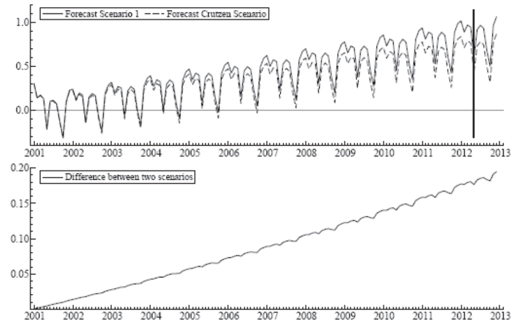

Figure 6: Forecasted temperature increase under the two scenarios.

sphere. We leave to further scientific research the practicalities of this proposal.

Finally, we draw the attention to an important aspect of endogeneity that has been completely ignored in this article. Successfully fighting global warming by increasing aerosol levels would obviously lower the incentives for each country to curb the emission of greenhouse gases. Fighting global warming requires a universal approach: the implementation of measure to fight it is an important political problem that needs as much (if not more) attention as the scientific aspects considered in this article.

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[4] Aerosols are assumed to increase linearly between 2000 and 2012.