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Impact of climate-related disasters on human migration in Mexico: a spatial model

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Abstract The great human-environmental diversity of Mexico provides a framework for an initial understanding of the wide disparities between rich and poor. Mexico is still dominated in many regions by agriculture, and during the last 25 years, weather-related disasters have accounted for about 80% of economic losses. This is dramatic, especially considering that this sector produces only ca. 4% of GDP while providing a livelihood to one-quarter of the country's population. Based on a spatial model, this paper tests the contribution of natural disasters to catalyzing the emigration process in vulnerable regions throughout Mexico. Besides coping and adaptive capacity, we assess the effect of economic losses from disasters in combination with adverse production and trade conditions during the 1990s in triggering out-migration.

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1 Introduction

Migration patterns of plants and animals have been changing and adapting around the world with changes in climate conditions (Gordo et al. 2005[1]; Pitelka 1997[2]). In the recent history of the earth, the sensitivity of human societies to climate variations has been less than that of other species, which can mainly be explained by the widespread adoption of sedentary means of production. However, the increased occurrence and severity of natural hazards seems to be altering human migratory patterns again. Most attention paid to the impact of climate events on human migratory patterns has centered on geological-anthropological registers, e.g. Pleistocene out-migration from Africa; see McNabb (2005),[3] and post-glaciation out-migration; see Allen et al. (1999). Less attention has been placed, however, on analyzing the impact of climate and weather events on recent human migratory flows.[4] Through an migration model, we test the hypothesis that recurrent natural disasters, mostly climate-related, together with decreasing income and lack of access to credit, are stimulating out-migration in Mexico. In addition, we show that migration is not a question of poverty itself, but rather of a combination of factors that, in turn, likely serve to alter income expectations. As the incidence of recurrent disasters and absence of credit reduce the current incomes of economic agents as well as their estimates of returns of future income, they have more incentives to leave their communities. Migration is here thought of as an economic phenomenon implemented by an economic unit to respond to harmful events; in other words, a coping strategy.

1.1 Vulnerability to natural hazards: definition of terms

The present paper is based on the Turner et al. (2003) approach to vulnerability, in which vulnerability is conceived of as a coupled human–environment systems interaction associated with a likelihood of experiencing harm due to exposure to hazards. Turner et al. (2003) define hazards as threats to the system which act by means of perturbations and stressors. A perturbation is a major alteration in the

[1] Gordo et al. (2005) provide evidence that the spring arrival of long-distance migrating trans-Saharan birds is more likely to be influenced by climate conditions in wintering areas, given their direct impact on the onset of migration and its progression.

[2] Pitelka (1997) provides pre-historic and contemporary evidence on plant migration. He emphasizes the contribution of human activities through habitat fragmentation on interference with plant migration to adapt to global climatic change.

[3] Based on an archaeological study of *hominin* colonization associated with the Early-Middle Pleistocene transition, McNabb (2005) points out that climate change and especially shifts in local aridity are explanatory factors of migratory moves out of Africa. However, he concludes, the Achealean behavioral repertoire did not change much across Africa and Europe over a million years, but merely adapted to local conditions.

[4] Among the scant research on this relationship, McLemann (2006) examines the influence of natural environment on human migration and settlement patterns of rural population. He analyzes households' response in a period of adverse climate conditions in rural eastern Oklahoma during the 1930s. The focus was on those who adapted by migrating to rural California.

system, of external origin, generating effects in excess of what the system can cope with; stress is a continuous increasing pressure upon the system. The model presented in this paper focuses on perturbations in the form of natural hazards. It is based on Kates (1971), who conceives of natural hazards as interactions between man and nature, ruled by a mutual state of adjustment between them—stable and self-regulating in the short term, adaptive and evolutionary in the long term. In this approach, natural hazards mainly include floods, storms, hurricanes, drought and frost. In addition, this model represents stressors by factors which include decreasing producer prices and poor production infrastructure.

An important component in vulnerability assessment is coping and adapting capacity in response to hazards. Kelly and Adger (2000) define coping capacity as the ability of a unit to respond to an occurrence of harm or to avoid its potential incidence, while adaptive capacity is the ability of a unit to gradually transform its structure, functioning or organization to survive under hazards threatening its existence. Following persistent or major hazards, coping and adaptive capacity of the most vulnerable economic units usually reaches a limit. If the economic units do not have access to mechanisms for re-activating production or restructuring their production processes under less vulnerable conditions—the usual case for subsistence farmers—their expectations of future income become more pessimistic and they may decide to emigrate. This leads us to consider migration not merely as a function of poverty, but of lowered expectations.

It may seem peculiar to consider being poor as synonymous with being vulnerable to natural disasters; but in fact, the most vulnerable segment of the population usually is the poor, the destruction of whose assets impedes them from improving their welfare. A number of empirical studies point out that the poor are the most disadvantaged in recovering from natural hazards. This is the case for Hurricane Katrina in the USA (O'Brien 2005), the tsunami in South-east Asia (WB 2005), earthquakes in El Salvador in 1986 and 2001 (ECLAC 2001; Moisa and Romano 1995), Hurricane Mitch in Honduras (Vatsa and Krimgold 2000), and Hurricane Georges in the Dominican Republic (Butterfield 1998), to name some examples.

Scholars increasingly argue that poverty is not only lack of income or consumption, but also a lack of assets (Haveman and Wolff 2000; Oliver and Shapiro 1990; Sherraden 1991). Assets are the key variable for understanding the poverty of a household, which Vatsa and Krimgold (2000) define as the stock of wealth used to generate well-being. This concept is important when considering the effects of natural disasters, because disasters may decrease the capital assets of households and businesses and subsequently reduce their potential for generating income/output. Output also varies widely, depending on the market price of the factor produced and the productivity of its use (Attanasio and Szekely 1999). As families pursue strategies to maximize their assets, they are in a better position to spread their risk to reduce their vulnerability. Chambers (1989), among other authors, cautions about the importance of increasing assets in low-income families, since doing so improves welfare beyond poverty in terms not only of flows, but also of structural vulnerability. To authors like Vatsa and Krimgold (2000), vulnerability is a broader and more dynamic concept, which includes the poor, but also households living above the poverty line at risk of falling below it in the event of an income shock (the "new poor"). Factors that hinder asset accumulation in turn impede the reduction of poverty and send additional members of the population into poverty.

Natural disasters disrupt production and damage assets, providing a reason to assume them to be a significant potential external shock on income (Polsky 2004; Kates et al. 1985; Kates 1971). The subsequent effect on economic activity is however still under debate within the disaster research community, as damages from disasters differ from country to country in terms of scale, damaged economic activities and coping capacity. For instance, Albala-Bertrand (1993) points out the negligible long-term impact of disasters on the economy in developing countries. Other authors find positive relationships between frequency of natural disasters and economic growth (Dacy and Kunreuther 1969); however this conclusion is less valid for Mexico as their analysis is limited to developed economies. Other studies consider natural disasters to have a positive effect on the economy as the destruction is biased toward obsolete capital stock, adding pressure for the adoption of more efficient technology, pushing up average industrial productivity and, in turn, product (Skidmore and Toya 2002). However, we discount that approach because, as shown in Saldaña-Zorrilla (2006), the population historically most affected in Mexico lives in poverty and is for the most part unable to obtain credit to upgrade technology. In contrast, some authors' results show a negative economic effect from natural disasters. Some of the case studies, however, are based on small islands or small economies, such as Dominica, Fiji, Vietnam and the Philippines (Benson and Clay 2000). These economies may be too small for any conclusion to be drawn for the Mexican case. Caballeros and Zapata (1995) assess the impact of natural disasters on economic performance, finding that relatively small Latin-American economies like Nicaragua experience the effects of disasters at a greater scale and for a longer period than larger, more diversified economies. In the case of Mexico, they state that the 1985 Mexico City earthquake did not have any noticeable long-term negative effects on macroeconomic variables, although they do not consider non-major but frequent disaster events in their analysis. We claim that natural disasters have a negative impact on the economy; directly in certain economic sectors and regions, but also by a damaging spillover effect which extends to other parts of the country.

1.2 Spatial econometrics

This paper presents a spatial econometric analysis which shows that recurrent natural disasters, along with lack of credit and decreasing income, stimulate out-migration in Mexico and that the out-migration process spills over to nearby municipalities. We attempt to prove that migration is not a question of poverty itself, but rather of income expectations. As the effect of recurrent disasters and the absence of financing reduce economic agents' estimates of their returns on future investments, they have more incentives to leave their communities.

Given that we are looking for relevant relationships between disaster effects and emigration, we must take into account that natural disasters are geographically conditioned across regions. In other words, each municipality can be associated with both an absolute and a relative location. In terms of econometrics, the problem of absolute location is easy to solve and does not require spatial econometric techniques. This is merely a question of searching for relevant relationships between disaster effects and location characteristics. Thus, each municipality has its own set of characteristics easily estimated through the inclusion of area-specific variables such as, for instance, irrigation, distance to market or municipality, or region-specific dummy variables.

For the question of spatial dependence it is rather the relative location, or the *relative distance* between objects that is of importance for spatial econometrics. In much the same way as in time-series analysis, where what happened in previous periods influences the outcome in the current period, in spatial econometrics, a municipality's neighbors influence the outcome in a given municipality. Since influence works in both[5] directions; that is, municipality A influences municipality B and vice versa, spatial econometrics is required for estimation. Unless this is done, one might end up with both biased and inefficient estimates, as a number of authors have pointed out in, for instance, the economic growth literature. Regional growth may be dependent on growth in other regions, giving more weight to those regions which are geographically closer (i.e. Sandberg 2004; Le Gallo et al. 2003; Fingleton 2003; Rey and Montori 1999; Fujita and Krugman 1995; David 1984).

Hence, in our case the location of a disaster-struck municipality relative to the location of other regions/municipalities in geographical space is of interest. In addition, geographical clusters of natural disaster occurrences across regions might correlate with low-income regions in Mexico. The use of spatial econometrics is therefore vital for correct estimation and for more detail in studies of these relationships; namely identifying how clusters of regions recurrently affected by disasters and without financial measures for disaster prevention are related to clusters of low-income workers (see Anselin 1995a).

The remainder of the paper is organized as follows. Section 2 discusses the nature of vulnerability to trade, production and natural disasters in Mexico. Section 3 presents the model, Section 4 discusses the results, and Section 5 concludes the paper.

2 Vulnerability to natural, production and trade-related hazards in Mexico

Along with production limitations and trade-related stressors, the increased frequency and severity of natural hazards in Mexico has a negative impact on household income throughout the country. In light of current adverse economic conditions, recurrence of extreme climate events, and lack of affordable instruments for hedging against disaster risk, municipalities of predominantly subsistence farmers cannot recover from pre-existing marginalized conditions. They remain trapped in a vicious circle of high vulnerability, insufficient disaster management instruments, and low income. As the income expectations of economic agents turn ever more pessimistic due to these hazards which threaten their future incomes, out-migration is stimulated. During the period analyzed here, the limited capacity of the rural economy to provide employment has also significantly increased the flow of migration from the most affected regions to large cities, as well as to abroad. This leads to a complex process, avoidable only by improving current production conditions and disaster prevention.

At the national level, out-migration in Mexico has increased dramatically over the past two decades. The 1990 population census reported that 0.24% of the Mexican population was residing abroad; in the 2000 census this figure had risen to 0.41% (INEGI 2000). As currently about one-quarter of Mexico's labor force still works

[5] Actually, the influence occurs in many directions over space among the n observations. The pattern of influence is summarised in a matrix W of spatial weights.

in agriculture, and as conditions in the countryside are continually worsening, rural workers do not have incentives to cease migrating not only to urban Mexico, but also to urban and rural USA, where today one of every three immigrants was born in Mexico (ca. 12 million). Mexicans make up the largest immigrant group in the USA as a whole, and in 31 of the 50 states of the country (Center of Migration Studies of Washington 2003; US Census Bureau 2002).

In Mexico, the agricultural sector experiences the most damage from disasters and contributes less than 4% to total GDP. However, disaster losses are critical for agricultural livelihoods and rural incomes, which involve around one-quarter of the national population. Depressed rural incomes can be attributed to the destruction of capital stock and disruption of production resulting from natural disasters along with increasing pressure from economic stressors, such as depressed agricultural prices.[6]

Although social programs in Mexico have attempted to tackle poverty, the resource flows they generate are temporary, as poverty is a structural issue caused by the working of the entire economic structure. As presented in Saldaña-Zorrilla (2006), the increased frequency of natural hazards over the past 35 years in Mexico has implied increased economic losses as well. Current production structure and trade-related hazards in the countryside have contributed to stressful living conditions, amplified by insufficient government response to mitigate the resulting negative impacts. Nearly half the total population of Mexico lives in poverty, which is mostly concentrated in rural areas, affecting as much as 74% of the rural population (WB 2002).

2.1 Exposure to natural hazards

In Mexico, weather and climate-related events have been the most recurrent and damaging natural disasters. They are responsible for 80% of economic disaster losses during the period 1980–2005, and affect mostly the agricultural sector. Floods and droughts are increasingly affecting the whole country, and in some regions in the north, a process of desertification has started (Saldaña-Zorrilla 2006), with consequences for the economy. In 2005, per capita GDP agricultural growth was negative, which is mainly explained by the severe hurricane season and delays in rainfall, reducing the crop area by 34% (INEGI 2006). The population most affected are small-scale rainfed farmers of traditional crops such as maize, beans and coffee (ECLAC 2006). Over the past 15 years, the area of irrigated farmland has remained constant, covering only 24% of total cultivated area (INEGI 2006). This makes agriculture extremely vulnerable to climate and weather conditions. During the past decade, 14 million hectares of crops, of which less than 10% were insured, were lost to natural disasters (La Red 2004).

In addition, climate change is predicted to to make these conditions even more challenging. Even slight variations in the climate implies very large costs in Mexico

[6]Despite the increasing frequency and economic losses from natural disasters in Mexico (Saldana 2006), the economic impact on migration have to date not been addressed. The existing literature addressing the economic aspect of natural disasters in this country is limited to the recording of loss from disasters (Bitrán 2001), and to assessing and projecting of insurance markets (Kreimer et al. 1999). Further research focuses on concrete issues, rather than providing a broader economic view.

as many places are already close to the upper temperature tolerance of activities such as crop production, what demands immediate adaptation (IPCC 2007).

2.2 Production and trade-related hazards

Current adverse economic conditions contribute to the stress of small-scale farmers in Mexico. Between 1993 and 2004, per capita GDP growth in the agricultural sector was 0.3%, compared to 1.2% in the economy overall. Agricultural growth was too low to support rural population growth, while overall economic growth was too low to absorb the excess workforce from the countryside. Low-income farmers represent 67% of all farmers, but contribute only 22% to overall agricultural production. The deterioration of terms of trade in the agricultural sector, discussed in Saldaña-Zorrilla (2006), can explain the long-term downward trend in agricultural prices, which the current trade liberalization process dramatically exacerbates. In the short term, the comparatively lower prices of agricultural goods sold by Mexico's trade partners, most likely due to high subsidies, have resulted in higher agricultural imports, accelerating the downward trend of agricultural prices over the past 20 years. Grain imports from the USA explain the high trade balance deficit in the agricultural sector to a large degree (ca. 20% of traded value; ECLAC 2006). Since the implementation of NAFTA, only a small proportion of farmers, namely those with access to technology, have re-oriented their production to higher-priced exportable crops. While exports of vegetables, grown mainly by high-technology farmers, have risen significantly (9.6%) during the period 1994–2004, grain exports, grown mainly by low-technology farmers, have remained practically unchanged. Grain imports, however, grew 7% during the same period (ECLAC 2006).

Based on a spatial-temporal approach, Mendelsohn et al. (1994) measure the economic impact of climate change on agricultural land prices in the US, and in turn on agricultural revenues. These account for the expected economic substitution made by economic agents as climate conditions change; that is, for the adoption by farmers of adaptation measures due to temperature and precipitation increases in order to shift from revenue-declining activities to those more profitable under such conditions, and so to maximize their *best-use value function*. Their estimates yield lower economic losses from climate change compared to the traditional production-function approach, as the latter leaves latent economic substitution out of the analysis. In the case of Mexico, economic substitution rarely explores in-place options, such as crop substitution, but rather tends to make use of out-migration (Saldaña-Zorrilla 2008). The production structure of agriculture in some regions of Mexico does not exploit local competitive advantages. Persistently growing grains (i.e. maize) in regions which are not climatically and environmentally suitable contributes to low productivity (Gay et al. 2004). In addition, these crops generally bring low prices, which means that farmers miss out on the opportunity to increase their income by changing to more profitable crops (e.g. vegetables; ECLAC 2006).

From the 1980s on, the Mexican government began withdrawing from the business of granting rural credit and marketing crops, making farmers' income uncertainty more acute. As part of an extensive series of reforms implemented over the past 20 years, agricultural policy has shifted towards less support and fewer subsidies, aiming to facilitate the emergence of a private sector-driven rural economy and largely liberalized markets. This has implied less public intervention in the agricultural marketplace through the dismantling of state-owned companies for agricultural production and marketing support. However, subsistence farmers are particularly susceptible to the negative effects of government withdrawal. Since they are often not eligible for private credit, the cost of key production and marketing services, e.g. freight, fertilizers, storage, and crop insurance become unaffordable to them (Conde et al. 2006). In addition, they have no access to technical and financial support for economic substitution. In fact, credit for the agricultural sector has decreased by 80% over the last 10 years, representing only 2.5% of total credit (ECLAC 2006), and irrigation coverage—despite being increasingly required—has not been expanded since the 1980s (INEGI 2006). Finally, high transport costs and poor roads have been crucial factors in lowering the competitivity of farmers. Freight costs in Mexico are higher than in its main trade partners. For instance, the average price of 1 ton-km of terrestrial freight is 20% more expensive in Mexico than in the USA; 0.035 and 0.029 USD/ton-km, respectively (Moreno-Quintero 2004).

2.3 Government intervention to reduce vulnerability

Despite the current availability of novel government instruments to prevent disasters in Mexico, the strategies of public disaster management have been mainly reactive. The social benefit of the few projects implemented to reduce the risk of future disasters is still unclear. The government rebuilds not only public infrastructure, but also housing, and provides some relief to the poor after disasters. Loss sharing is based on a combination of ex-post instruments, including, for example, budget diversion and foreign credit. Risk transfer uses mainly ex-ante instruments such as insurance, mitigation, and more recently a contingency fund and a catastrophic bond. However, there is more emphasis on ex-post instruments, mainly on rebuilding, and fewer resources allocated to prevention measures. Unlike current insurance cross-subsidization in the UK (Linerooth-Bayer and Vari 2004), in the early 1990s the Mexican government started reducing the fiscal burden to farmers in low-risk areas, who in fact were subsidizing farmers growing crops in high-risk areas through flat premiums. Although the current subsidy system of crop insurance is financially much healthier than during the 1970s and 1980s, cultivated insured land in Mexico decreased from 40 to 10% between 1990 and 2000. During the same period crop damage due to natural disasters doubled. Despite the sophisticated design of current disaster mitigation instruments, few resources have been allocated to them during the past two decades. The contribution of investment to reducing vulnerability to natural disasters seems to be underestimated. In 2003, expenditure on rural natural disaster management represented less than 0.01% of spending on social programs, and less than 0.02% compared to agricultural programs in Mexico (Saldaña-Zorrilla 2006). These proportions seem to be too low if one considers the effect of natural hazards on income, which is further tested using the models of the present paper.

3 The model

In the absence of financing instruments for disaster prevention and recovery, regions where natural disasters and adverse economic conditions occur more frequently tend to maintain low capital accumulation rates. This leads, all else being equal, to a reduced capital-labor ratio and in turn to a lower marginal product of labor (Barro and Sala-i-Martin 1995). Assuming that the marginal product of labor determines salaries, mean salary tends to decrease in these regions. As other regions have higher salary levels, the labor force is stimulated to emigrate, first to higher income regions within the country (Krugman and Obstfeld 2006), and then abroad if these regions are unable to fulfill future income expectations (Saldaña-Zorrilla 2008).

For Todaro (2000), migration is primarily an economic phenomenon, which for the individual migrant can be a quite rational decision despite the existence of urban unemployment. The Todaro model postulates that migration takes place in response to rural-urban differences in expected income rather than actual earnings. The decision to migrate is taken in order to maximize expected earnings in the individual's lifetime, and so for a given time horizon, urban areas might therefore be a rational alternative. In other words, if the damage from hazards exceeds the coping and adaptive capacity of vulnerable economic agents, they find emigration to higher-income regions to be a viable strategy, even in the face of restrictions on labor mobility and the difficulty of crossing international borders.

As migration determinants, our model includes increases in the share of population earning less than twice the minimum wage (impoverishment), access to credit, frequency of natural disasters, production structure, level of education, and distance to the closest trading center. We here emphasize the recurrence of disasters to underline the importance of repetitive disasters in influencing expectations. Empirical evidence from Mexico shows that if large economic losses affecting income are experienced in a municipality due to just one major event, households do not necessarily perceive it as a threat for the future. If the municipality is a low-frequency-disaster municipality, isolated disasters do not necessarily alter expectations of future income (Saldaña-Zorrilla 2006). For this reason, we use the cumulative number of reported disasters instead of monetary economic losses. Availability of credit in these regions may counteract the chain reaction triggered by recurrent disasters, regenerating expectations of future income. Access to credit is included to account for a representative (financial) coping strategy, which may counteract reductions in the capital/labor ratio following disasters and improve income expectations. We model adverse production structure through high ratios of grains (prices falling) to vegetables (prices rising), included in the variable GRAVE. Level of education and distance to trading centers are included in order to examine the propensity the most educated population to emigrate and the role of proximity to urban centers.

3.1 Sources and methods

The regression analysis was performed on data from the 2,443 municipalities of Mexico. Data sources on natural disasters are DesInventar, La Red, and CENAPRED. Data on household income, asset value, credit, geographic distances, insurance and irrigation were obtained from the National Institute of Statistics and Informatics of Mexico (INEGI), corresponding to the 1990 and 2000 agricultural and economic national census. Data on agricultural prices were obtained from SIACON, the Ministry of Agriculture and Livestock. The regression analysis was performed using the SpaceStat program, version 1.91 (Anselin 1995b).

Two kinds of spatial dependence are commonly assumed to have the potential to contaminate the analysis. The first arises when, for instance, prices of adjacent observations move together due to unobservable common or correlated variables, i.e. lack of stochastic independence between observations. This dependence leads to inefficient estimates if left unresolved. The problem is discussed at length in Cliff and Ord (1972, 1973). A partition of the error term into two parts, together with a spatial weights matrix, solves this spatial dependence problem. This model is known as the Spatial Error Model.

$$y = X\beta + \varepsilon$$

$$\varepsilon = \lambda W\varepsilon + \xi$$

The second and more serious problem of spatial dependence occurs when there is spatial correlation in the dependent variable between observations. An example of this is the growth rate in one region being influenced by growth rates in nearby regions and vice versa. Such dependence leads to estimates that are both biased and inefficient. For a further discussion of this problem, see Anselin (1988). The problem may be resolved in various ways. The most common is to include the dependent variable of the other observations on the right hand side of the equation, lagged by a spatial weights matrix. This model is known as the Spatial Lag Model.

$$y = \rho Wy + X\beta + \varepsilon$$

As usual, additional problems may occur during estimation, such as heteroskedasticity. These problems are solved by standard econometric methods. The classical estimation method for a proper model specification under the potential influence of spatial dependence is given, for instance, in Florax et al. (2003). The initial model is estimated by means of Ordinary Least Squares (OLS). The residuals are then used to test the hypothesis of no spatial dependence caused by an omitted spatial lag or by spatially autoregressive errors by means of two Lagrange Multiplier tests (the LM-lag test and the LM-error test), e.g., Anselin (1988) and Burridge (1980). When the hypothesis cannot be rejected (no spatial dependence is present), the results from the OLS may be used. However, in the event that the hypothesis is rejected by both tests, a new model should be constructed. The proper model is indicated by the most significant LM test. If only the LM-lag test is significant, the next step would be to estimate a Spatial Lag Model, and if only the LM-error test is significant, a Spatial Error Model.

The base model is a standard linear formulation, estimated by OLS:

$$\begin{aligned} lnM = \alpha_0 + \beta_1 \Delta LIP + \beta_2 lnCRE + \beta_3 lnNDR + \beta_4 GRAVE_i \\ + \beta_5 lnEDUCSEC + \beta_6 lnDIST_{+}\varepsilon, \end{aligned} \tag{1}$$

Further, Eq. 1 can be expanded in order to deal with the two kinds of spatial dependence, spatial lag dependence (Eq. 2) and spatial error dependence (Eq. 3) mentioned above.

$$\begin{aligned} lnM_i = \rho W_i LM_i + \alpha_0 + \beta_{li} \Delta LIP_i + \beta_{2i} lnCRE_i + \beta_{3i} lnNDR_i + \beta_{4i} GRAVE \\ + \beta_{5i} lnEDUCSEC_i + \beta_{6i} lnDIST_{i+}\varepsilon_{l,} \end{aligned} \tag{2}$$

$$\begin{aligned} lnM_i = \alpha_0 + \beta_{li} \Delta LIP_i + \beta_{2i} lnCRE_i + \beta_{3i} lnNDR_i + \beta_{4i} GRAVE_i \\ + \beta_{5i} lnEDUCSEC_i + \beta_{6i} lnDIST_{i+}\varepsilon_i \end{aligned} \tag{3}$$

$$\varepsilon_i = \lambda W\varepsilon_i + \mu$$

$i = 1, 2, 3, ..., n$ (municipalities),

where W is a row-standardized first-order contiguity matrix, ρ and λ are the spatial autoregressive coefficients, and μ is a vector of i.i.d. errors with variance σ^2.

In addition to these specifications, we will also use the Spatial Durbin Model (Anselin 2001). By re-arranging Eq. 3 it can be shown that the spatial error model is equivalent to an extended version of the spatial lag model which includes both a spatially lagged dependent variable and a set of spatially lagged independent variables (excluding the constant term). A second addition deals with spatial heterogeneity or structural change. As the assumption that a fixed relationship between the explanatory variables and the dependent variable holds over the complete dataset ceases to be tenable, heterogeneity may be present. This heterogeneity may be expressed as a different regression intercept and/or slopes for subsets of the data. Here, heterogeneity is controlled for by dividing the dataset into two subsets based on whether a municipality is marginalized or not. Fingleton (2003) and Sandberg (2004), for example, have used this approach.

Before presenting the results of the regression analysis, we give a description of the variables used in the analysis. The variable names with prefix *ln* refer to a variable which is a logarithmic transformation of the raw data.

lnM, migration This variable is a measure of the share of municipal population aged 12 years and over who migrated between 1990 and 2000, according to the INEGI (2000) national household survey.

ΔLIP, low income population increase This variable represents the increase in poverty, calculated as the increase in the percentage of municipal workforce with income below twice the minimum wage between 1990 and 2000 (2000 constant prices). In fact, this variable does not reflect poverty itself, but rather deterioration in household income. Indeed, the greatest reductions in income occurred in the less marginalized regions of the country, although the repercussions on migration have been greater among the most marginalized, as shown below.

lnCRE, credit This variable is a measure of the number of agricultural units of the municipal total with access to credit. After natural disasters, this is crucial for rebuilding, for continuing to make use of their assets, and to cope with price fluctuation and further income uncertainty. We expect access to credit to have a negative impact on emigration, most likely due to its virtue of re-stimulating expectations of future income within the same geographical area.

lnNDR, number of disaster reports This variable is the count of natural disasters affecting a municipality over the period 1990–2000; that is, the recurrence level of disaster events by municipality. Regions with a higher frequency of natural disasters are more prone to out-migration. If the model is run with per capita economic losses from natural disasters instead, the coefficient is positive as well but not statistically significant. Indeed, these two variables measure different things. While the latter has a clear impact on income, confirmed in the low-income model, the former influences the perception of natural disasters in the community. Saldaña-Zorrilla (2006) verified this, showing that in communities with comparatively low economic losses but quite frequent natural disasters, more interview subjects have plans to migrate. In contrast, in communities with higher economic losses but less frequent disaster events, there is less desire to migrate.

GRAVE, basic grains to vegetables ratio This is the ratio of production of the five main grains to the ten main vegetables in Mexican agriculture (measured in tons). Given the structure of Mexican agriculture, grain producers are in a less competitive position, to judge by the notable decline in grain prices and the dramatic increase in imports of the same grains from the USA. High values for this variable are interpreted as weak trade competitivity in a municipality, while low values represent greater export potential, as Mexico has a clear advantage in vegetables compared to the USA and Canada (see Lederman et al. 2003). Given the declining trend of the relative price of grains compared to vegetables in the past two decades in Mexico (ECLAC 2006), this variable may also represent a sort of intra-branch negative terms of trade.

lnEDU, middle school education This is the proportion of the municipal population 12 years and older that has completed middle school. We assume that for an individual, a higher level of education facilitates more a effective response to changing conditions, i.e. to natural disasters, price volatility, changes in price the price of inputs and technological change, among others.

lnDIST, distance to nearest trading center This variable uses Euclidean distance as a measure of the distance between a given municipality and the geographically closest major trading center. The variable allows us to account for the effect of distance in reducing competitivity on local production due to increased transport costs and isolation from technological centers. The 50 most important benchmarked trading centers considered here are the main markets for agricultural producers, either because of their consumption or as a transfer node. Included are 25 state capitals, 12 maritime ports, the eight most important border crossings (seven to the USA, one to Guatemala), and five other large cities.

3.2 Model specification

We first estimate the model of Eq. 1 by OLS. The main reason for doing this is to make use of the OLS residuals to test for spatial dependence, and to provide guidance on how to proceed towards the final model specification, as mentioned above. As observed in Table 1, the OLS regression in column 1 yields expected parameter estimates with a goodness of fit of 25%. However, there are clear indications of spatial dependence, dominated by spatial error dependence as well as heteroskedasticity.

Since the Lagrange-Multiplier tests (LM) indicate that the spatial dependence problem may be resolved by an error correction, we begin with this correction for the model specification of Eq. 3. The regression is estimated by means of Maximum Likelihood (ML) and the results are presented in column 2. The parameter estimates mostly stay the same, as one would expect from this error correction. The log likelihood (LIK) increases significantly, but the common factor hypothesis (Burridge 1981) is rejected.

This means that the current model is misspecified and that the omission of spatially lagged variables cause spatially correlated residuals and should therefore be included (Florax and Folmer 1992). By addressing the omitted variable bias, the WX terms help capture the influence of omitted variables whose effect would otherwise be subsumed in the error term, and they also provide detailed information about the

Table 1 Spatial regression results of migration, global model

Variables/tests	(1) OLS	(2) ML-Error	(3) ML-err, Het	(4) Spatial Durbin	(5) Spatial Durbin Het
ρ				0.672***	0.671***
λ		0.699***	0.698***		
Constant	0.479***	0.679***	0.666***	0.021	−0.004
ΔLIP	0.007***	0.006***	0.005***	0.005***	0.005***
lnCRED	−0.054***	−0.011	−0.010	−0.003	−0.003
GRAVE	0.000	−0.000	−0.000	0.000	0.000
lnNDR	0.099***	0.107***	0.103***	0.107***	0.104***
lnDIST	0.001	−0.007	−0.006	−0.005	−0.005
lnEDU	0.30***	0.203***	0.206***	0.191***	0.194***
$W\_\Delta LIP$				−0.003***	−0.003***
W_lnCRED				−0.030***	−0.030***
W_GRAVE				0.000	0.000
W_lnNDR				−0.084***	−0.086***
W_lnDIST				0.011	0.012
W_lnEDU				−0.006	−0.003
Gr. Variance_0			0.184***		0.181***
Gr. Variance_1			0.157***		0.155***
R2	0.25	0.15	0.15	0.44	0.43
R2adj	0.25				
Sq.corr.	0.27	0.24	0.24	0.55	0.55
LIK	−1,846.84	−1,372.20	−1,236.15	−1,349.81	−1,347.80
AIC	3,707.69	2,758.39	2,486.30	2,727.62	2,723.60
Sig-sq	0.27	0.16		0.16	
Heterosk. Random, (Koenker-Basset)	16.99***				
Hetersk. Marginalization, (Koenker-Basset)	4.74**				
Heterosk._Random (Spatial Breuch Pagan)		24.22***		66.82**	
Heterosk_Marginalization (Spatial Breuch Pagan)				3.93**	
Lik. Ratio. Heterosk.			272.09***		4.02**
LM-Error	1,265.83***				
LM-Error, Robust	73.81***				
LM-Lag	1,247.12***				
LM-Lag, Robust	55.10***				
Common Factor (Wald)		37.46***			
Lik. Ratio. weight matrix		949.30***		883.96***	
LM on sp.Lag		18.16***			
LM on sp. Error				101.91***	

***, **, and * indicate significant values at 10, 5 and 1 percent level, respectively

spatial dependence present. Thus the Spatial Durbin model captures the influence of all other omitted variables that vary across space.

The spatially lagged variables consist of spatial averages of neighboring values, determined by the previously specified spatial weights matrix W of values for each observation. The parameter estimates of the spatially lagged explanatory variables are the average influence that neighbors have on the income level in each municipality. The regression results with and without correction for groupwise heteroscedasticity are included in columns 3 and 4. That is, we allow the variance to vary within two groups in order to resolve heteroskedasticity so as to decrease overall variance by allowing the variances to deviate between the two groups. The split is done on the basis of whether or not a municipality is marginalized. This categorization of the municipalities is then dichotomous. The variance for the group that contains the municipalities that are not marginalized is denoted Gr. Variance_0 in Table 1, and the variance of the marginalized municipalities is denoted Gr. Variance_1.

As can be seen in column 4 in Table 1, within-group variances are quite different between the groups. This is also confirmed by the Likelihood Ratio test (Lik. Ratio Marginalization), which rejects the null hypothesis of similar variances. Another way of seeing this is by comparing the group variances with the common variance (Sig-sq.). Compared to the results of the OLS regression model, the spatial Durbin specification clearly improves the goodness of fit, almost doubling the log likelihood value.

The spatial lag dependence parameter estimate (ρ) is positive and significant, indicating that municipalities with a high (low) degree of out-migration tend to lie clustered together and spill over to each other since they are influencing each other in income creation. Further comments on additional results are given in Section 4.

3.3 Controlling for marginalization

Now let us disaggregate the model into two types of municipalities; marginalized and non-marginalized. The marginalization index from the National Council of Population (CONAPO) serves as a category variable in this model. The composite index integrates measures including access to health, housing conditions, access to public utilities (drainage, clean water, etc), and others.[7] Its composition identifies the lack of sufficient individual and collective asset accumulation. This desegregation lets us observe structural differences between two different asset availability levels. Hence, we allow the parameter estimates for the two categories to vary across space; i.e. spatial heterogeneity. The model specification now becomes:

$$\begin{aligned} lnM_{ij} = \alpha_{0ij} + \beta_{lij}\Delta LIP_{ij} + \beta_{2ij}lnCRE_{ji} + \beta_{3ij}lnNDR_{ij} + \beta_{4ij}GRAVE_{ij} \\ + \beta_{5ij}lnEDUCSEC_{ij} + \beta_{6ij}lnDIST_{ij+}\varepsilon_{ij,}, \end{aligned} \tag{4}$$

with the addition of similar spatial adjustments where necessary, as mentioned above.

$i = 1, 2, 3, ..., n$ (municipalities)
$j = 0$, if i is a non-marginalized municipality
$j = 1$, if i is a marginalized municipality

Table 2 presents the regression results. The results at the top of the table are the parameter estimates for non-marginalized municipalities, followed by the estimates for marginalized municipalities. Tests for spatial heterogeneity (the Chow test to test for overall structural stability and the stability of individual coefficients) are included

[7]For details about the methodology used for the CONAPO marginalization index, see http://www.conapo.gob.mx/publicaciones/indices/pdfs/006.pdf.

Table 2 Spatial regression results of migration by subsets of marginalization

	Variables/tests	(1) OLS-Marg	(2) ML-Lag	(3) Spatial Durbin, Marg
Non-marginalized	ρ		0.633***	0.648***
	Constant	1,704***	1.03***	1,443***
	ΔLIP	0.001	−0.004	−0.005
	lnCRED	−0.064***	−0.014	0.010
	GRAVE	0.001	0.000	0.003*
	lnNDR	0.196***	0.114***	0.126***
	lnDIST	0.004	−0.009	−0.008
	lnEDU	−0.103*	−0.062	−0.045
	W_ΔLIP			0.002
	W_lnCRED			−0.045
	W_GRAVE			−0.003
	W_lnNDR			−0.037
	W_lnDIST			−0.016
	W_lnEDU			−0.161*
Marginalized	*Constant*	0.263***	−0.089	−0.256**
	ΔLIP	0.006***	0.002***	0.005***
	lnCRED	−0.035***	−0.014*	0.002
	GRAVE	0.001	0.000	−0.000
	lnNDR	−0.031	−0.003	0.054**
	lnDIST	0.018**	0.010*	0.005
	lnEDU	0.326***	0.207***	0.209***
	W_ΔLIP			−0.004***
	W_lnCRED			−0.020
	W_GRAVE			0.001
	W_lnNDR			−0.115***
	W_lnDIST			0.024***
	W_lnEDU			0.018
	Chow test	21.90***	87.02***	112.19***
	Constant	34.47***	32.73***	39.18***
	ΔLIP	2.40	5.85**	9.51***
	lnCRED	1.68	0.00	0.08
	GRAVE	0.37	0.01	1.64
	lnNDR	29.64***	12.46***	3.47*
	lnDIST	1.63	4.55**	1.89
	lnEDU	44.80	27.76***	21.37***
	W_ΔLIP			2.69
	W_lnCRED			0.43
	W_GRAVE			2.76*
	W_lnNDR			1.79
	W_lnDIST			5.89**
	W_lnEDU			3.79**
	R2	0.29	0.46	0.47
	R2adj	0.29		
	Sc.corr		0.55	0.57
	LIK	−1,772.09	−1,327.60	−1,294.26
	AIC	3,572.17	2,685.21	2,642.52
	Sig-sq	0.25	0.16	0.15
	Hetersk. Marginalization, (Koenker-Basset)	0.00		

Table 2 (continued)

Variables/tests	(1) OLS-Marg	(2) ML-Lag	(3) Spatial Durbin, Marg
Heterosk_Marginalization (Spatial Breuch Pagan)		0.05	0.06
Lm-Error	1,151.86***		
LM-Error, Robust	65.08***		
LM-Lag	1,156.86***		
LM-Lag, Robust	70.08***		
Lik. Ratio. weight matrix		888.97***	801.86***
LM on sp. Lag			
LM on sp. Error		9.40***	66.80***

***, **, and * indicate significant values at 10, 5 and 1 percent level, respectively

at the bottom of the table. The table concludes with a section of ordinary regression diagnostics.

The test of the residuals from the OLS estimation points to a spatial lag model. The spatial lag model with adjusted groupwise heteroskedasticity is estimated by Maximum Likelihood. The regression results are given in column 3.

In terms of goodness of fit, this model explains about 47% of the variance, and the loglikelihood (LIK) value of $-1{,}293$ is a clear improvement over the biased and inefficient OLS regression results, which yielded a log likelihood value of just $-1{,}772$.

4 Interpretation of results

Regions more frequently affected by natural disasters, with relatively high increases in poverty and declining crop prices have historically had higher migration rates (Table 1). In addition, high levels of migration occur in regions with high education levels within marginalized regions (Table 2), confirming the presence of human capital drain. The classical belief that reducing excess workforce leads to increasing the marginal product of labor is a risky statement in light of these results, since the workforce remaining in the community is the least skilled. In addition, distance proves not to be a real obstacle to migration, given that most migration originates in more isolated communities (Table 2).

The positive sign of ΔLIP in Table 1 suggests that municipalities with a workforce that has experienced larger reductions in wages are more prone to out-migration. This suggests that the greater the poverty increase during the 1990s, the greater the migration rate between 1990 and 2000. From Table 2 we may conclude that this effect operates only in marginalized municipalities. Hence, out-migration occurs significantly more often in marginalized municipalities as a result of an increased proportion of low-income population than in non-marginalized municipalities. Out-migration is further influenced by factors in the surrounding municipalities; increased poverty in neighboring municipalities of municipality i inhibits migration from i, (W_ΔLIP).

Credit is not statistically significant in its effect on migration in the overall model (Table 1). As with insurance, the availability of agricultural credit decreased dramatically (ca. 80%) during the 1990s, making hard to measure its impact on income. The sign on the coefficient of credit in marginalized regions is positive, although insignificant (Table 2, column 3). We have reason to assume that lack of credit would stimulate the workforce to migrate, given that they recur directly to out-migration when faced with adverse conditions, as they cannot count on credit as a feasible coping strategy.

We observe, however, a significant negative coefficient for the spatially lagged variable W_lnCRED in Table 1. This means that having neighbors with comparatively higher access to credit helps to keep migration rates lower. As credit conventionally facilitates a means for increasing the risk pool, helping to smooth the negative effects of hazards, a positive spillover effect from neighbors with low losses may facilitate obtaining jobs nearby, and lessen the chances of immediately recurring to out-migration.

Our results show that a high disaster frequency encourages more people to move away from their municipalities. All else being equal, a 10% increase in disaster frequency raises migration rates by 13% in non-marginalized regions, and 5% in marginalized ones. Factors in the surrounding municipalities limit migration, as shown by the prevailing negative coefficients of the corresponding spatially lagged exogenous variables in Table 1. For instance, high disaster frequency in surrounding regions, W_lnNDR, reduces the probability that people will migrate. It is most likely due to the catch-up increases in crop prices that may be set by less-affected producers due to increased scarcity.

A higher frequency of natural disasters tends to make the non-marginalized population comparatively more prone to migrate, perhaps due to their higher educational levels, making them better informed about emigration as a coping strategy in the absence of credit and other alternative financing sources.

Although the ratio of grains to vegetables (GRAVE) provides negligible results for the overall model, the marginalization partition suggests that those non-marginalized regions growing predominantly grains tend to have increased migration levels (Table 2). This is most likely due to their greater involvement in trade, while the most marginalized municipalities rely more on self-consumption. All else being equal, a decrease of 10% in the grain–vegetables ratio in the less marginalized municipalities leads to a 3% decrease in out-migration.

As observed, education is positively correlated with out-migration (Table 1). However, as shown in Table 2, the results for non-marginalized municipalities are no longer significant. For the marginalized municipalities, education is still significant for explaining out-migration. This means that among marginalized municipalities, migrants come from regions with a comparatively higher mean level of education. This also suggests that less educated people are less prone to implement migration as a way to cope with hazards either because they are more averse to changing their residence, have less means to do so, or have a more resigned attitude, given hierarchical governmental organization prevailing in the recent past, which has a greater effect on the marginalized population, and is still present in many regions. The prevailing fatalistic way of life of most subsistence farmers with low levels of education, abundantly expounded in Thompson et al. (1990), provides further evidence for these results.

High out-migration rates in marginalized municipalities occur if they have experienced a notable increase in their low-income population combined with an initial high education level. In the spatial Durbin model, having a greater proportion of educated people in non-marginalized municipalities reduces migration. This could be because their more educated neighbors generate more economic activity and hence jobs in the region, or simply that the opportunities at home are already sufficient.

It was expected that marginalized people near big cities would be more likely to migrate as their distance and transport costs to large cities are lower. This is not the case, however, since none of the models present any significant parameters for this factor, except for the spatially weighted distance variable for marginalized municipalities (Table 2), which has a positive significant parameter. One interpretation may be that marginalized households are unable to find jobs in nearby municipalities that are far from the market, and a solution to find employment would then be to migrate a greater distance.

In summary, lower income, disaster frequency, and education proved to determine migration with much better results than any other variables in the overall model. In general terms, the prototype of an emigration-prone municipality in Mexico has the following combination of characteristics: substantially dropped income over the past 10 years, frequently affected by natural disasters, marginalized, relatively more educated, grain-intensive farming, located far from larger urban centers, and low access to credit.

5 Conclusions

As weather and climate-related disasters are becoming more frequent and destructive in Mexico, the model suggests that out-migration will continue to rise in the coming years if an active disaster prevention strategy and structural adaptation measures are not duly implemented. Municipalities with higher emigration rates were those with greater income decreases and increasingly affected by recurrent natural disasters during the 1990s. The model suggests that out-migration may be a result of future income expectations. Migration is therefore a rational decision made by economic agents based on estimated future returns on their assets, accounting for expected net assets and income losses after internalizing available financial resources. The model also suggests that increasing access to agricultural credit may reduce the stimulus to migrate as it reduces the negative impacts of hazards in the affected region. The population segment most significantly prone to migrate is that of those who are marginalized, have higher levels of education, and live far from trading centers. As the current transportation infrastructure does not support them sufficiently to enable them to compete as economic agents, they are utilizing it instead to migrate.

The temporal-geographic identification of out-migrating regions in this study may serve as a baseline for government decision-making on investment projects for expanding crop insurance coverage, access to credit, and promoting more public infrastructure investment in areas identified as vulnerable by climate change scenarios. Finally, current investment in education will continue to yield benefits merely as an instrument for training potential migrants as long as reforms to enable the accumulation of assets and consequently to reduce social polarization do not materialize in this country.

Appendix I: Notes concerning construction of data bases and time series

The natural disaster data used for this case study are reports of disasters from LaRed and CENAPRED, complemented by extrapolations based on records from other agencies. Data from these sources were integrated and harmonized as follows:

1. Reports of disasters were added from CENAPRED into the LaRed data base in some cases in order to scale down from state to municipal level data and in other cases to weight agricultural prices and losses. Data sampling was increased by 20%, providing valuable data on economic losses from disasters and numbers of hectares of crops damaged.
2. In order to make monetary data comparable, current economic losses were transformed to constant 2002 values.
3. In order to enlarge the sample size of economic losses, we included those observations without records of monetary loss but with number of hectares, by estimating monetary loss. Lost crop area was transformed into monetary losses by multiplying area by mean weighted price per ton ($/ton) and average yield (ton/ha). This increased the sample by 40%. Mean weighted agricultural prices were based on records of mean rural prices and production from SIACON (*Subsistema de Informacion Agricola*, SAGARPA 2004).

List of municipalities selected as main trading center cities

Acapulco de Juárez	Irapuato	Reynosa
Aguascalientes	Iztapalapa	Salina Cruz
Ahome	Juárez	Saltillo
Benito Juárez	León	San Luis Potosí
Cajeme	Manzanillo	Tampico
Campeche	Matamoros	Tapachula
Celaya	Mazatlán	Tepic
Centro	Mérida	Tijuana
Chihuahua	Monterrey	Toluca
Coatzacoalcos	Morelia	Torreón
Cuernavaca	Nogales	Tuxtla Gutiérrez
Culiacán	Nuevo Laredo	Veracruz
Durango	Oaxaca de Juárez	Victoria
Guadalajara	Paz, La	Xalapa
Guaymas	Piedras Negras	Zacatecas
Hermosillo	Puebla	Zapotlán del Rey
Hidalgo del Parral	Querétaro	

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