Economics Bulletin

Volume 33, Issue 2

# The Fall of Bretton Woods: Which Geography Matters?

Leila Ali
*University of Poitiers/CRIEF-MOFIB*

Marie Lebreton
*University of Bordeaux 4/GRETHA*

## Abstract

This paper analyses the spatial diffusion of the speculative attacks during the fall of the Bretton Woods System. First, we study the spatial heterogeneity of the relationship between speculative pressures and their determinants via a locally linear framework. Here, relationships were assumed to reflect mainly geographical space. However, mapping the countries in crisis also showed that the spatial diffusion of attacks was not linear. Therefore, we used a neuro-coefficient smooth transition auto-regressive model to investigate more complex interactions between geographical space and crises. Our results suggest that combining geographical and socio-economic spaces is useful for predicting the location of future victims.

The authors would like to thank the teams of CRIEF-MOFIB and GRETHA, André Cartapanis, Jean-Pierre Allegret, Christian Dunis and Anne Peguin-Feissolle for their helpful comments on a preliminary version of this paper.
**Citation:** Leila Ali and Marie Lebreton, (2013) "The Fall of Bretton Woods: Which Geography Matters?", *Economics Bulletin*, Vol. 33 No. 2 pp. 1396-1419.
**Contact:** Leila Ali - leila.ali@univ-poitiers.fr, Marie Lebreton - marie.lebreton@u-bordeaux4.fr.
**Submitted:** March 10, 2013.   **Published:** June 10, 2013.

## 1. Introduction

In spite of extensive research, the epidemic nature of currency speculative attacks among countries is still not well understood. In particular, the spatial spread of turbulences remains difficult to forecast, though it can be useful to draft rescue plans. Here, we investigate spatial econometrics that can help to predict the location of future victims of currency crises. While currency crises in emerging markets during the 1990s tended to be bunched at regional level, the fall of Bretton-Woods in the early 1970s was not confined to a specific region. Indeed, it had both regional and global components. For that reason, the meltdown of Bretton-Woods seems well suited for assessing the potential usefulness of spatial econometric frameworks.

The intuition about the geographical impact can be summarized as follows: economic and financial links are likely to be at least partially space-dependent, the strength of these ties diminishing with increasing distance. Typically, because trade of goods is positively linked to geographical proximity that lowers transaction costs, and because devaluation of a partner can be costly in terms of competitiveness to maintain parity, currency crises may be contagious at a regional level[2]. Therefore, we first study the spatial heterogeneity of the relationship between speculative pressures and their determinants via a linear geographical weighted regression (GWR). In this approach, economic and financial relationships are assumed to reflect mainly the geographical space.[3]

However, mapping countries in crisis sometimes reveals non-linearity in the spatial diffusion of attacks. Fiurthermore, outside crisis periods, interactions with distant countries have always been detected. Examples include the relationships between Japan and the United States or, more recently, China and the United States. Yet, the locally linear framework (GWR) does not appear to be flexible enough to deal with non-linear relationships. Therefore, we then used a neuro-coefficient smooth transition auto-regressive (NCSTAR) model to investigate more complex interactions between space and speculative pressures. This flexible model can be seen as a linear model whose coefficients are given by the outputs of an artificial neural network (ANN) model. These outputs are non-linearly related to geographical proximity as well as to some macroeconomic proximity. Because it is an ANN model, NCSTAR acts as a universal approximator (Hornik et al. (1989, 1990), Cybenko (1989). Thus, the functional form of this function does not need to be specified. Moreover, model specification is done via statistical tests and is an integral part of the estimation procedure.

The paper is organised as follows. In Section 2, we present both econometric models, and then apply both models to the 1971 and 1973 monetary crises in Section 3. Section 4 concludes.

[2] See Dasgupta et al. (2011), Glick and Rose (1999) or Fratzcher (1998) for empirical approaches and Gerlach and Smets (1995), Chan and Kasa (2001) or Corsetti et al. (2000) for theoretical developments.
[3] This investigation sharpens the analysis of Ali and Lebreton (2007) and Ali and Kestens (2006) that focus on 1990s crises.

## 2. The spatial models

### 2.1 The geographically weighted regression (GWR) model

The GWR method introduced by MacMillen (1996) and so named by Brunsdon et al. (1996) uses weighted sub-samples of the data to give estimates for each sample point in space. For each observation *i*, this method computes a matrix of weights in which the largest values are assigned to the corresponding nearest observations of *i*. The model can be written as follows:

$$W_i^{1/2} y = W_i^{1/2} \tilde{X} \beta_i + W_i^{1/2} e, \quad i = 1, \cdots, n, \tag{1}$$

where $y$ is a vector of the dependent variable, $\tilde{X} = [1, X]$ is an $n \times (p+1)$ matrix of explanatory variables, $\beta_i$ is a $(p+1) \times 1$ vector of parameters and $W_i$ is an $n \times n$ matrix of weights. The latter are associated with *i* so they are $n$ vectors of parameters and $n$ matrices of weights, one for each point in space. The errors $e$ are independently and normally distributed with zero mean and constant variance. Before estimating eq. (1), a function must be chosen for the spatial weight matrix. It is composed of a vector of distances calculated from the coordinates of latitude and longitude for each observation and a decay parameter, because for a particular point *i*, the nearest observations have more weight than farthest observations. Brunsdon et al. (1996) suggest using an exponential function which is written as follows:

$$W_i = \sqrt{\exp(-d_i / \theta)}, \tag{2}$$

with $d_i$, the vector of distance between observation i and all other observations and $\theta$, the decay parameter. However, as mentioned by Lesage (1999), matrix inversion problems may arise during the estimation of parameters with this function. The tri-cube function proposed by McMillen and McDonald (1997) takes the following form:

$$W_i = \left(1 - (d_i / q_i)^3\right)^3 I(d_i < q_i), \tag{3}$$

where $q_i$ denotes the distance between observation *i* and its $q^{th}$ nearest neighbours and $I$ is an indicator function that equals 1 when the condition is true and 0 otherwise. The GWR method uses only one value of $\theta$ (or $q$) for all observations and it is often determined by cross-validation. The optimal bandwidth, $\hat{\theta}$ is the one that minimises the following score function:

$$\sum_{i=1}^{n} [y_i - \hat{y}_{\neq i}(\theta)]^2 \tag{4}$$

where $\hat{y}_{\neq i}(\theta)$ is the fitted value of $y_i$ with observation for point *i* omitted from the calibration process (for details, see Brunsdon et al.(1999)). The solution of eq. (1) is given by:

$$\hat{\beta}_i = \left(\tilde{X}' W_i \tilde{X}\right)^{-1} \left(\tilde{X}' W_i y\right), \quad i = 1, \ldots, n. \tag{5}$$

**2.2 The neuro-coefficient smooth transition autoregressive (NCSTAR) model**

The NCSTAR model as a simple multilayer perceptron (i.e. feedforward ANN model) is composed of an input layer, a hidden layer and an output layer. Because it is feedforward, the hidden units receive only connections coming from the input-units while the output-units are connected with the hidden units and sometimes also with the input-units. In the latter case, these connections are called direct connections. The variables in the input layer are linearly combined and sent to the *h* units of the hidden layer, giving a non-linear transformation to this combination. Then, they are linearly combined and sent to the output layer. It is written as:

$$y_i = \Phi_i^{'} \tilde{x}_i + e_i, \quad i = 1, \ldots n, \tag{6}$$

where $y_i$ is the $i^{th}$ element of the dependent variable, $\tilde{x}_i^{'} = \left[1, x_i^{'}\right]$ is a $(p+1) \times 1$ vector of explanatory variables and $\Phi_i$ is a $(p+1) \times 1$ vector of real coefficients with $\Phi_i = \left[\Phi_i^{(0)}, \Phi_i^{(1)}, \ldots, \Phi_i^{(p)}\right]^{'}$. More specifically, each output of the network with *h* hidden units is given by:

$$\Phi_i^{(j)} = \sum_{k=1}^{h} \beta_{jk} F\left(w_k s_i - c_k\right) - \beta_{j0,} \tag{7}$$

for $j = 0, \ldots, p$ and $i = 1, \ldots n$ and where $\beta_{jk}$ and $\beta_{j0}$ are real coefficients. $F\left(w_k s_i - c_k\right)$ is the logistic activation function, where $s_i$ is a $(q \times 1)$ vector of transition variables, $w_k = \left[w_{1k}, \ldots w_{qk}\right]^{'}$ and $c_k$ are real parameters. As in Medeiros and Veiga (2000), it is assumed that $s$ consists of elements belonging to $x$ and also other variables; the composition of $s$ and $x$ are determined via statistical tests. However, the approach is still valid if $s$ is only composed of elements of $x$, as in Medeiros et al. (2001) or if $s = x$, as in Medeiros and Veiga (2001). The activation function is defined as:

$$F\left(w_k s_i - c_k\right) = \frac{1}{1 + \exp\left(-\left(w_k s_i - c_k\right)\right)} \tag{8}$$

Putting eq. (7) into eq. (6) and re-parameterising leads to the following equation:

$$y_i = G\left(\tilde{x}_i, \tilde{s}_i, \psi\right) = \alpha^{'} \tilde{x}_i + \sum_{k=1}^{h} \beta_k \tilde{x}_i F\left[\gamma_k \left(\tilde{\delta}_k^{'} \tilde{s}_i\right)\right] + e_i \tag{9}$$

where $G\left(\tilde{x}_i, \tilde{s}_i, \psi\right)$ is a non-linear function of the variables $\tilde{x}_i$ and $\tilde{s}_i$ with $\tilde{s}_i = \left[1, s_i^{'}\right]$ and $\psi = \left[\alpha^{'}, \beta_1^{'}, \ldots, \beta_h^{'}, w_1^{'}, \ldots, w_h^{'}, c_1, \ldots c_h\right]^{\prime}$ is a $(p+1) \times (h+1) + (q+1) \times h$ parameter vector with elements $\alpha = \left[\alpha_0, \ldots, \alpha_p\right]^{\prime} = \left[-\beta_{00}, \ldots, \beta_{p0}\right]^{\prime}$ and $\beta_k = \left[\beta_{0k}, \ldots, \beta_{pk}\right]^{\prime}$. Moreover $\gamma$ is a $(h \times 1)$ vector of slope parameters with $\gamma_k = \left\| \tilde{w}_k \right\|$ and, $\tilde{\delta}_k^{'} = \left[-\tilde{c}_k, \tilde{w}_k\right]$ with $\tilde{w}_k^{'} = \dfrac{w_k}{\gamma_k}$ and $\tilde{c}_k = \dfrac{c_k}{\gamma_k}$ for $k = 1, \ldots, h$. Equation (9) is, in principle, neither globally identified nor locally identified. Thus, restrictions have to be imposed on the parameters. Medeiros and Veiga (2000) suggest imposing in eq. (8), $c_1 < \ldots < c_h$, to solve the first reason for non-identification and $w_{1k} > 0, \ k = 1, \ldots h,$ to resolve the second one. Finally a network with only relevant hidden units will ensure its identifiability. To determine the optimal specification of the network architecture, Medeiros and Veiga (2000) developed a specific-to-general procedure based on Rech et al. (1999) to select variables and on Luukkonen et al. (1988) and Teräsvirta et al. (1994) to determine the number of hidden units. We followed this approach because it avoids over-parameterisation and it is simple to compute. The optimal vector of parameters, $\hat{\psi}$, is the one that minimises the following function:

$$\sum_{i=1}^{n}\left[y_i - G(\tilde{x}_i, \tilde{s}_i, \psi)\right] \tag{10}$$

According to Medeiros and Veiga (2000), under general conditions and when $n \to \infty, \sqrt{n}(\hat{\psi} - \psi)$ converges to a multivariate normal distribution with mean zero and a covariance matrix $C$ that can be estimated, following Davidson & MacKinnon (1993), using:

$$C = \hat{\sigma}^2\left(\hat{H}'\hat{H}\right)^{-1} \tag{11}$$

where $\hat{H}$ is the matrix which $i^{th}$ row is the first derivative of $G(\tilde{x}_i, \tilde{s}_i, \hat{\psi})$ with respect to each parameter. To solve eq. (10), the BFGS optimisation algorithm is used with a STEPBT linear search. Before training the network, the variables have to be standardised. After training, eq. (9) is rewritten as eq. (6) and the resulting $\Phi_i'$ parameters are then post-processed to compare the estimated and the real dependents. The standard deviations of the $\Phi_i'$'s are determined via the delta method (see Weisberg, 2001).

## 3. An application to the spatial diffusion of crises

### 3.1 Data and variables

Following Kaminsky et al. (1998), we built an index of speculative pressure (ISP), based on the average of changes in the nominal exchange rate and changes in international reserves:

$$ISP_t = \vartheta \Delta FX_t - \zeta \Delta RES_t \tag{12}$$

$FX$, $RES$ and $\Delta$, respectively, denote the nominal exchange rate, international reserves and the percentage of growth. The parameters $\vartheta$ and $\zeta$ are respectively defined as the inverse of the standard deviation of $\Delta FX_t$ and $\Delta RES_t$ taken monthly and over the three years before the crisis. The index rises (or resp. decreases) when the standardised rate of depreciation (resp. appreciation) and/or the standardised rate of international reserve loss increase(s) (resp. decreases). Here, we studied two years: 1971 and 1973. Speculative pressure indices were calculated at different time horizons after the "ground zero" crisis: ISP1 measuring speculative pressures one month after the ground zero crisis, ISP3 three months after, etc...For both episodes, Germany is the ground zero country, where the crisis first erupted. Regressors were divided into two groups: a trade competitiveness variable and macro-financial variables. The former is indirect trade competitiveness, which is competitiveness in third markets. The concept of a trade share index, provided by Glick and Rose (1999), was used. Large values of this index (trade-share) indicate that a country's exports compete intensively with the ones of "ground zero" in third markets. Macro-financial variables includes: the ratio of money supply to reserves (M2/res); the annual growth rate of domestic credit (dlcred); the current account as a percentage of GDP (cacc); the growth rate of real GDP (dly); the domestic inflation (dlp); the degree of undervaluation (under)[4] and the degree of openness (open)[5].

The latitudes and longitudes used correspond to those of the capitals of each country. The 1971 (resp. 1973) sample contains 51 (resp. 58) observations which are sorted from west to east. Observations from -91 to -50 belonged to America, from 0 to 25 to Europe (with Germany, the first victim for both years located at point 18 on the x axis), from 25 to 60 to Africa, from 60 to 140 to Asia, from 140 to 175 to Oceania. The [-50, 0] interval is a heteroclitic one. Details are given in Appendix A. Both variables were used to select the sub-sample on which the GWR model was conducted for each observation. However, these variables were part of the explanatory variable set in the NCSTAR model.

The regionality of crises is well illustrated in figures 1 and 2 which plot the index of speculative pressure for both episodes at different time horizons. While crises seemed to be mainly clustered in Europe during the 1971 attacks, another crisis clustered around the United States can be observed in 1973. Besides, although the magnitude of speculative pressures seemed to be lower in 1973 than in 1971, they were also more numerous. Even so, both speculative events shared a common salient feature due to the apparent heterogeneity of crises, not only between regions, but also within the most infected regions themselves. Finally, speculative pressures seemed to increase with time.

**Figure 1: 1971 ISPs at different time horizons**

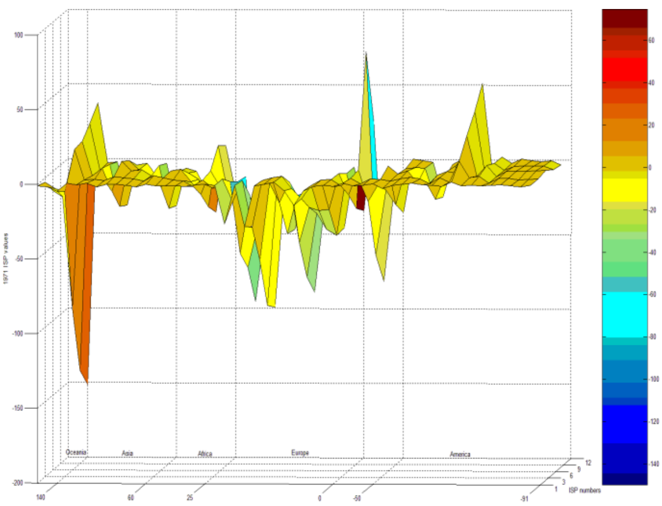
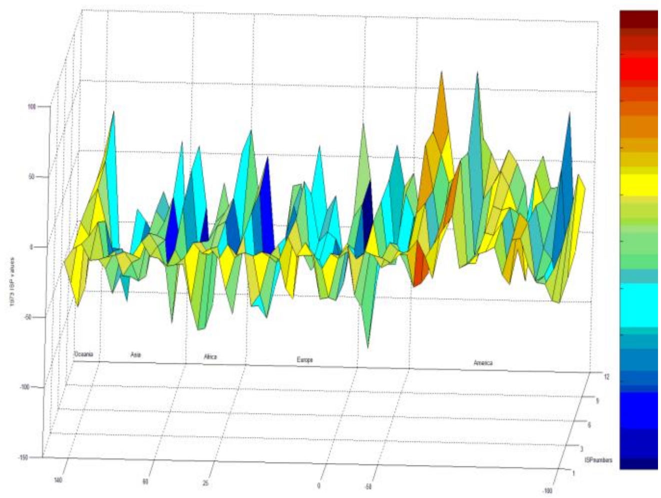



**Figure 2: 1973 ISPs at different time horizons**




### *3.2 GWR Results*

Table 1 gives the first results of the GWR model with

$\tilde{X} = [1, dlcred, M2/res, cacc, dly, dlp, under, trade-share, open]$ in eq. (1).

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[4] Defined as the percentage change in the real effective exchange rate index between the average of the three prior years and the episode year. A positive value indicates that the real exchange rate is undervalued (the case of Germany during the 1970s).

[5] All macroeconomic data are extracted from the IMF's International Financial Statistics Database. We use 1970 data for the 1971 epidode and 1972 data for the 1973 crisis.

TABLE 1. *Optimal bandwidth and GWR measure of goodness of fit*

| | *1971 ISP1* | *1971 ISP12* | *1973 ISP1* | *1973 ISP3* | *1973 ISP9* |
|---|---|---|---|---|---|
| $\hat{q}$ | 30 | 33 | 14 | 39 | 25 |
| $\bar{R}^2$ | 0.730 | 0.678 | 0.912 | 0.476 | 0.620 |

The results for 1973 appeared at first sight to be better than the ones for 1971. However, the greatest (resp. lowest) value of the adjusted correlation coefficient was simply the consequence of the lowest (resp. greatest) value of the optimal bandwidth (i.e. the optimal single number of observations that the GWR takes into account for the estimation of every $\beta_i$) and it accompanied more (resp. less) volatile parameter estimates. Since the GWR approach produces a set of parameter estimates for each observation in the sample and these parameters are functions of each country's nearest neighbours in terms of geographical distance, the figures related to the GWR model show the estimated values of the parameters for each country. To get a general idea of the temporal evolution of parameters, 3-D graphs are provided in appendices in figures 3 and 4 for the 1971 and 1973 turbulences, respectively.

The magnitude of coefficients varied across time and countries. Larger fluctuations in parameter values were observed in Europe and North America, where intra-regional differences were also apparent. The signs of regressors generally conformed to the expected ones for the 1971 episode[6] dlcred (+), M2/res (+), cacc (-), dly (-), dlp (-), under (-), Trade-share (-); but not for the 1973 crisis. Regardless the value of the estimated parameters, these geographical results show that the global ordinary least squares (OLS) approach conceals differences between countries.

The visually detected heterogeneity of parameters must be confirmed or invalidated by statistical tests. Leung et al. (2000a) propose a test statistic for the goodness of fit of the GWR model. It compares OLS and the GWR models. In the OLS regression, the estimated dependent can be written as $\hat{y} = Sy$ with $S = \tilde{X}\left(\tilde{X}'\tilde{X}\right)^{-1}\tilde{X}'$ as the hat matrix and in the GWR model, the $i^{th}$ raw value of $S$ takes the form $S = \tilde{X}\left(\tilde{X}'W_i\tilde{X}\right)^{-1}\tilde{X}'W_i$. The corresponding p-values are listed in Table 2.

TABLE 2. *The p-values of the Leung et al.'s goodness of fit test for the GWR model*

| | *1971 ISP1* | *1971 ISP12* | *1973 ISP1* | *1973 ISP3* | *1973 ISP9* |
|---|---|---|---|---|---|
| p-value | 0.252 | 0.044** | 0.149 | 0.318 | 0.206 |

Notes: *, **, *** denote significant at 10%, 5% and 1%, respectively.

According to these results, a global linear model fits the data better than the local one. However, the above statistic is global and can hide local variation of estimated parameters. To gain insight into the above results,

[6] Keeping in mind that crises during the 1970's lead to the appreciation of many currencies instead of their depreciation.

the p-values of the Leung et al. (2000a) test for spatial variability in the parameter estimates are given in Table 3. The null hypothesis of no significant spatial variation in the parameter estimates is rejected for the coefficients of several variables. For different time horizons, among our eight variables, six were spatially non-stationary.

TABLE 3. *The p-values of the Leung et al.'s variability test for each GWR estimate*

| | *dlcred* | *M2:res* | *cacc* | *dly* | *dlp* | *under* | *trade-share* | *open* |
|---|---|---|---|---|---|---|---|---|
| 1971 ISP1 | 0.836 | 0.000*** | 0.477 | 0.797 | 0.203 | 0.208 | 0.04** | 0.721 |
| 1971 ISP12 | 0.604 | 0.000*** | 0.193 | 0.455 | 0.013** | 0.018** | 0.147 | 0.464 |
| 1973 ISP1 | 0.786 | 0.284 | 0.471 | 0.521 | 0.201 | 0.190 | 0.170 | 0.431 |
| 1973 ISP3 | 0.729 | 0.334 | 0.088* | 0.04** | 0.156 | 0.159 | 0.08* | 0.661 |
| 1973 ISP9 | 0.800 | 0.234 | 0.23 | 0.06* | 0.447 | 0.396 | 0.091* | 0.200 |

Finally, the Leung et al. (2000b) test for spatial autocorrelation among the GWR residuals was conducted because the hypothesis of constant variance of the GWR residuals may not be met in presence of spatial autocorrelation (Table 4).

TABLE 4. *The p-values of the Leung et al.'s autocorrelation test for the GWR residuals*

| | *1971 ISP1* | *1971 ISP12* | *1973 ISP1* | *1973 ISP3* | *1973 ISP9* |
|---|---|---|---|---|---|
| p-value | 0.207 | 0.429 | 0.786 | 0.942 | 0.517 |

The p-values of this test mean that the null hypothesis of no autocorrelation among the GWR residuals cannot be rejected at the 0.05 significance level. To summarise, we showed that the relationship between speculative intensity and its determinants was generally stationary over space. As a consequence, apparent clustering is the result of similar economic fundamentals and disequilibria, whereas the heterogeneous pattern of crisis within Europe indicates that some differences in fundamentals persist. Even so, the individual non-stationarity of some variables confirms our assertion. The visual inspection of some determinants show that intra-regional differences persist. So, it is tempting to claim that geography plays a non-trivial role and that a non-linear local model is worth investigating.

### *3.3 The NCSTAR results*

The architecture of the network[7] including the inputs denoted $\tilde{x}$ , the transition variables noted $\tilde{s}$ , the vector of estimated parameter and the associated goodness-of-fit measure of eq. (9) are presented in Table 5 for 1971 ISP and in Table 6 for 1973 ISP. Moreover, when the network indicated non-linearity in the data, a single hidden unit was sufficient to capture it. Otherwise, a network could not be constructed and a linear model was more appropriate (as for 1971 ISP3, 6 and 9).

TABLE 5. *NCSTAR results for 1971*

| **ISP1: $R^2$=0.944, h=1** |
|---|
| $\tilde{x}$ = [1, under, trade-share] |
| $\tilde{s}$ = [1, trade-share, dlcred, M2/res, cacc, dly, dlp, open, east, north] |
| $\hat{\alpha}$ = [0.24, 0.014, -0.032], $\hat{\beta}$ = [-0.009, -2.066, -1.528] |
| $\hat{\gamma}\hat{\delta}$ = [-45.3 ,36.7,4.8,-51.7,27 .9,-4.9,-2.8,22.9,10.6,-6.6] |
| **ISP12: $R^2$ = 0.7055, h = 1** |
| $\tilde{x}$ = [1, M2/res, cacc, dly, dlp, trade-share] |
| $\tilde{s}$ = [1, dlp, dlcred, under, open, east, north] |
| $\hat{\alpha}$ = [0.35, 0.16, -0 .17, 0.32, 0.26, -0.49], $\hat{\beta}$ = [-2.76, -2.69, -0.22, -0.34, 0.02, -1:03] |
| $\hat{\gamma}\hat{\delta}$ = [-7.4, 5.9, 0.4, 0.09, 4.63, 7.68, 1.67] |

TABLE 6. *NCSTAR results for 1973*

| **ISP1: $R^2$=0.51, h=1** |
|---|
| $\tilde{x}$ = [1, dlcred, cacc] |
| $\tilde{s}$ = [1, dlcred, M2/res, dly, dlp, under, trade-share,open, east, north] |
| $\hat{\alpha}$ = [-0.24, -0.004, 0.07], $\hat{\beta}$ = [1.22, 1.44, -1.12] |
| $\hat{\gamma}\hat{\delta}$ = [-136.2,-41.6,349.5,-11.3,-46.9,-258.2,34.5,-49,-26.8,-112.1] |
| **ISP3: $R^2$=0.59, h=1** |
| $\tilde{x}$ = [1, dlcred, cacc, trade-share] |
| $\tilde{s}$ = [1, dlcred, M2/res, dly, dlp, under, open, east, north] |
| $\hat{\alpha}$ = [-0.25, 0.73, 0.18, 0.03], $\hat{\beta}$ = [0.81, -0.22, 0.19, -1.66] |
| $\hat{\gamma}\hat{\delta}$ = [-29.3, 47.1, 77.7, -13.1, 79.3, -102.2, 67.5, -24.6, 7.2] |
| **ISP9: $R^2$=0.55, h=1** |
| $\tilde{x}$ = [1, dlcred, cacc, trade-share] |
| $\tilde{s}$ = [1, dlcred, M2/res, dly, dlp, under, open, east, north] |
| $\hat{\alpha}$ = [ -0.25, 0.62, -0.36, -0.04], $\hat{\beta}$ = [ 0.58,-0.13, 0.69,-1:14] |
| $\hat{\gamma}\hat{\delta}$ = [ -72.2, -20.4, 51.5, -42.4, 113.7, -4, 194.9, -193, -10.2] |

[7] The source code has been written in GAUSS by Marie Lebreton.

For the 1971 episode, the trade-share and undervaluation variables were selected as inputs. Their estimated coefficients can be seen in figures 5 and 6 provided in appendices. They were related to the trade-share, dlcred, M2/res, cacc, dly, dlp, open, east and north variables in a non-linear way via the logistic function defined in eq. (8). In other words, in this case, trade-share and real undervaluation were the most important determinants of crises. This was especially true for the trade variable. Accordingly, this variable plays directly on speculative pressure as the selected input variable and it also indirectly governs the role of undervaluation on speculative pressure. In fact, the role of inputs was clearly influenced by a combination of transition variables, which can be seen as catalytic variables, such as geographical position, etc...

As shown in figure 5, the pattern of heterogeneity is geographically very constrained to the European region. In a more acute manner than for the GWR model, heterogeneity in the NCSTAR model seemed to be restricted to Europe one month after the beginning of the crisis. Everywhere, undervaluation and trade competitiveness played negatively on speculative pressure, but the magnitude is higher for european countries. At one year after the beginning of the crisis (ISP12), figure 6 indicates that speculation was not driven by the same determinants. Parameters showed a shift in regime on all continents. The network was denser, suggesting an increasing complexity of speculation across time. It is linearly determined by the M2-to-reserves ratio, current account, inflation and competitiveness and non-linearly by credit growth rate, undervaluation, openness and geographical position. In regard to the 1973 estimates in figures 7, 8 and 9, results are different from 1971 in terms of inputs and transition variables, stressing the transformation of crises.

## 4. Final section

While the bulk of the literature on currency crises assumes the effects of various determinants to be spatially stationary, this paper provides some empirical evidence on the role of geography in propagating crises across countries. Due to the localised set of estimates, spatial approaches may help to define appropriate thresholds for policy interventions in each country of the dataset. In particular, the GWR framework suggests that some economic fundamentals of neighbouring countries could be used in a country's currency monitoring system. However, considering geography through the GWR approach makes the assumption that the process generating data is constant over time. In doing so, we neglected the "virtual space" (Tjahjawandital et al. (2009)) drawn by institutions, governance, trade agreements, political and technological evolutions, etc. Allowing more flexible interactions between space and speculative attacks, the NCSTAR shows that some catalytic variables may make a priori non unsustainable imbalances to trigger a crisis. Therefore, building complex warning systems with double-stage signalling can be expected to be useful. Nevertheless, because outcomes from neural networks do not have a readily interpretable meaning, our work only indicates that a flexible model combining geographical and socio-economical space, might be useful for predicting the location of future victims of international crises. Along these lines, building on the work of Steyer (2005) on diffusion in the form of spatial avalanches of social interaction, a speculation model could be developed to build warning systems of contagion.

# Appendices

**Appendix A: Countries sorted from west to east. Additional countries included in the 1973 model are shown in in lower case.**

| COUNTRIES | COORDINATES | COUNTRIES | COORDINATES |
|---|---|---|---|
| Mexico | -99.14 | SWITZERLAND | 7.44 |
| GUATEMALA | -90.55 | NORWAY | 10.75 |
| EL SALVADOR | -89.19 | ITALY | 12.5 |
| HONDURAS | -87.22 | DENMARK | 12.57 |
| Costa Rica | -84.08 | MALTA | 14.52 |
| PANAMA | -79.53 | AUSTRIA | 16.37 |
| ECUADOR | -78.5 | SWEDEN | 18.07 |
| PERU | -77.05 | GERMANY | 18.38 |
| U.S.A | -77.02 | GREECE | 23.73 |
| Canada | -75.71 | FINLAND | 24.94 |
| COLOMBIA | -74.09 | SOUTH AFRICA | 28.22 |
| HAITI | -72.34 | CYPRUS | 33.38 |
| Chile | -70.64 | ISRAEL | 35.22 |
| DOMINICAN REP | -69.91 | Jordan | 35.22 |
| Venezuela | -66.93 | ETHIOPIA | 38.74 |
| BOLIVIA | -65.26 | MADAGASCAR | 47.51 |
| TRINIDAD | -61.51 | MAURITIUS | 57.51 |
| GUYANA | -58.16 | PAKISTAN | 73.06 |
| PARAGUAY | -57.63 | INDIA | 77.22 |
| URUGUAY | -56.17 | SRI LANKA | 79.85 |
| Sierra Leone | -13.24 | THAILAND | 100.5 |
| MOROCCO | -6.84 | Malaysia | 101.71 |
| IRELAND | -6.25 | SINGAPORE | 103.85 |
| SPAIN | -3.71 | INDONESIA | 106.83 |
| GHANA | -0.2 | PHILIPPINES | 120.97 |
| U.K | -0.1 | KOREA | 126.99 |
| FRANCE | 2.34 | JAPAN | 139.77 |
| BELGIUM | 4.33 | AUSTRALIA | 149.13 |
| NETHERLAND | 4.89 | NEW ZEALAND | 174.78 |

### Figure 3 a-h GWR parameter estimate values for the 1971 speculativre episode

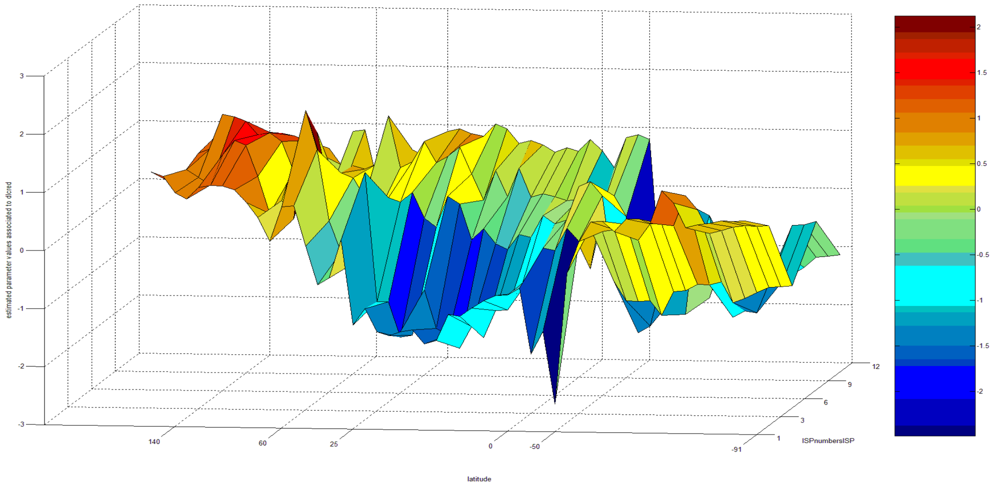



Figure 3(a) GWR parameter estimate values for dlcred in 1971

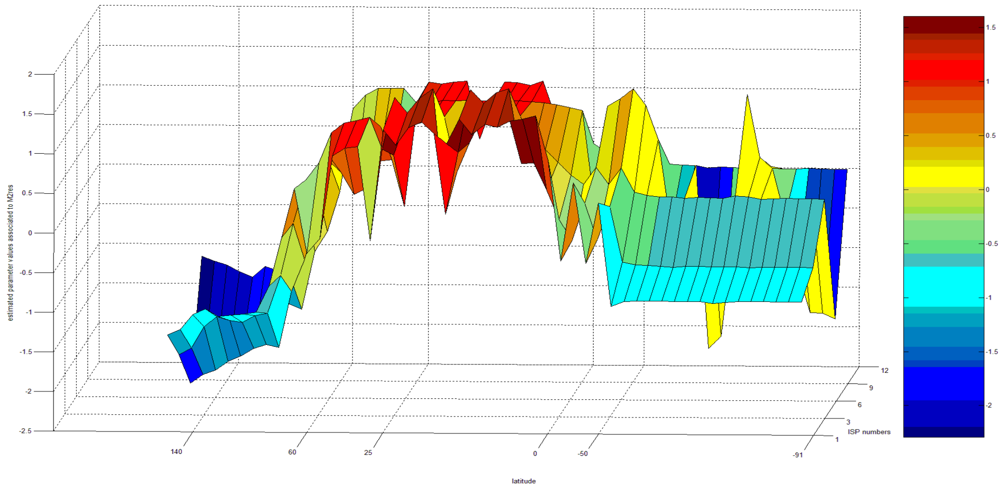



Figure 3(b) GWR parameter estimate values for M2res in 1971

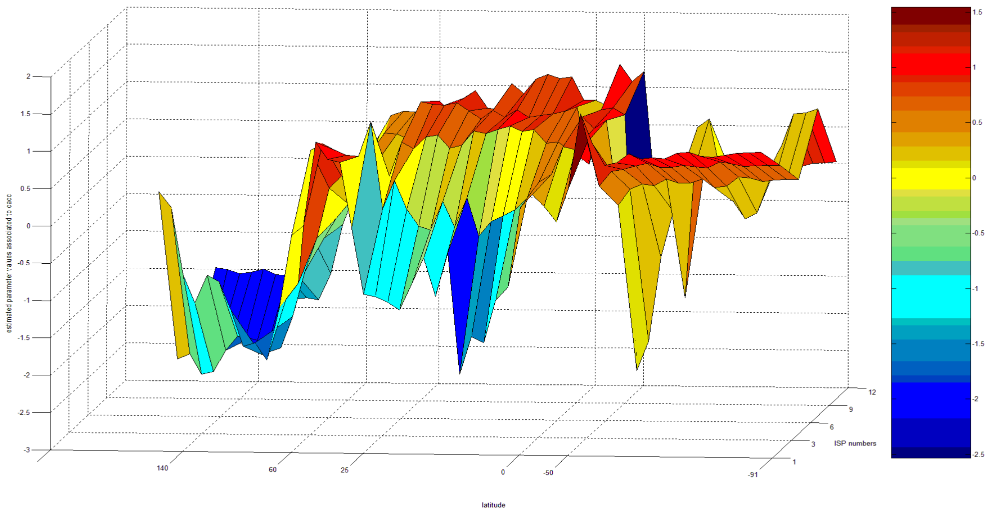



Figure 3(c) GWR parameter estimate values for cacc in 1971

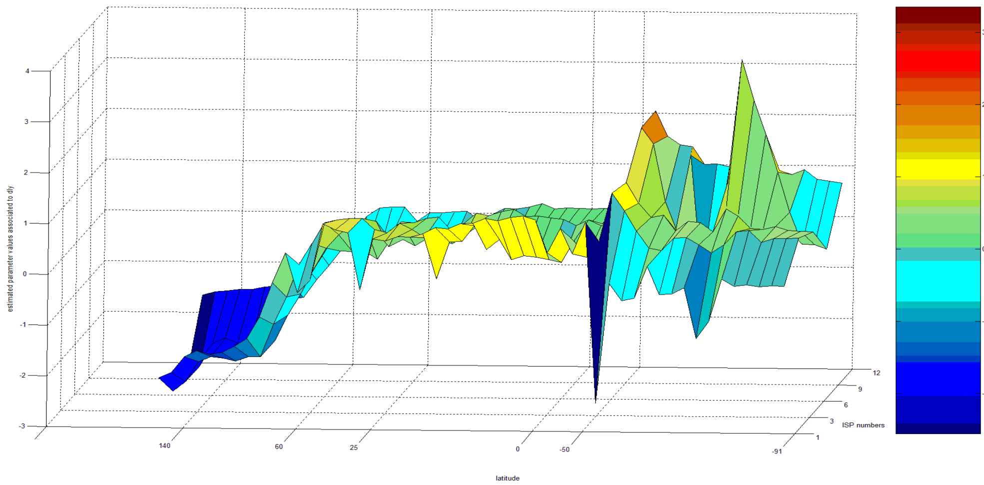



**Figure 3(d) GWR parameter estimate values for dly in 1971**

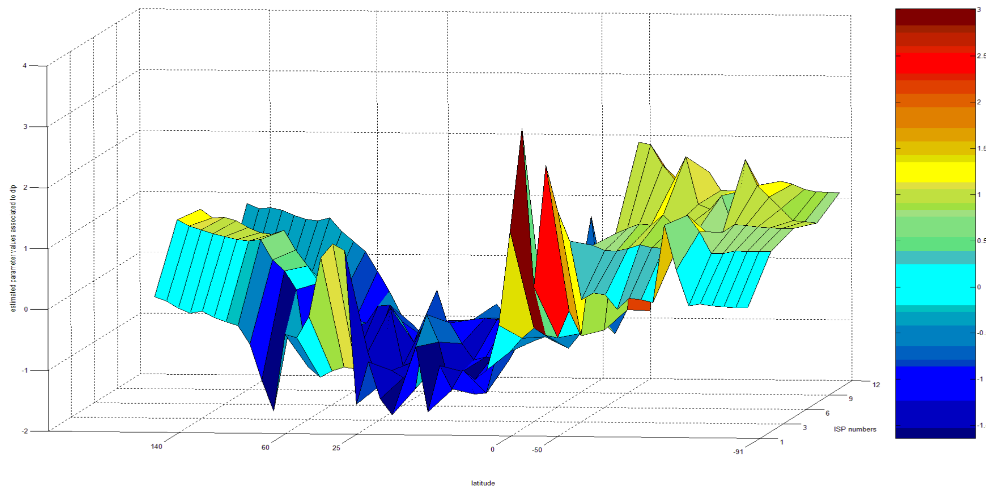



**Figure 3(e) GWR parameter estimate values for dlp in 1971**

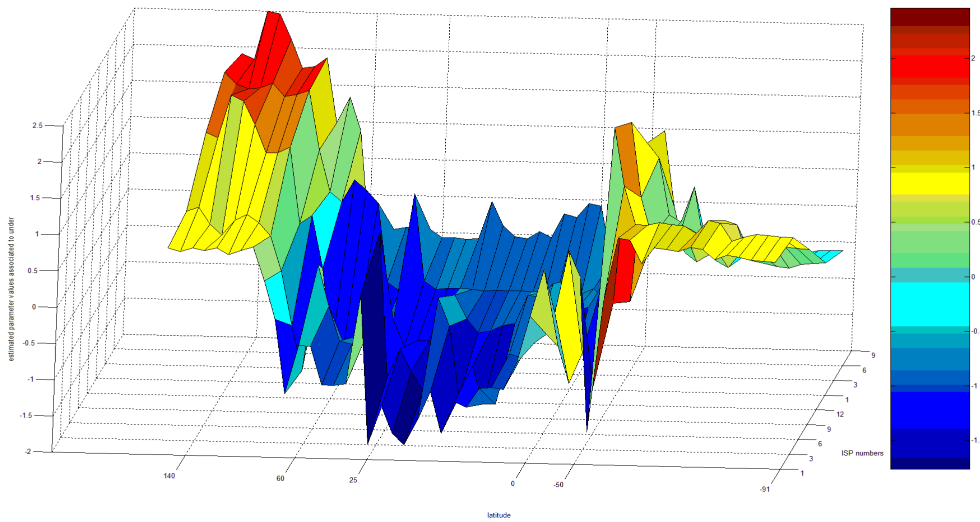



**Figure 3(f) GWR parameter estimate values for under in 1971**

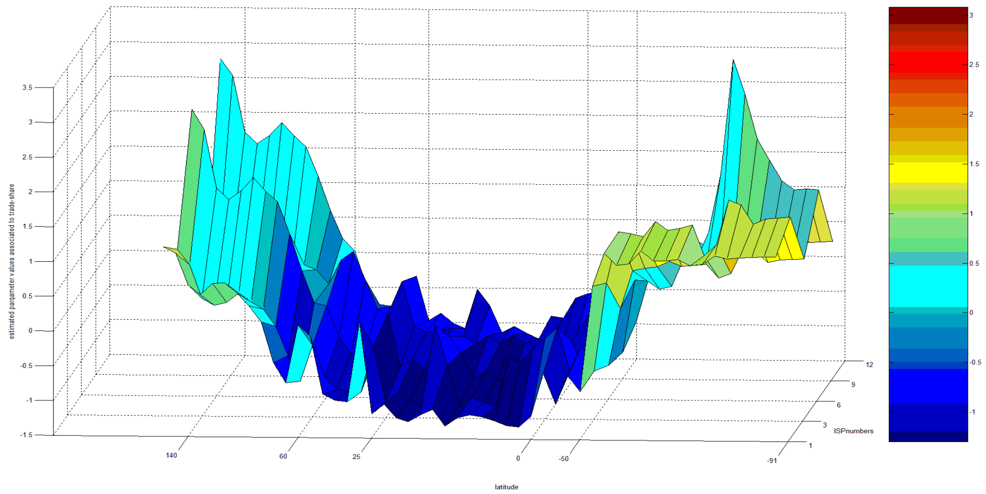



**Figure 3(g) GWR parameter estimate values for trade-share in 1971**

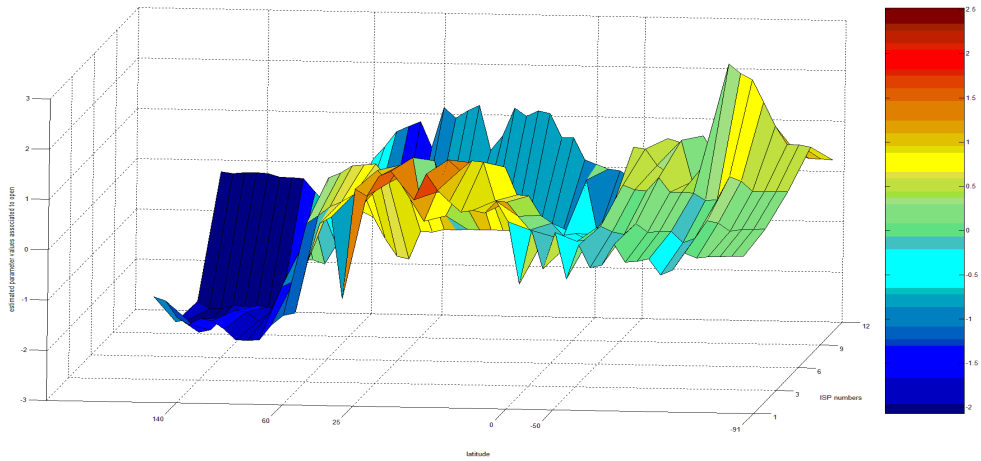



**Figure 3(h) GWR parameter estimate values for open in 1971**

**Figure 4 a-h GWR parameter estimate values for the 1973 speculative episode**

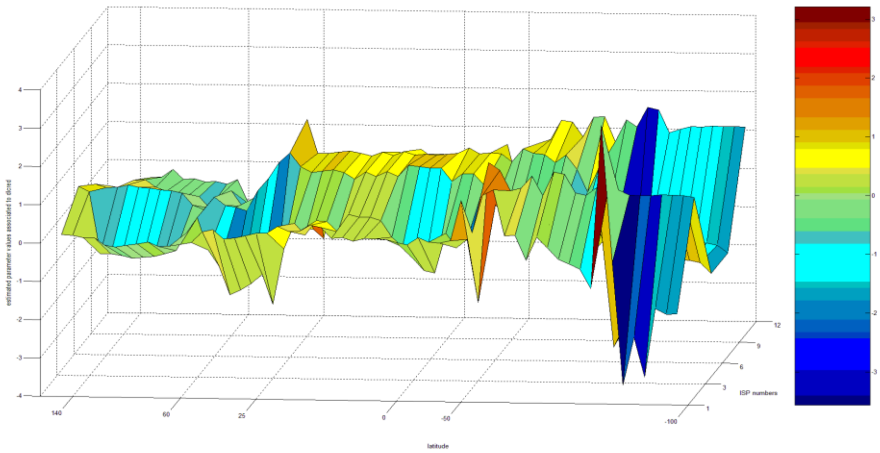


Figure 4(a) GWR parameter estimate values for dlcred in 1973

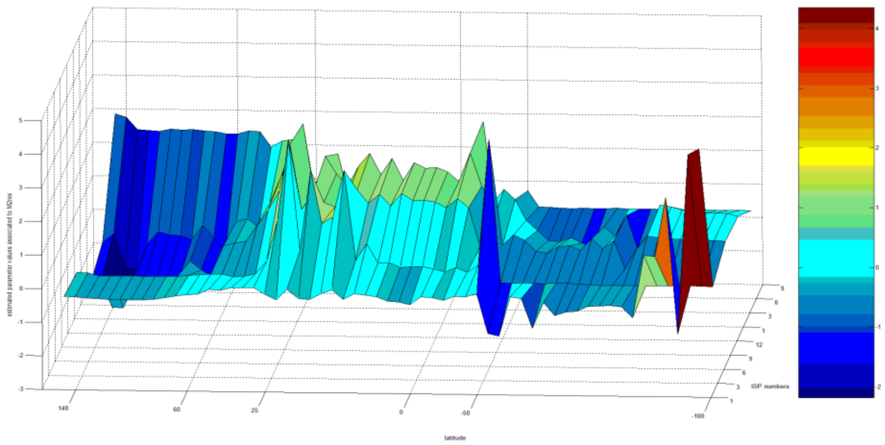


Figure 4(b) GWR parameter estimate values for M2res in 1973

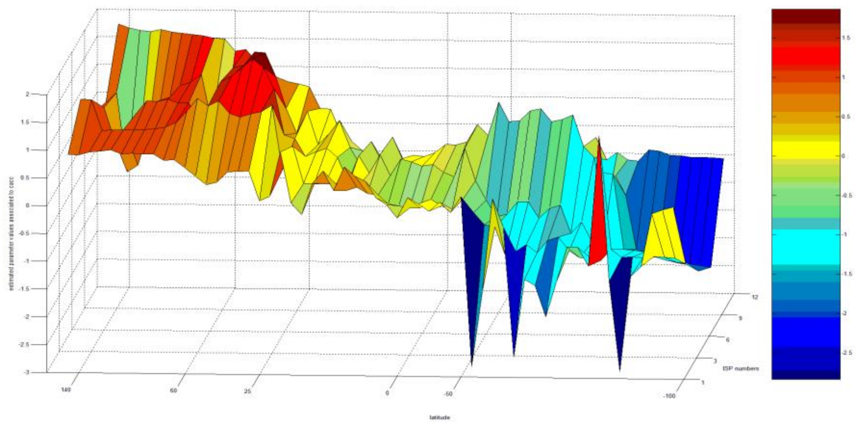


Figure 4(c) GWR parameter estimate values for cacc in 1973

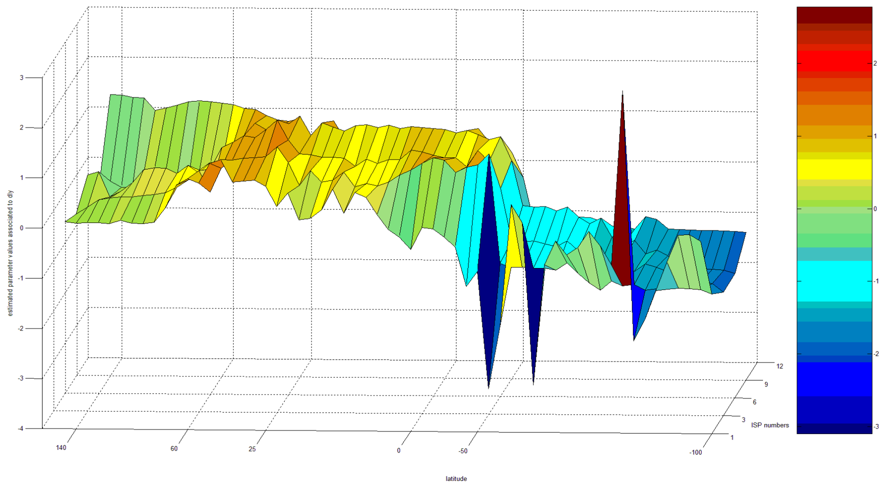



**Figure 4(d) GWR parameter estimate values for dly in 1973**

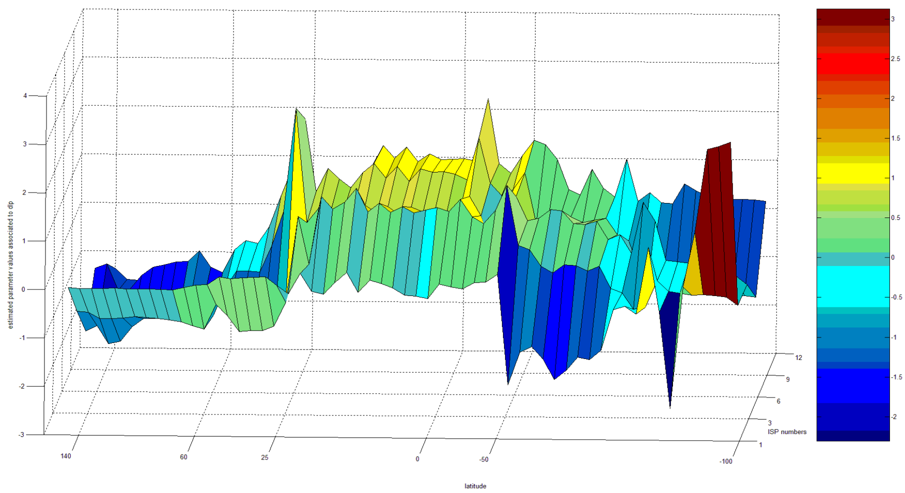



**Figure 4(e) GWR parameter estimate values for dlp in 1973**

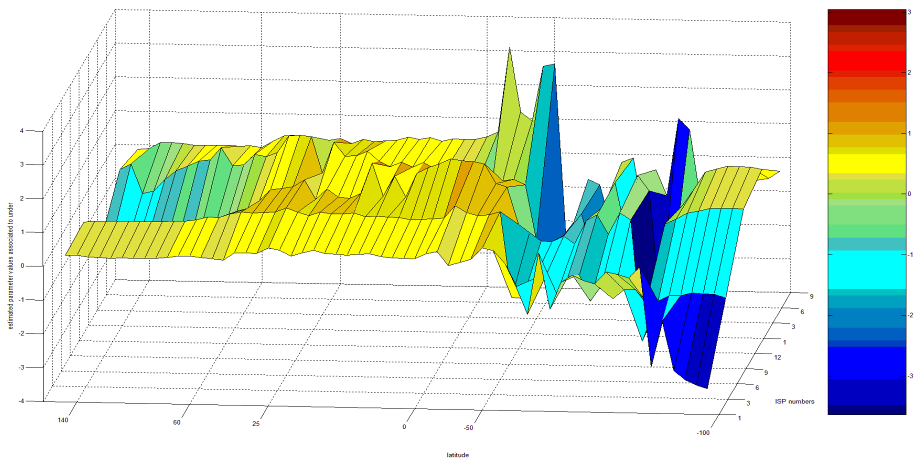



**Figure 4(f) GWR parameter estimate values for under in 1973**

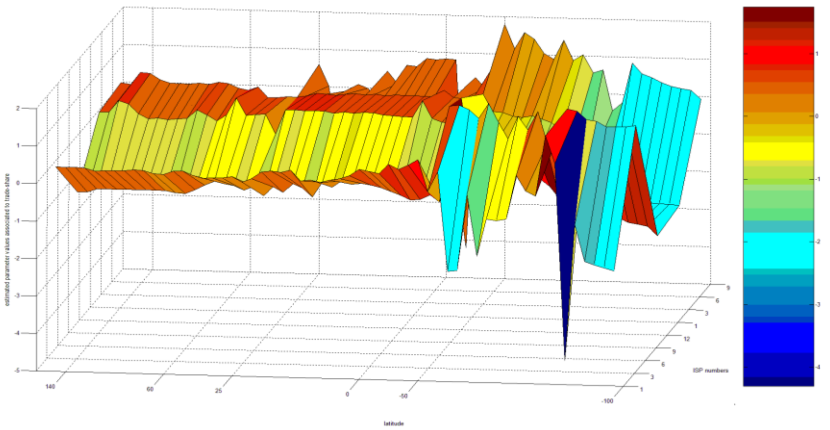


Figure 4(g) GWR parameter estimate values for trade-share in 1973

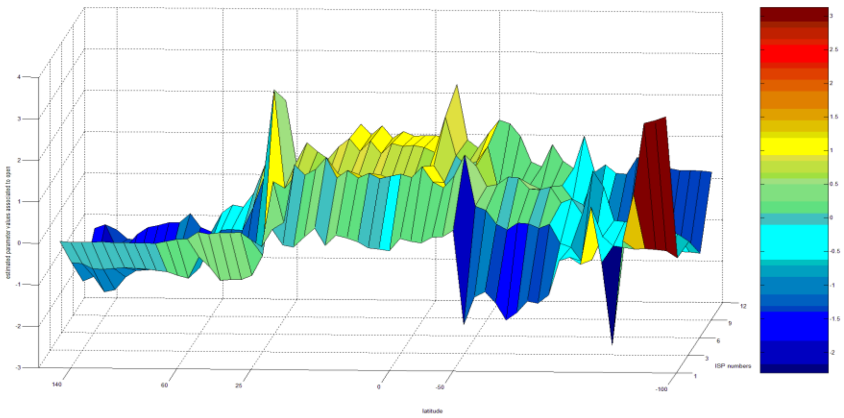


Figure 4(h) GWR parameter estimate values for open in 1973

Figure 5: NCSTAR impacts of trade-share and under on 1971 ISP1

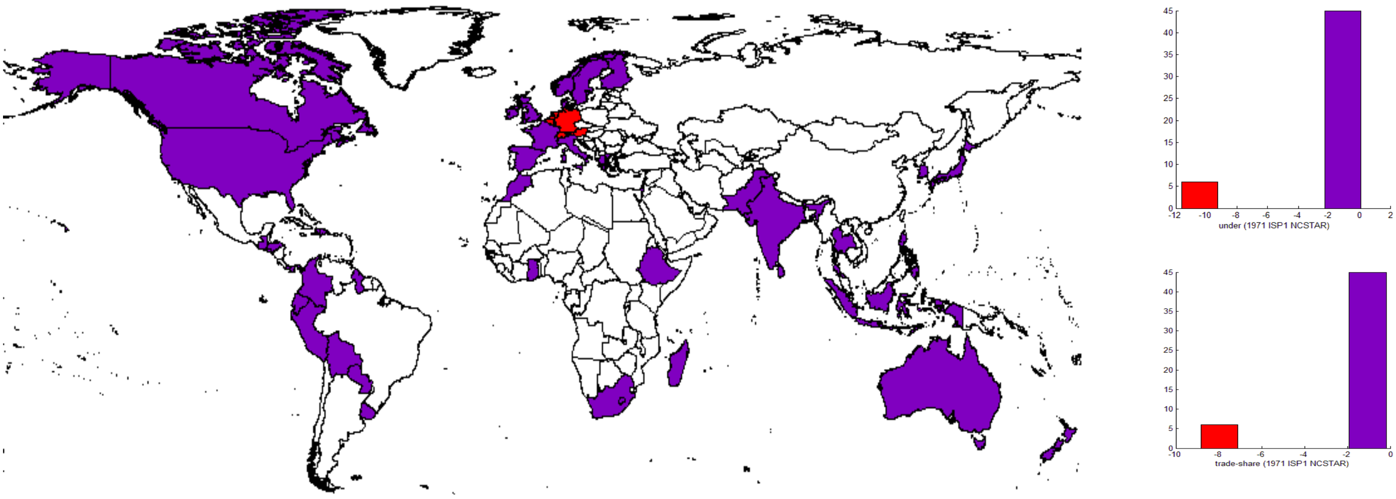
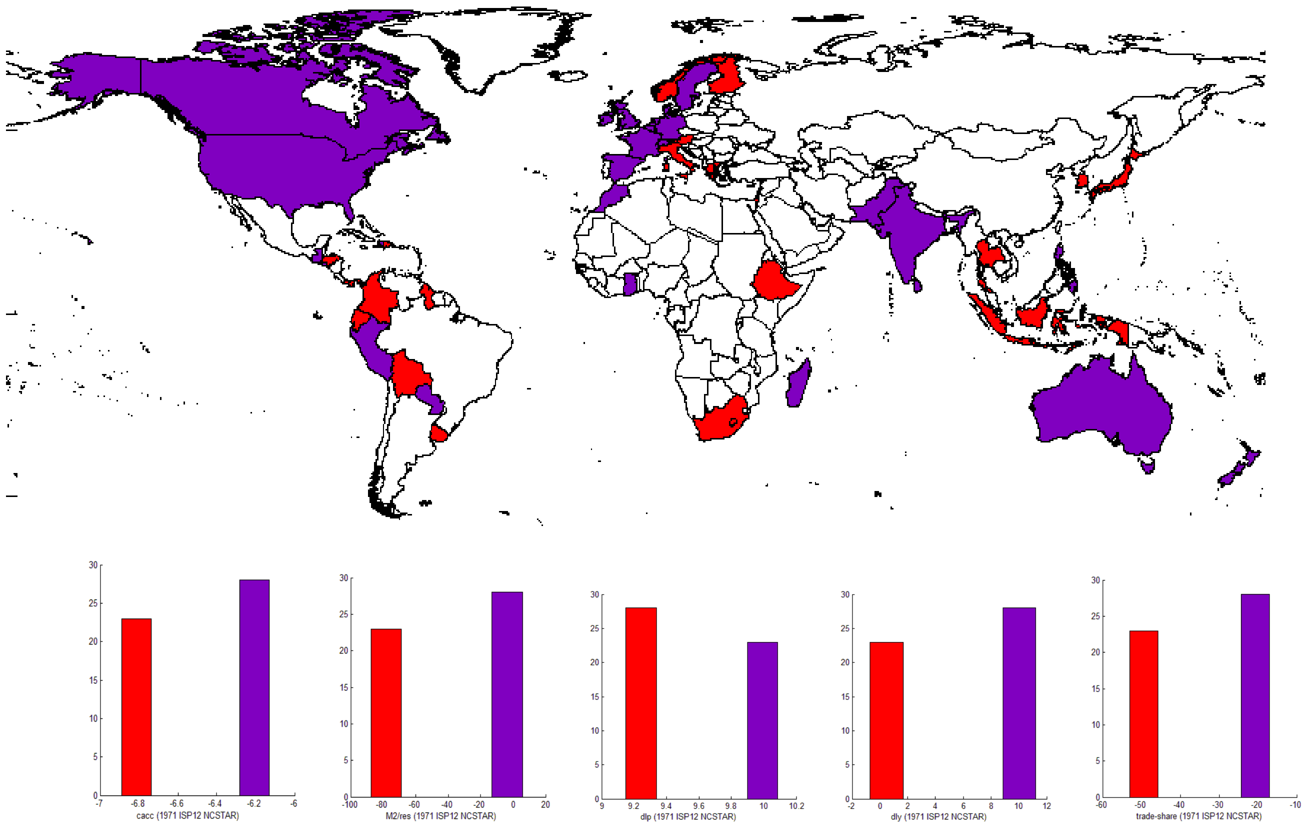



Figure 6: NCSTAR impacts of cacc, M2/res, dlp, dly and trade-share on 1971 ISP12



## Figures 7 a-b NCSTAR impacts of cacc and dlcred on 1973 ISP1

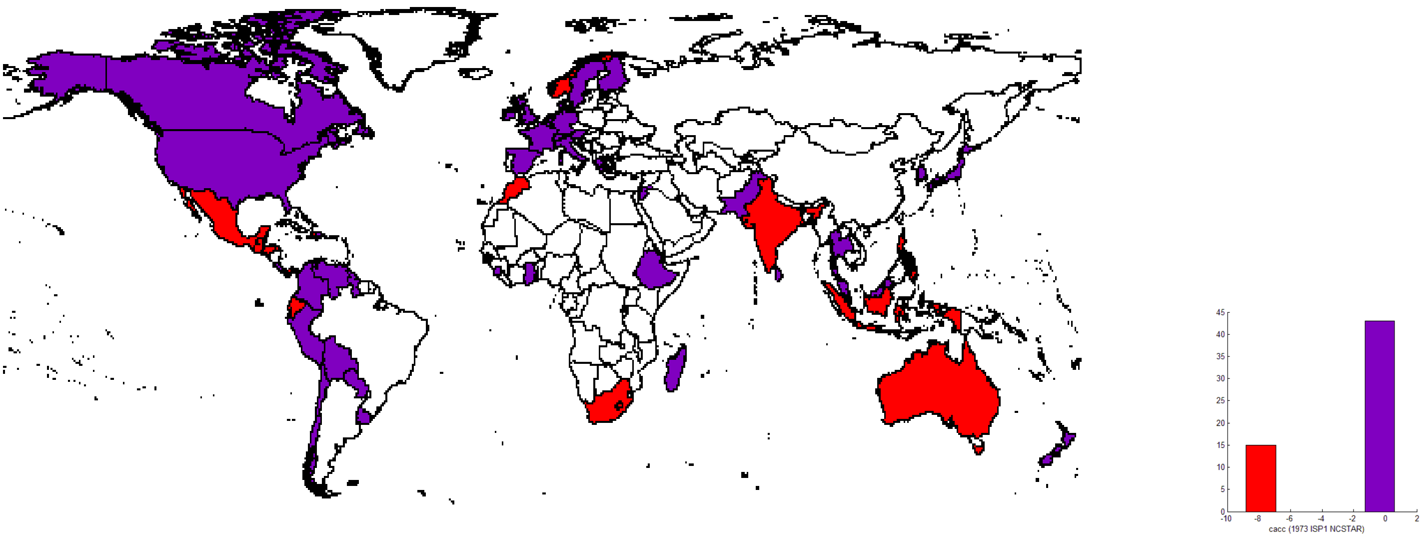



Figure 7(a) NCSTAR impacts of cacc on 1973 ISP1

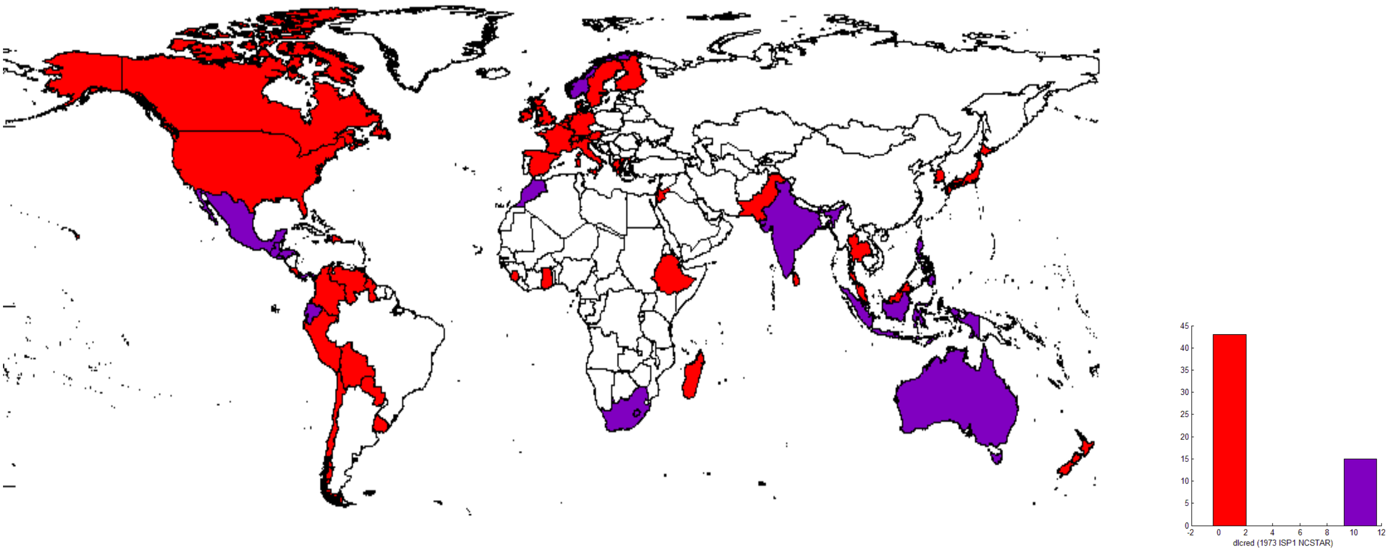
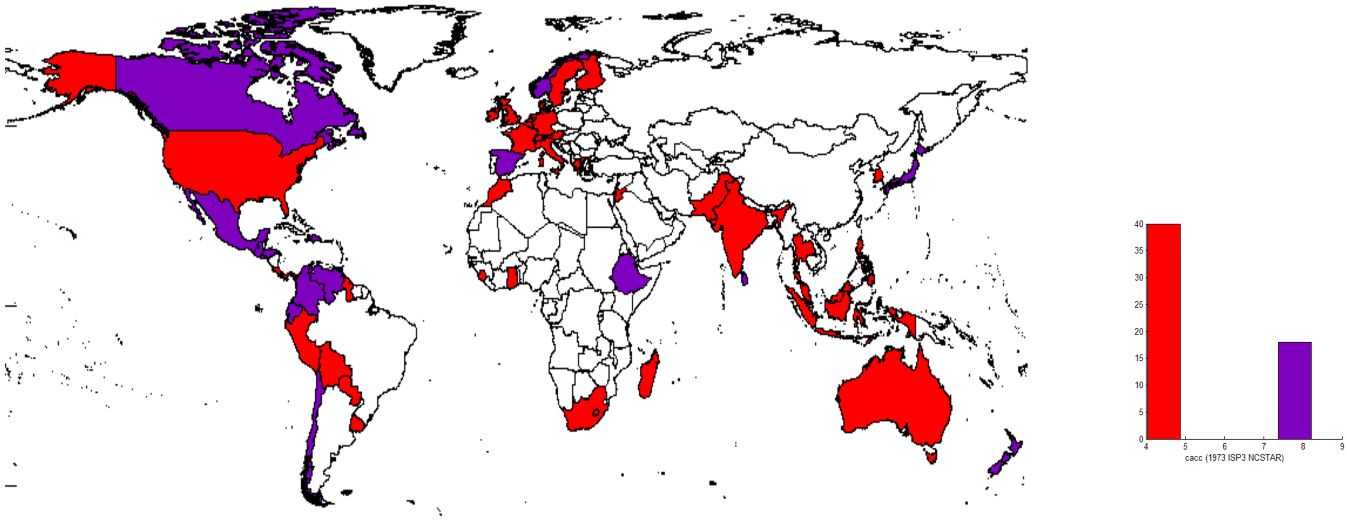



Figure 7(b) NCSTAR impacts of dlcred on 1973 ISP1

**Figures 8 (a-b) NCSTAR impacts of cacc, dlcred and trade-share on 1973 ISP3**




**Figures 8(a) NCSTAR impacts of cacc on 1973 ISP3**

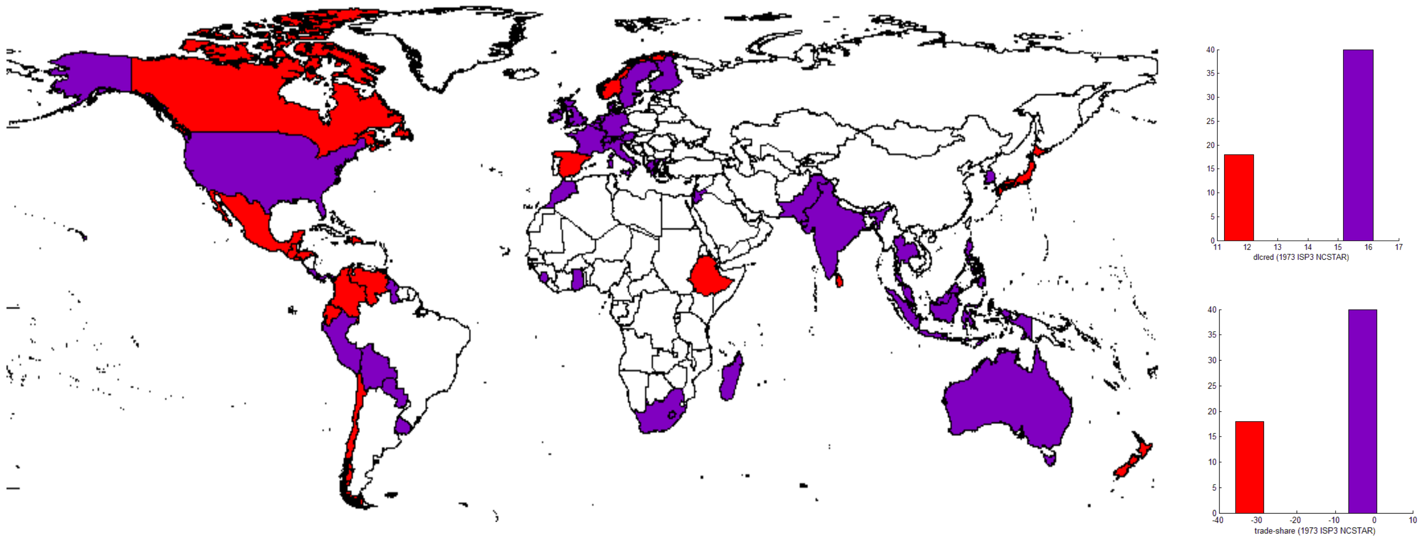



**Figure 8(b) NCSTAR impacts of dlcred and trade-share on 1973 ISP3**

## Figures 9 (a-c) NCSTAR impacts of dlcred, cacc and trade-share on 1973 ISP9

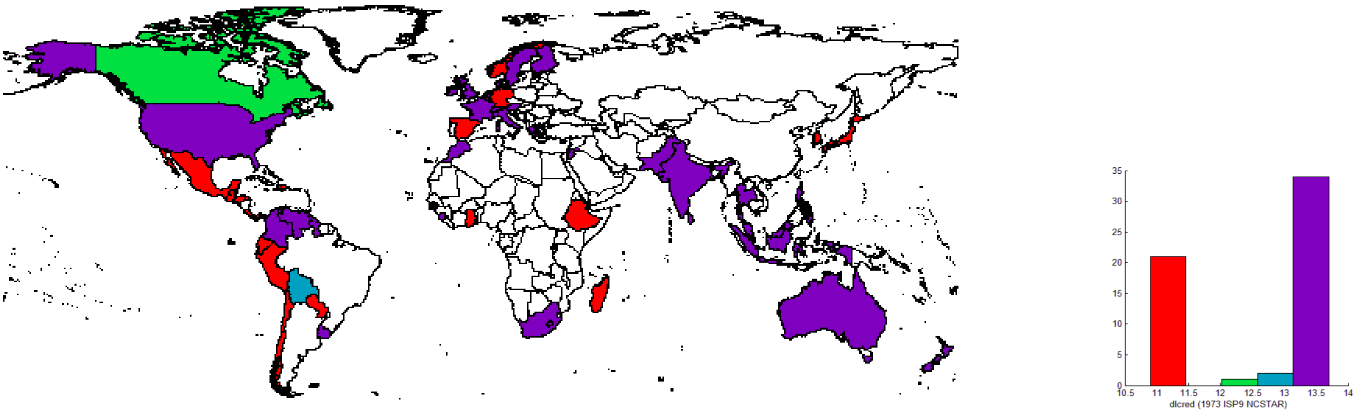



Figure 9(a) NCSTAR impacts of dlcred on 1973 ISP9

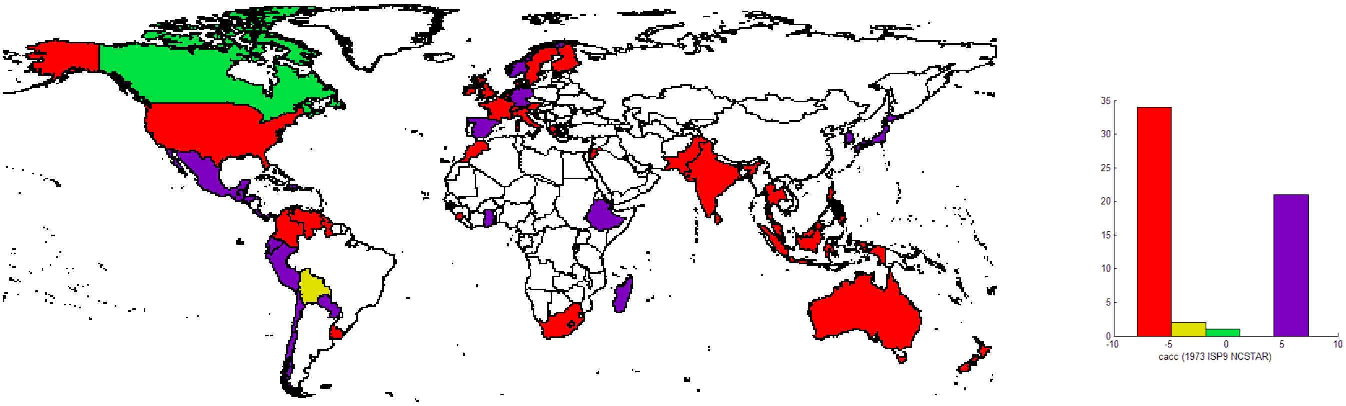



Figure 9(b) NCSTAR impacts of cacc on 1973 ISP9

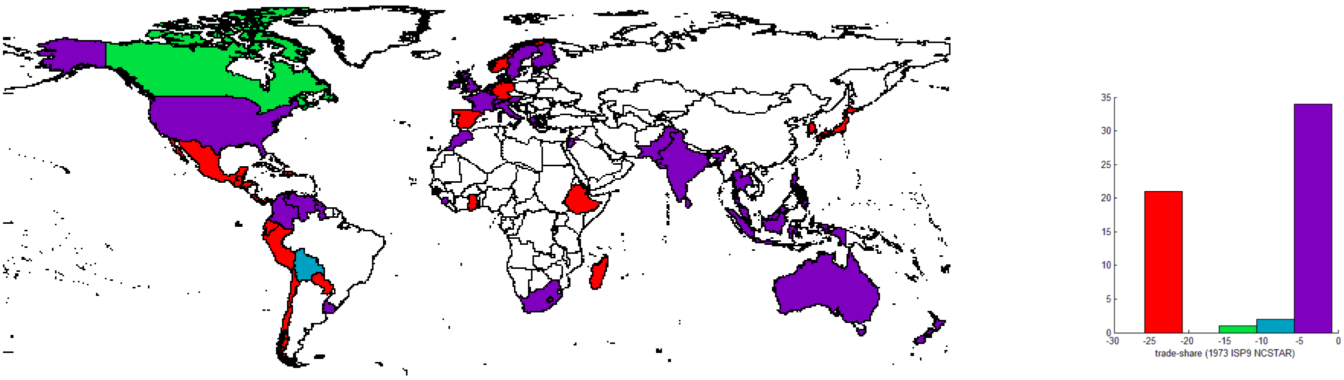



Figure 9(c) NCSTAR impacts of trade-share on 1973 ISP9

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