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# Does Geography Matter for the Clean Development Mechanism?*

**Yongfu Huang**[a†] **Terry Barker**[a]
[a]4CMR, Department of Land Economy, University of Cambridge
19 Silver Street, Cambridge CB3 9EP

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**Abstract**

Under the Kyoto Protocol, the Clean Development Mechanism (CDM) is designed to serve the dual purposes of allowing the industrialised countries to earn credits by investing in project activities that reduce greenhouse gas (GHG) emissions, while contributing to sustainable development in developing countries via the flows of technology and capital. The fact that the geographic distribution of CDM projects is highly uneven motivates this research into whether certain geographic endowments matter for the CDM development. This research suggests that CDM credit flows in a country are positively affected by those in its neighbouring countries. Countries with higher absolute latitudes and elevations tend to initiate more CDM projects, whereas countries having richer natural resources do not seem to undertake more CDM projects. This finding sheds light on the geographic determinants of uneven CDM development across countries, and has implications for developing countries in terms of international cooperation and national capacity building to effectively access the CDM.

**Keywords:** Clean Development Mechanism; Geography; Natural Resources; Spatial Dependence

**JEL Classification:** Q01; Q56

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†Corresponding author: Email: yh279@cam.ac.uk; Tel: 0044-1223 764873; Fax: 0044-1223 337130; URL: http://www.landecon.cam.ac.uk/yh279/huangyf.htm.

# 1 Introduction

Global warming has emerged as one of the most critical issues of our age, and a key issue in the global economic and environmental debates. Under the Kyoto Procotol, the Clean Development Mechanism (CDM) is designed to realize the benefits in terms of capital flow, technological transfer, sustainable development, and cost-effective emission abatement. However, the geographic distribution of CDM projects by host country and region has been found to be highly uneven. This paper aims to address the issue of whether the geographic endowments in the host countries matter for CDM development using recently-developed spatial econometric techniques.

In response to climate change, the global community adopted the Kyoto Procotol in 1997. The Kyoto Procotol came into force in Februry 2005 and calls for legally binding limits on the greenhouse gas (GHG) emissions by developed countries (or Annex I countries) by at least 5 percent in comparison to the 1990 levels over the first commitment period (i.e. 2008-2012). Although each Annex I country is assigned an amount of $CO_2$ equivalents (expressed in Assigned Amount Units, AAUs) to be used over the period 2008-2012, some Annex I countries still face the projected shortfall in GHG emission reductions. To meet their commitments, these countries usually seek emission reduction credits through the three "flexibility mechanisms" defined under the Kyoto Protocol: International Emission Trading (IET), Joint Implementation (JI), and CDM.

The CDM is defined in Article 12 of the Kyoto Protocol, and is the only such mechanism that involves developing countries. By joining in the CDM, on the one hand, developing countries can get access to significant foreign capital flows and technology transfer to achieve more sustainable, less

GHG-intensive pathways of development. On the other hand, the Annex I countries can purchase and utilize the emission reduction credits, called Certified Emission Reductions (CERs), generated from CDM projects towards meeting their quantified emission targets under the Protocol.

The geographic distribution of CDM projects by host country and region has been observed as lopsided, both in terms of the number of projects and the volume of credits. More specifically, two regions, Asia and the Pacific, and Latin America, together dominate the distribution of CDM projects and CER flows, while by the end of September 2008 China, India, Brazil and Mexico account for 45%, 23%, 5% and 1% of CDM projects, respectively.[1] Developing countries with large populations and economies are expected to account for a large number of CDM projects and CER flows. However, do countries with particular geographic characteristics like higher absolute latitudes, higher elevations, and richer resource endowments, have more CDM projects and CERs flows?

Economists have long noted the crucial role of geography in economic development: transport costs, human health, agricultural productivity and ownership of natural resources. The climate theory of underdevelopment has been widely recognised in the sense that certain geographic endowments have an adverse impact on economic development. For example, some geographic endowments (like mineral resource endowments) may influence the inputs into production function, while others (like tropical location) may make the production technologies much harder to be employed and affect the technological development in the very long term (Sach, 2003; Sachs and Warner, 1995; Diamond, 1997; Gallup *et al.* 1999).

While there is considerable research examining the sustainable develop-

[1] Data are from the UNEP Risoe Centre (2008).

ment impacts of CDM development, much less work has aimed to explore the fundamental determinants of CDM development across countries. In this paper, we empirically evaluate whether cross-sectional differences in CDM development can be explained by cross-sectional differences in geographic characteristics and resource endowments, once controlling for other potential factors.

The cross-country experience of CDM project selection and foreign direct investment indicates the existence of neighbourhood effects or spillovers among countries[2]. The neighborhood effects of CDM projects, together with "a new and deeper version of globalization" since 1970 (Crafts, 2000) which causes a closer interdependence across countries, suggest that spatial correlation is an important phenomenon to be considered in this application. By employing the spatial econometric method recently-developed by Kelejian and Prucha (2007), this paper conducts a cross-country study on 48 developing countries over the period from December 2003 up to September 2008.

This research has led to two significant findings. Firstly, it provides evidence that positive spatial dependence among observations exists in this context. More specifically, the CDM credit flows in a country increase by about 0.34 to 0.48 units if those in its neighbouring countries increase by one unit; and countries with larger CDM credit flows tend to be geographically clustered with other large CDM host countries. Secondly, by allowing for spatial dependence and accounting for the size of economy (initial population and initial GDP per capita), this research finds that absolute latitude and elevation have positive impacts on CDM credit flows, suggesting that

[2] For example, as the only two CDM host countries in Asia in 2003, India and South Korea were immediately followed by 4 Asian host countries in 2004 and 9 other Asian host countries in 2005 (UNEP Risoe Centre, 2008).

countries further from the equator and having higher elevations tend to initiate more CDM projects and issue more CDM credit flows. Larger service exporting countries seem to have more advantages in getting access to CDM projects, and on the contrary, larger natural resources exporting countries have smaller CDM credit flows, indicating that natural resource abundance may not be necessarily attractive to CDM projects.

This finding sheds light on the geographic determinants of uneven CDM project development across countries. It has rich implications for developing countries in terms of international cooperation and national capacity building to effectively access the CDM for their national sustainable development objectives. This research also suggests that the geographic considerations should be introduced into the econometric and theoretical cross-country studies of climate change and mitigation.

The remainder of the paper proceeds as follows. Section 2 describes the data and shows some stylized facts. The empirical results are presented in Section 4 following a description of econometric methods in section 3. Section 5 concludes.

## 2 Data and stylized facts

This section outlines the measures and data for CDM, key geographic variables and the control variables.

The dependent variable is the Clean Development Mechanism credit flows, simply denoted by $CDM$. The indicator for $CDM$ is the average of the Certified Emission Reductions (2012 kCERs) generated by the CDM projects in the pipeline over the period from December 2003 to September 2008.[3] One country has one observation. To diminish the impacts of out-

[3]A country with k monthly non-zero observations (up to September 2008) has its

liers and measurement errors, it is taken in logs. The CDM projects in the pipeline include not only those called "confirmed projects" that have been at the registration stage, either registered or requested registration, but also those called "probable projects" that are at the validation stage, waiting to be registered and implemented over the next 3 years. One CER equals to one metric ton of $CO_2$e.[4] Data on CERs flows are from the UNEP Risoe Centre (2008).

To examine the impacts of particular geographic characteristics on CDM project development, three geographic variables, absolute latitude, elevation and land area, are considered. Absolute latitude ($LATITUDE$) equals the absolute distance from the equator of a country. The closer the countries are to the equator, the more tropical climate they have. Elevation ($ELEV$) is the mean elevation (meters above sea level) calculated in geographic projection, and used in logs. The land area ($AREA$) in square kilometers for each country is in logs. Data on latitude, elevation and land area are taken from the physical factors dataset of Center for International Development (CID) at Harvard University.[5]

To assess the role of natural resource endowments, this research uses two groups of variables. One group of variables consists of dummies for the manufactured goods exporting countries ($EXPMANU$), service exporting countries ($EXPSERV$), and non-fuel primary goods exporting countries ($EXPPRIM$) from the Global Development Network of World Bank (GDN). The other group of variables, taken from Isham *et al.* (2005), in-

averaged CDM being its total CERs divided by k.

[4] $CO_2$e is the Carbon Dioxide Equivalent, the unit of measurement used to indicate the global warming potentials defined in decision 2/CP.3 of the Marrakech Accords or as subsequently revised in accordance with Article 5 of Kyoto Procotol.

[5] Data on latitude, elevation and land area for Singapore are added to the physical factors dataset of CID.

cludes dummies for the exporters of point source natural resources (e.g. oil, diamonds, plantation crops) ($RESPOINT$), "diffuse" natural resources (e.g. wheat, rice, animals) ($RESDIFF$) and coffee/cocoa natural resources ($RESCOFF$).

Control variables included in this analysis are the initial GDP per capita ($GDP03$), the initial population ($POP03$), an ethnic fractionalisation index ($ETHNIC$), a religious fractionalisation index ($RELIGION$), and legal origin dummies, $COMLEG$ and $CIVLEG$.

The inclusion of the initial GDP per capita and the initial population is to control for the size of economy where $GDP03$ is the real GDP per capita in 2003 in constant 2000 US$ (chain series), and $POP03$ is the population in 2003. Both $GDP03$ and $POP03$ are used in logs and from the Penn World Table 6.2 due to Heston *et al.* (2006). The variables, $ETHNIC$ and $RELIGION$, characterise social divisions and cultural differences. The data on $ETHNIC$ and $RELIGION$ are taken from Alesina *et al.* (2003)[6]. $COMLEG$ is the Common Law legal origin dummy for countries with British legal origin, while $CIVLEG$ is the Civil Law legal origin dummy for countries with French, Germany and Scandinavian legal origins. Data on $CIVLEG$ and $COMLEG$ are from the GDN[7].

The sample includes 48 CDM host countries from Asia and the Pacific, Latin America and the Caribbean, Middle East and North Africa, Sub-

[6] This inclusion is stimulated by the works of Alesina *et al.* (2003) and Stulz and Williamson (2003) for example. Alesina *et al.* (2003) argue that the ethnic and religious fractionalisations in a country are associated with its economic success and institutional quality. Stulz and Williamson (2003) show that culture, proxied by differences in ethnic, religion and language, explain why investor protection differs across countries and how investor rights are enforced among countries.

[7] The inclusion is due to La Porta *et al.* (1998) who suggest that legal origin of a country is helpful in explaining the extent to which investor rights are protected in that country. More specifically, countries with Common Law tradition tend to place more emphasis on private rights protection and less on the rights of the state, while countries that have adopted a Civil Law tradition are the opposite.

Saharan Africa, and Europe and Central Asia as listed in the Appendix Table 1. Countries with less than three monthly non-zero observations (up to September 2008) in terms of credit flows (2012 kCERs) have been removed.

Figure 1 presents the scatter plots between CDM credit flows and absolute latitude and elevation, respectively. Despite the existence of outliers such as China and Paraguay, the positive associations between absolute latitude and CDM credit flows, and between elevation and CDM credit flows, can be observed. Countries with higher absolute latitudes and higher elevations are more likely to have more CDM projects as well as CERs credit flows.

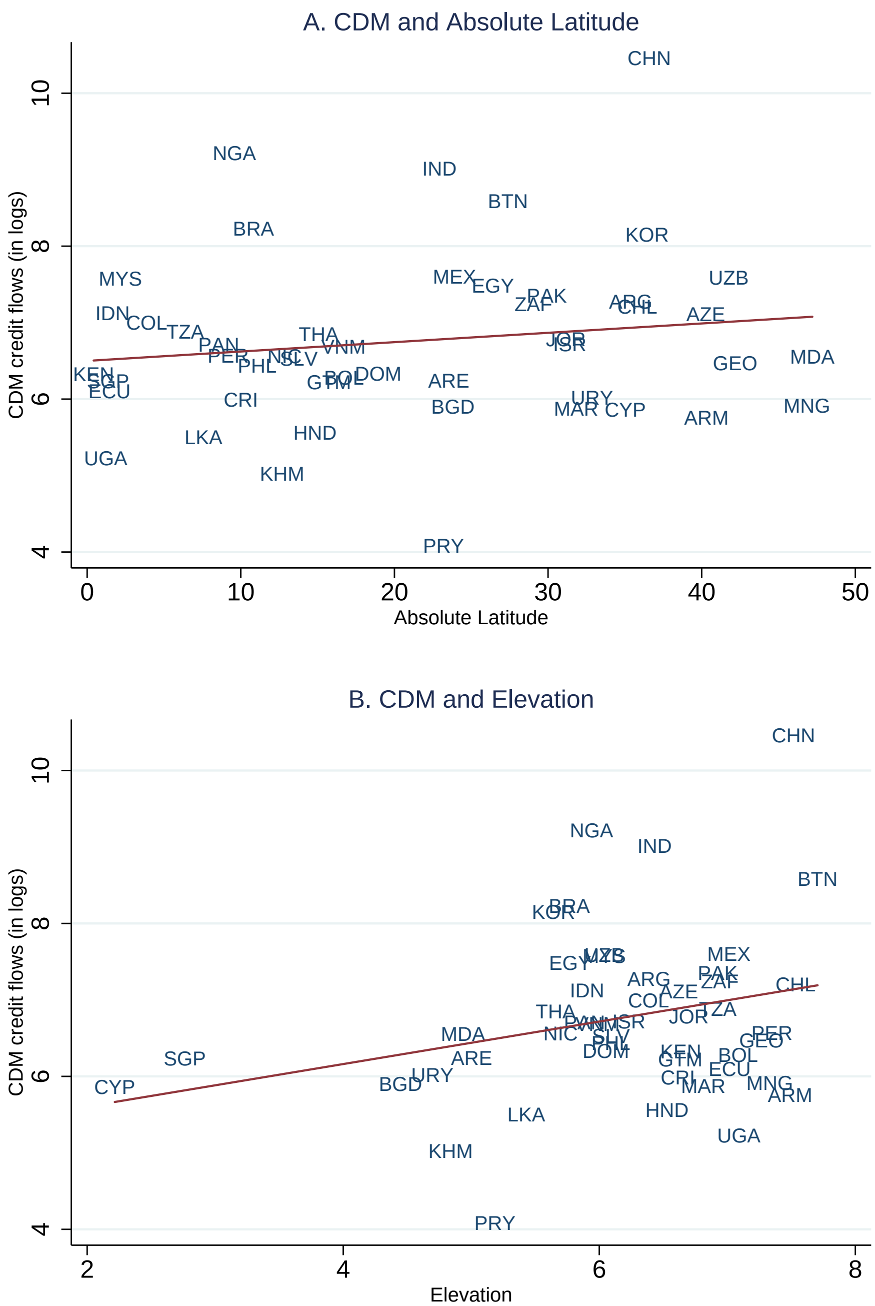
Figure 2 demonstrates, in the upper chart, that CDM credit flows in coffee exporters, diffuse exporters, and point source exporters are in general smaller than those in the non-exporters of relevant resources. The lower chart shows that manufactured goods exporters, service exporters, and non-fuel primary goods exporters tend to have fewer CDM credit flows in comparison to their counterparts.

# 3 Econometric method

To study the impacts of geography on CDM project development, this research conducts a cross-sectional study allowing for spatial correlation on 48 countries over the period from December 2003 to September 2008. It starts from an Ordinary Least Square (OLS) estimation on a basic model:

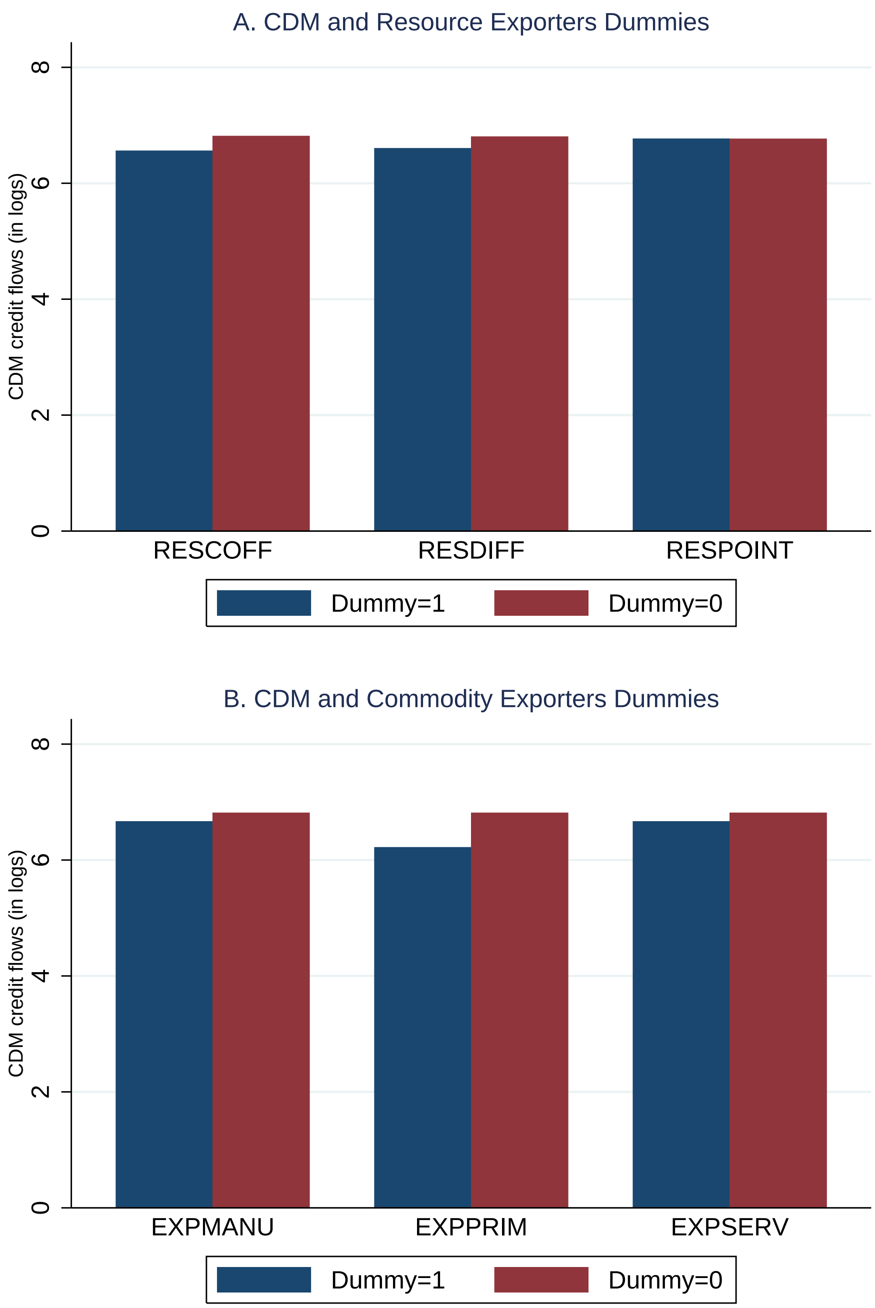
$$\begin{aligned} Y_n &= X_n' \beta + \epsilon_n \\ n &= 1, 2, ....48 \end{aligned} \tag{1}$$

## Figure 1: Scatter Plots of CDM and Geography




Note: Variables and data sources are described in the text. These figures show scatter plots of the absolute latitude, and the elevation, against CDM credit flows (CERs).

Figure 2: CDM and Resource Endowments




Note: Variables and data sources are described in the text. These figures show the comparisons of CDM credit flows (CERs) for different dummies of exporters.

where $Y_n$ is a $n \times 1$ ($n$ is the number of cross section units) vector of observations on dependent variable $CDM$.

$X_n$ is a $n \times k$ matrix of observations on $k$ exogenous explanatory variables which consist of geographic variables ($LATITUDE$, $ELEV$, $AREA$, $EXPSERV$, $EXPPRIM$, $RESPOINT$, $RESDIFF$ and $RESCOFF$), and the control variables including $GDP03$, $POP03$, $ETHNIC$, $RELIGION$ and legal origin dummies ($CIVLEG$, $COMLEG$).

$\beta$ is a $k \times 1$ parameter vector. The error term $\epsilon_n$ is a $n \times 1$ vector with $E(\epsilon) = 0$ and $E(\epsilon\epsilon^{'}) = \delta^2 I$.

The OLS specification typically follows the assumption of no spatial interdependence or spatial correlation. However, spatial dependence associated with social interactions or unobserved common shocks has been widely recognized. On the one hand, considerable research has been done to explore the implications of social or spatial interactions in terms of neighborhood effects, spatial spillovers or networks effects (Manski, 2000; Brock and Durlauf, 2001). The fact that one agent's decision variable is affected by those of other agents is typically formulated as a spatial lagged dependent variable, or a spatial lag term to be included in the right-hand side of the regression model. In the context of financial liberalisation and reform, Abiad and Mody (2005) find that regional diffusion in terms of the liberalization gap from the regional leader is significantly associated with the policy change.

On the other hand, in a globalised world common shocks, either observed global shocks like macroeconomic shocks or unobserved global shocks like technological shocks, are believed to cause closer interdependence across countries. Andrews (2005) analyzes the impact of common shocks in the cross section regression in which the observations are i.i.d. across population units conditional on common shocks, providing a general framework for spatially correlated errors.[8] In examining the origins of financial openness, Quinn and Inclán (1997) argue that the common trend, such as changes in consumer tastes and technology, may substantially affect government liberalization policies as "fundamental but unobservable forces".

Obviously, the OLS estimation provides the foundation for spatial analysis. This research incoporates the spatial correlation structure into the basic linear model to account for both spatial lag dependence and spatial error dependence.

A spatial lag model is a formal specification of spatial lag dependence due to the presence of social and spatial interactions. Its basic form is the mixed regressive, spatial autoregressive model[9]:

$$Y_n = X_n^{'}\beta + \lambda W_n Y_n + \epsilon_n,\ |\lambda|<1 \tag{2}$$

where $\lambda$ is the spatial autoregressive coefficient or spatial interdependence coefficient, measuring the dependence of $Y_i$ on neighboring $Y_n$. $W_n$ is a $n \times n$ spatial weighting matrix of known constants, reflecting the neighboring relationships with zero across diagonals and row-standardized form. The added variable, $\lambda W_n Y_n$, an average of the neighboring values, is refered to as a spatially lagged dependent variable, or a spatial lag of $Y_n$. The error term, $\epsilon_n$, is a $n \times 1$ idiosyncratic error vector, assumed to be distributed independently across the cross-sectional dimension with zero mean and constant variances

[8] The Andrews (2005) approach is very general in the sense that the effects of common shocks, which is $\varsigma$-measurable, may differ across the population units, in a discrete or continuous fashion, and may be local or global in nature.

[9] The addition of the spatially lagged dependent variable results in a form of endogenity, rendering the OLS an unapplicable method for spatial lag model. To consistently estimate the spatial lag model, the Generalised 2SLS and Maximum Likelihood approach (ML) have been proposed (Kelejian and Prucha, 1998, 1999; Lee, 2003, 2007; Kelejian *et al.*, 2004; Anselin, 2006)

$\sigma_\epsilon^2$.

When the spatial dependence exists in the error term due to unobserved effects of common shocks (for example, macroeconomic shocks, political shocks or environmental shocks), a spatial error model can be used as follows[10]:

$$\begin{aligned} Y_n &= X_n'\beta + u_n \\ u_n &= \rho M_n u_n + \epsilon_n, \ |\rho|<1 \end{aligned} \tag{3}$$

where $\rho$ is the spatial autoregressive coefficient, measuring the amount of spatial correlation in the errors. $M_n$ is the spatial weighting matrix, may or may not be the same as $W_n$. $u_n$ are spatially correlated residuals and $\epsilon_n$ are the independent and identically distributed disturbances with zero mean and constant variances $\sigma_\epsilon^2$. $M_n u_n$ is known as a spatial lag of $u_n$.

By plugging the error term of the spatial error model (3) into the spatial lag model (2), one can generate the spatial autoregressive model with autoregressive disturbances of order (1, 1), that is SARAR(1, 1) model, as follows,

$$\begin{aligned} Y_n &= X_n\beta + \lambda W_n Y_n + u_n, \ |\lambda|<1 \\ u_n &= \rho M_n u_n + \epsilon_n, \ |\rho|<1 \end{aligned} \tag{4}$$

The above model is believed to be very general in the sense that it

[10] Since the spatial error model is a special case of a regression specification with a non-spherical error variance-covariance matrix, more specifically, the off-diagonal elements are non-zero. OLS estimates remain unbiased while the standard errors are biased. The OLS method can therefore be applied to this model with the standard errors adjusted to allow for error correlation. The spatial error model can be consistently estimated by GMM or ML (Kelejian and Prucha, 1998, 1999; Anselin, 2006).

allows for spatial spillovers stemming from endogenous variables, exogenous variables and disturbances. It can be rewritten as:

$$
\begin{aligned}
Y_n &= Z_n^{'}\delta + u_n \\
u_n &= \rho M_n u_n + \epsilon_n
\end{aligned}
\tag{5}
$$

where $Z_n^{'} = [X_n, W_nY_n]$, $\delta = [\beta^{'}, \lambda]^{'}$

The corresponding transformed model can be obtained by pre-multiplying (5) by $I_n - \rho M_n$,

$$
Y_{n^*}(\rho) = Z_{n^*}^{'}(\rho)\delta + \epsilon_n \tag{6}
$$

where $Y_{n^*}(\rho) = Y_n - \rho M_n Y_n$ and $Z_{n^*}(\rho) = Z_n - \rho M_n Z_n$.

To estimate a general spatial model like (4), a number of approaches have been proposed in the literature, for example, Kelejian and Prucha (1998, 1999), Kelejian *et al.* (2004), Lee (2003, 2007), and Lee and Liu (2006). However, these approaches in general assume that the innovations in the disturbance process are homoskedastic, which may not hold in many applications. To fill this gap, Kelejian and Prucha (2007) develop a Generalised Spatial Two-Step Least Square (GS2SLS) estimator with a three-stage procedure of inference for the SARAR (1, 1) model that allows for unknown heteroskedasticity in the innovations. Arraiz *et al.* (2008) provide simulation evidence showing that, when the disturbances are heteroskedastic, the GS2SLS estimator produces consistent estimates while the ML estimator produces inconsistent estimates.

This paper examines the impacts of geography on CDM development within a general SARAR (1,1) framework. To estimate the SARAR(1,1) model, it employs the three-stage procedure of Kelejian and Prucha (2007), which can be summerized in the following:

In the FIRST step, the model (5) is estimated by Two-Stage Least Square (2SLS) estimator using the instruments $H_n$. The instruments, $H_n$, is the matrix of instruments which is formed as a subset of linearly independent columns of $(X_n,\ W_nX_n,\ W_n^2X_n ...)$. The first step 2SLS estimator is as follows:

$$\widetilde{\delta_n} = (\widetilde{Z_n'}Z_n)^{-1}\widetilde{Z_n'}Y_n \tag{7}$$

$$\widetilde{u_n} = Y_n - Z_n\widetilde{\delta_n} \tag{8}$$

where $\widetilde{Z_n} = P_HZ_n = [X_n, \widehat{W_nY_n}]$, $\widehat{W_nY_n} = P_HW_nY_n$ and $P_{H_n} = H_n(H_n'H_n)^{-1}H_n'$.

In the SECOND step, $\rho_n$ and $\sigma_\epsilon^2$ are estimated, where $\rho_n$ is the spatial autoregressive parameter and $\sigma_\epsilon^2$ is the variance of the innovation term $\epsilon_n$. They are estimated by applying the Generalised Method of Moment (GMM) to the model (5), based on the 2SLS residuals $\widetilde{u_n}$ obtained from the First step. More secifically, this estimator is $\widetilde{\rho_n}$, defined as

$$\widetilde{\rho_n} = \underset{\rho\epsilon[-a^\rho,\ a^\rho]}{\arg\min}\,[m(\rho,\widetilde{\delta_n})'\widetilde{\Psi_n}^{-1}m(\rho,\widetilde{\delta_n})] \tag{9}$$

where $\widetilde{\Psi}_n$ is an estimator of the variance-covariance matrix of the limiting distribution of the normalised sample moments $n^{\frac{1}{2}}m(\rho, \tilde{\delta}_n)$.

$$
\begin{aligned}
m(\rho, \tilde{\delta}_n) &= g_n(\tilde{\delta}_n) - G_n(\tilde{\delta}_n)\begin{bmatrix} \rho \\ \rho^2 \end{bmatrix} \\
g_n(\tilde{\delta}_n) &= \frac{1}{n}\begin{bmatrix} \tilde{u}_n^{\prime}\tilde{u}_n \\ \overset{\simeq}{u}_n^{\prime}\overset{\simeq}{u}_n \\ \tilde{u}_n^{\prime}\overset{\simeq}{u}_n \end{bmatrix} \\
G_n(\tilde{\delta}_n) &= \frac{1}{n}\begin{bmatrix} 2\tilde{u}_n^{\prime}\overset{\simeq}{u}_n & -\overset{\simeq}{u}_n^{\prime}\overset{\simeq}{u}_n & n \\ 2\overset{\simeq}{u}_n^{\prime}\overset{\cong}{u}_n & -\overset{\cong}{u}_n^{\prime}\overset{\cong}{u}_n & Tr(M_n^{\prime}M_n) \\ \tilde{u}_n^{\prime}\overset{\simeq}{u}_n + \overset{\cong}{u}_n^{\prime}\overset{\cong}{u}_n & -\overset{\simeq}{u}_n^{\prime}\overset{\cong}{u}_n & 0 \end{bmatrix} \\
\overset{\simeq}{u}_n &= M_n\tilde{u}_n \\
\overset{\cong}{u}_n &= M_n^2\tilde{u}_n
\end{aligned}
$$

In the THIRD step, $\delta$ in the transformed model (6) can be estimated by a generalised spatial 2SLS procedure (GS2SLS) after replacing $\rho$ by $\tilde{\rho}_n$. The GS2SLS estimator of $\delta$ is defined as

$$\hat{\delta}_n(\tilde{\rho}_n) = [\hat{Z}_{n^*}(\tilde{\rho}_n)^{\prime}Z_{n^*}(\tilde{\rho}_n)]^{-1}[\hat{Z}_{n^*}(\tilde{\rho}_n)Y_{n^*}(\tilde{\rho}_n)] \tag{10}$$

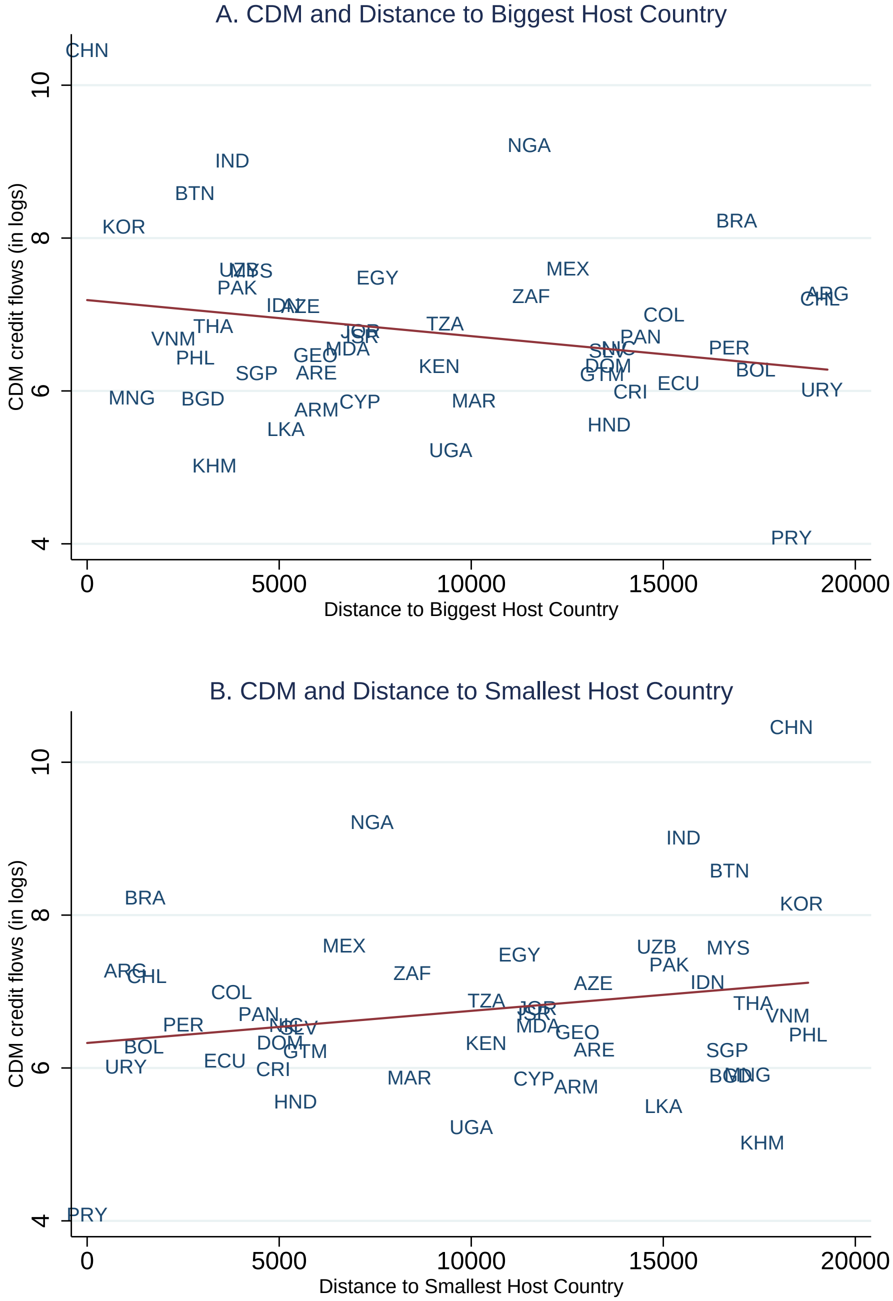
where $Y_{n^*}(\tilde{\rho}_n) = Y_n - \tilde{\rho}_n M_n Y_n$ , $Z_{n^*}(\tilde{\rho}_n) = Z_n - \tilde{\rho}_n M_n Z_n$, and $\hat{Z}_{n^*}(\tilde{\rho}_n) = P_H$ $Z_{n^*}(\tilde{\rho}_n)$.

# 4 Empirical evidence

This section presents the empirical evidence for the impacts of various geographic variables on CDM credit flows. Before proceeding to detailed econometric analysis, we briefly test for spatial dependence of CDM credit flows across countries with evidence presented in Figure 3 and Table 1.

Figure 3 plots the averaged CDM credit flows of all sample countries against the distance to the country with the largest CDM credit flows in

## Figure 3: CDM and Distance to Biggest and Smallest Host Countries




Note: Variables and data sources are described in the text. These figures show scatter plots of the distances to the biggest CDM host country (China) and to the smallest host country (Paraguay), against CDM credit flows (CERs).

the upper chart, and the distance to the country with the smallest CDM credit flows in the lower chart. Data on the great circle distance are from Gleditsch *et al.* (2001). This figure clearly shows that countries closer to the biggest CDM host country, which is China, tend to have more CDM credit flows, whereas countries closer to the smallest CDM host country, which is Paraguay, tend to have less CDM credit flows.[11] Countries with more (less) CDM credit flows appear to be geographically clustered with other larger (smaller) CDM host countries.

By using two different spatial weighting matrices, an inverse-distance spatial weighting matrix and a binary spatial weighting matrix, two standard test statistics of spatial autocorrelation have been calculated (Table 1). The inverse-distance spatial weighting matrix gives the inverse of the distance to each sample point within a 4000km neighbourhood, and zero otherwise, while the binary spatial weighting matrix gives a weight of 1 to all sample points within a 4000km neighbourhood, and zero otherwise.[12] Both matrices are row-standardized of one. Following Kelejian and Prucha (1999), the spatial weighting matrices have been "idealized" so that each unit has the same number of neighbours with "one neighbour ahead and one neighbour behind" in a wrap around world.

Table 1 contrasts the Moran's I and Gearcy's C statistics for CDM credit flows. Both Moran's I and Gearcy's C statistics examine the null hypothesis of no spatial dependence. No matter which matrix is chosen, two Moran's I statistics are greater than the expected value (-0.021) and two Gearcy's C statistics are smaller than the expected value (1.000), suggesting posi-

[11] This evidence is preliminary. One might find that countries like Brazil, closer to Paraguay, have large CDM credit flows. This suggests that, apart from geographic distance, other geographic variables are also important in the process of CDM development, and so are the institutional variables and financial variables.

[12] Data on the great circle distance are from Gleditsch et al. (2001) as well.

tive spatial dependence of CDM credit flows across countries.[13] Moreover, both Moran's I and Gearcy's C statistics reject the null at about 10% significance level with an inverse-distance spatial weighting matrix, and at 5% significance level with a binary spatial weighting matrix. This shows that the positive spatial dependence of the CDM credit flows is significant across countries.

Tables 2 and 3 investigate whether countries with particular geographic endowments are more likely to attract CDM projects, for which 8 geographic endowment variables as explained earlier are selected from various sources.[14]

Column 1 of Table 2 reports the OLS estimates for the non-spatial model (1). Firstly, an OLS heteroskedasticity test due to White (1980) and Koenker (1981) is conducted to examine whether there is heteroskedasticity in the estimation regression that is related to any of the geographic variables we examine.[15] The White/Koenker test rejects the null at 10% significance level, indicating that heteroskedasticity exists in the estimations and should be taken into account for this context.

To test for which type(s) of spatial dependence, spatial lag dependence

[13] If Moran's I is greater (smaller) than its expected value, E(I), and/or Gearcy's C is smaller (larger) than its expected value, E(C), the overall distribution of the variable in question can be reflected by positive (negative) spatial autocorrelation.

[14] In this analysis, we also explore the impacts on CDM credit flows of other geographic factors such as being landlocked, minimum distance from one of the three capital-goods-supplying centers (New York, Rotterdam and Tokoyo), mean distance to nearest coastline or seanevigable river, the proportion of a country's total land area with 100km of the ocean or ocean-navigable river, and the proportion of a country's total land area in Koeppen-Geiger temperate zones. In general we find no evidence to support any significant associations between these factors and CDM credit flows. This may suggest that, as more and more modern technologies have been employed in the areas of transportation and telecommunications, and more and more railways, automobiles, airtransport and all forms of telecommunications become available, the geographic advantages in terms of easy access to the sea and/or international trade centers tend to be diminishing in the process of economic development.

[15] Under the null of no heteroskedasticity, the test statistic is distributed as Chi-square with degree of freedom being the total number of the regressors.

or spatial error dependence or both, exist(s) in this context, we carry out two simple Lagrange Mulitiplier tests (LM) separately. The hypothesis of no spatially lagged dependent variable is rejected at about 10% significance level while the hypothesis of no spatially autocorrelated error term can not be rejected. Furthermore, the p-values for the robust LM tests due to Anselin *et al.* (1996) and the log-likelihood statistics are reported to test for whether a spatial lag model is more appropriate than a spatial error model for this context. The evidence that the robust LM test doesn't reject the null hypothesis of no spatially autocorrelated error term, but reject the null of no spatially lagged dependent variable (at about 10% significance level), together with the evidence that the log-likelihood statistic for the spatial lag model (-41.03) is bigger than that for the spatial error model (-41.61), suggest that a spatial lag model is prefered to a spatial error model.

Columns 2 to 4 report the ML estimates for the spatial lag model (2) and spatial error model (3), and the GS2SLS estimates due to Kelejian and Prucha (2007) for the SARAR (1, 1) model (4). An inverse-distance spatial weighting matrix has been used to calculate the ML estimates and GS2SLS estimates.[16]

The spatial autocorrelation parameter, "$\rho$" appears to be insignificant in both the spatial error model and the SARAR(1,1) model. For the spatial autoregressive parameter, "$\lambda$", it has been found weakly significant in the spatial lag model and significant in the the SARAR(1, 1) model, with larger coefficient in the SARAR (1,1) model. The GS2SLS estimate of "$\lambda$" in the SARAR(1, 1) model shows that the CDM credit flows in a country increase by 0.34 units if those in its neighbouring countries increase by one unit.

The explanatory variables described in Section 2, except for $EXPMANU$,

[16] The spatial weighting matrices, $W_n$ and $M_n$, are treated as the same.

have been found closely related to CDM credit flows with expected signs. In particular, the GS2SLS estimates show that the the geographic variables, $LATITUDE$ and $ELEV$, are positively associated with CDM development. For the resource and commodity exporter dummies, $EXPSERV$ is positively, while $RESPOINT$, $RESDIFF$ and $RESCOFF$ are negatively related to CDM development. All control variables including $GDP03$, $POP03$, $ETHNIC$, $RELIGION$ and legal origin dummies ($CIVLEG$, $COMLEG$) are in general found significantly associated with CDM development and should be included in the model.[17]

With a row-standardized binary weighting matrix, Table 3 in general confirms the findings of Table 2 in terms of positive impacts of $LATITUDE$, $ELEV$ and $EXPSERV$, and negative impacts of $RESPOINT$, $RESDIFF$ and $RESCOFF$ on CDM credit flows. Table 3 seems to provide stronger evidence than Table 2, especially for the spatial autoregressive coefficients, "$\lambda$" and "$\rho$". According to the SARAR(1, 1) model, the degree of neighbourhood effects for the CDM credit flows increases to 0.48.

The finding on the positive association between absolute latitude and CDM credit flows is consistent with the literature. On the one hand, research by Diamond (1997), Gallup *et al.* (1999) and Sachs (2003) suggests that countries in the tropical location in terms of a smaller absolute latitude are often associated with poor crop yields and production due to adverse ecological conditions such as fragile tropical soils, unstable water supply and prevalence of crop pests. On the other hand, tropical location can be characterised as an inhospitable disease environment, believed to be a primary cause for "extractive" institutions and in conjunction with weaker institutions according to the settler mortality hypothesis of Acemoglu *et al.*

[17] The GS2SLS estimates suggest that the impacts of $AREA$ and $EXPPRIM$ have been less precisely estimated.

(2001). Countries further from the Equator are more likely to have better climate conditions and stronger institutions, which are conducive to CDM project development.

The finding on the positive association between elevation and CDM credit flows is in line with recent research. It is widely known that the Earth's average surface temperature has risen by approximately $0.6^0$C in the 20th century and will rise a few degree (C) in this century. Global warming is likely to raise the sea level and change the land area and elevation for many countries. Countries with higher elevations are therefore supposed to have more potentials to attract CDM projects.

Some growth literature indicates that natural resource abundance is connected with social and economic instability and weak institutional quality, which hamper CDM project development. Isham *et al.* (2005) find that, in comparison to manufacturing exporters, the exporting countries of "point source" natural resources (e.g. oil, diamonds, plantation crops) and coffee/cocoa natural resources are more likely to have severe social and economic divisions, and less likely to develop socially cohesive mechanisms and effective institutional capacities for managing shocks.

In sum, this research produces the following significant findings. Firstly, this research provides evidence for the presence of positive spatial dependence among observations for this context, especially the spatial lag dependence associated with neighbourhood effects and social interactions. CDM credit flows in a country is significantly affected by those of its neighbouring countries, more specifically, the CDM credit flows in a country increase by about 0.34 to 0.48 units if those in its neighbouring countries increase by one unit. Secondly, by allowing for spatial dependence and accounting for the size of economy (initial population and initial GDP per capita), this research finds that the absolute latitude and elevation have positive impacts on the CDM credit flows, suggesting that countries further from the equator and having higher elevation tend to initiate more CDM projects and issue more CDM credit flows. Countries with more exports of service seem to have more advantages in attracting CDM projects, and on the contrary, countries with more exports of natural resources have smaller CDM credit flows, indicating that natural resource abundance may not be necessarily conducive to CDM development.

## 5 Concluding remarks

Under the Kyoto Procotol, the Clean Development Mechanism (CDM) is designed to provide the non-Annex I countries (developing countries and economies in transition) with access to the flows of technology and capital that could contribute to their sustainable development objectives, while allowing Annex 1 countries to earn credits to meet their Kyoto commitments by investing in GHG emission reduction projects in non-Annex I countries.

This paper investigates whether the cross-sectional differences in geographic endowments can explain the cross-sectional differences in CDM credit flows. It conducts a cross-country study allowing for both spatial error dependence and spatial lag dependence for 48 CDM host countries over 12/2003-09/2008.

This research leads to two significant findings. Firstly, it provides evidence for a positive relationship between CDM credit flows in a country and those in its neighbouring countries, more specifically, the CDM credit flows in a country increase by about 0.34 to 0.48 units if those in its neighbouring countries increase by one unit. Countries with larger (smaller) CDM credit flows have been found geographically clustered with other larger (smaller)

CDM host countries. Secondly, by allowing for spatial dependence and accounting for the size of economy (initial population and initial GDP per capita), this research finds that the absolute latitude and elevation have positive impacts on CDM credit flows, suggesting that countries further from the equator and having higher elevations are in better positions to attract CDM projects. Countries with more exports of service are more associated with larger CDM credit flows, on the contrary, countries with more exports of natural resources have fewer CDM credit flows, indicating that natural resource abundance doesn't necessarily play a large role in promoting CDM development. These findings are robust to the choices of different spatial weighting matrics, an inverse-distance spatial weighting matrix and a binary spatial weighting matrix. We also control for an ethnic fractionalisation index, a religious fractionalisation index and legal origin dummies.

This finding sheds light on the geographic determinants of uneven CDM project development across countries, and has rich implications for developing countries in terms of international cooperation and national capacity building to effectively access the CDM for their national sustainable development objective. This research may contribute to our understanding of the cross-country differences in CDM development and contain some merits for the UNFCCC in terms of improving geographic distribution of CDM project activities and capacity building. This research also suggests that the geographic considerations should be introduced into the econometric and theoretical cross-country studies of climate change and mitigation.

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## Table 1. Moran's I and Geary's C for CDM

| | Moran's I | E(I) | SD(I) | z-statistic | p-value |
|---|---|---|---|---|---|
| **Inverse-distance Weights** | 0.086 | -0.021 | 0.084 | 1.250 | [0.102] |
| **Binary Weights** | 0.094 | -0.021 | 0.067 | 1.714 | [0.043]** |
| | **Gearcy's C** | **E(C)** | **SD(C)** | **z-statistic** | **p-value** |
| **Inverse-distance Weights** | 0.902 | 1.000 | 0.092 | -1.064 | [0.144] |
| **Binary Weights** | 0.870 | 1.000 | 0.074 | -1.748 | [0.040]** |

Note: This table reports Moran's I and Gearcy's C tests for spatial autocorrelation for the averaged CDM credit flows in logs for 48 CDM host countries listed in the Appendix Table 1. The test statistics are calculated using an inverse-distance weighting matrix and a binary weighting matrix, respectively, as described in the text. * significant at 10%; ** significant at 5%; *** significant at 1%.

**Table 2. Geography and Clean Development Mechanism (by inverse-distance weights)**

| | Non-spatial Model | Spatial Lag Model | Spatial Error Model | SARAR (1, 1) |
|---|---|---|---|---|
| λ | | 0.185 | | 0.339 |
| | | [0.135] | | [0.033]** |
| ρ | | | 0.315 | -0.300 |
| | | | [0.226] | [0.239] |
| LATITUDE | 0.016 | 0.017 | 0.016 | 0.018 |
| | [0.090]* | [0.088]* | [0.111] | [0.140] |
| ELEVATION | 0.276 | 0.270 | 0.255 | 0.274 |
| | [0.048]** | [0.008]*** | [0.012]** | [0.031]** |
| AREA | 0.155 | 0.135 | 0.125 | 0.118 |
| | [0.150] | [0.173] | [0.219] | [0.331] |
| EXPSERV | 0.965 | 0.888 | 0.851 | 0.860 |
| | [0.004]*** | [0.002]*** | [0.004]*** | [0.020]** |
| EXPPRIM | -0.287 | -0.320 | -0.337 | -0.307 |
| | [0.368] | [0.211] | [0.184] | [0.333] |
| RESPOINT | -1.587 | -1.642 | -1.565 | -1.678 |
| | [0.013]** | [0.000]*** | [0.000]*** | [0.002]*** |
| RESDIFF | -1.059 | -1.098 | -0.998 | -1.147 |
| | [0.013]** | [0.002]*** | [0.005]*** | [0.010]*** |
| RESCOFF | -1.368 | -1.484 | -1.435 | -1.525 |
| | [0.022]** | [0.001]*** | [0.001]*** | [0.011]** |
| GDP03 | 0.258 | 0.236 | 0.279 | 0.185 |
| | [0.259] | [0.090]* | [0.056]* | [0.264] |
| POP03 | 0.360 | 0.366 | 0.367 | 0.360 |
| | [0.004]*** | [0.001]*** | [0.001]*** | [0.007]*** |
| ETHNIC | 1.336 | 1.467 | 1.367 | 1.606 |
| | [0.050]* | [0.015]** | [0.031]** | [0.027]** |
| REGLIGION | 2.077 | 2.067 | 2.061 | 2.001 |
| | [0.013]** | [0.000]*** | [0.000]*** | [0.004]*** |
| COMLEG | 0.557 | 0.541 | 0.520 | 0.552 |
| | [0.261] | [0.117] | [0.135] | [0.190] |
| CIVLEG | 1.278 | 1.354 | 1.393 | 1.331 |
| | [0.046]** | [0.004]*** | [0.003]*** | [0.022]** |
| Constant | -4.312 | -5.175 | -4.064 | -5.571 |
| | [0.074]* | [0.003]*** | [0.018]** | [0.006]*** |
| Observations | 48 | 48 | 48 | 48 |
| R-squared | 0.73 | 0.74 | 0.72 | |
| Log Likelihood | | -41.03 | -41.61 | |
| White/Koenker test | [0.105] | | | |
| Spatial lag: | | | | |
| LM | [0.107] | | | |
| Robust LM | [0.107] | | | |
| Spatial error: | | | | |
| LM | [0.572] | | | |
| Robust LM | [0.570] | | | |

Note: Dependent variable is the averaged CDM credit flows (2012 kCERs) in logs. Robust p values are reported in brackets. Variables and data sources are described in text. λ is the spatial autoregressive parameter in dependent variable in the spatial lag model and SARAR (1,1) model. ρ is the spatial autoregressive parameter in the disturbance in spatial error model and SARAR (1,1) model. The White/Koenker test is to examine the null of no heteroskedasticity. The spatial weighting matrix used here is a row-standardized inverse-distance weighting matrix described in text. Robust p values are reported in brackets. * significant at 10%; ** significant at 5%; *** significant at 1%.

**Table 3. Geography and Clean Development Mechanism (by binary weights)**

| | Non-spatial Model | Spatial Lag Model | Spatial Error Model | SARAR (1, 1) |
|---|---|---|---|---|
| λ | | 0.288 | | 0.476 |
| | | [0.068]* | | [0.023]** |
| ρ | | | 0.495 | -0.299 |
| | | | [0.041]** | [0.205] |
| LATITUDE | 0.016 | 0.018 | 0.016 | 0.020 |
| | [0.090]* | [0.065]* | [0.094]* | [0.108] |
| ELEVATION | 0.276 | 0.255 | 0.232 | 0.256 |
| | [0.048]** | [0.011]** | [0.018]** | [0.047]** |
| AREA | 0.155 | 0.115 | 0.118 | 0.087 |
| | [0.150] | [0.244] | [0.232] | [0.479] |
| EXPSERV | 0.965 | 0.831 | 0.779 | 0.796 |
| | [0.004]*** | [0.004]*** | [0.006]*** | [0.034]** |
| EXPPRIM | -0.287 | -0.334 | -0.401 | -0.319 |
| | [0.368] | [0.187] | [0.118] | [0.306] |
| RESPOINT | -1.587 | -1.671 | -1.574 | -1.717 |
| | [0.013]** | [0.000]*** | [0.000]*** | [0.002]*** |
| RESDIFF | -1.059 | -1.127 | -1.023 | -1.182 |
| | [0.013]** | [0.001]*** | [0.003]*** | [0.008]*** |
| RESCOFF | -1.368 | -1.515 | -1.529 | -1.546 |
| | [0.022]** | [0.001]*** | [0.001]*** | [0.009]*** |
| GDP03 | 0.258 | 0.220 | 0.267 | 0.162 |
| | [0.259] | [0.111] | [0.063]* | [0.325] |
| POP03 | 0.360 | 0.382 | 0.358 | 0.392 |
| | [0.004]*** | [0.000]*** | [0.001]*** | [0.004]*** |
| ETHNIC | 1.336 | 1.581 | 1.395 | 1.765 |
| | [0.050]* | [0.009]*** | [0.027]** | [0.018]** |
| REGLIGION | 2.077 | 1.940 | 2.011 | 1.834 |
| | [0.013]** | [0.000]*** | [0.000]*** | [0.006]*** |
| COMLEG | 0.557 | 0.559 | 0.482 | 0.602 |
| | [0.261] | [0.101] | [0.150] | [0.155] |
| CIVLEG | 1.278 | 1.407 | 1.408 | 1.457 |
| | [0.046]** | [0.002]*** | [0.002]*** | [0.014]** |
| Constant | -4.312 | -5.591 | -3.544 | -6.221 |
| | [0.074]* | [0.001]*** | [0.042]** | [0.003]*** |
| Observations | 48 | 48 | 48 | 48 |
| R-squared | 0.73 | 0.75 | 0.71 | |
| Log Likelihood | | -40.56 | -40.99 | |
| White/Koenker test | [0.105] | | | |
| Spatial lag: | | | | |
| LM | [0.055]* | | | |
| Robust LM | [0.070]* | | | |
| Spatial error: | | | | |
| LM | [0.385] | | | |
| Robust LM | [0.563] | | | |

Note: The spatial weighting matrix used for the spatial lag model, spatial error model and SARAR(1,1) model in this table is a row-standardized binary weighting matrix described in the text. See Table 2 for more notes.

**Appendix Table 1: The List of Countries in the Full Sample**

| Code | Country Name | Code | Country Name |
|---|---|---|---|
| ARE | United Arab Emirates | KHM | Cambodia |
| ARG | Argentina | KOR | Korea, Rep. (South) |
| ARM | Armenia | LKA | Sri Lanka |
| AZE | Azerbaijan | MAR | Morocco |
| BGD | Bangladesh | MDA | Moldova, Republic of |
| BOL | Bolivia | MEX | Mexico |
| BRA | Brazil | MNG | Mongolia |
| BTN | Bhutan | MYS | Malaysia |
| CHL | Chile | NGA | Nigeria |
| CHN | China | NIC | Nicaragua |
| COL | Colombia | PAK | Pakistan |
| CRI | Costa Rica | PAN | Panama |
| CYP | Cyprus | PER | Peru |
| DOM | Dominican Republic | PHL | Philippines |
| ECU | Ecuador | PRY | Paraguay |
| EGY | Egypt, Arab Rep. | SGP | Singapore |
| GEO | Georgia | SLV | El Salvador |
| GTM | Guatemala | THA | Thailand |
| HND | Honduras | TZA | Tanzania |
| IDN | Indonesia | UGA | Uganda |
| IND | India | URY | Uruguay |
| ISR | Israel | UZB | Uzbekistan |
| JOR | Jordan | VNM | Vietnam |
| KEN | Kenya | ZAF | South Africa |

Note: This table lists the country codes and country names for 48 CDM host countries considered in this analysis. Data are from the UNEP Risoe Centre CDM/JI Pipeline Analysis and Database (2008).

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