CSS 600 Fall 2024
Group 4 Final Paper
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12/16/2024

Migration Movement Agent-Based Model

Abstract

Migration to the U.S.-Mexico border is a phenomenon that has long been studied. However, the demographics of those arriving at the southwest border have changed over the last decade. Building on an existing agent-based model that simulates decision-making of Mexican citizens migrating to the U.S., this project adds migrants from Central America. This expanded ABM provides the opportunity to study the effects of border restrictions, willingness to migrate and risk aversion at the country level. Analyses reveal statistically significant differences between countries. The findings further indicate that varying levels of willingness to migrate and risk aversion have significant effects on migration. Overall, Mexico continues to have the highest percentage who migrate to the U.S.-Mexico border given its proximity and larger population density.

Introduction

In a recent Gallup survey, 28% of Americans named immigration as the most important problem facing the country ahead of inflation, homelessness, and crime. Immigration has consistently ranked as a top concern for the past few years. The U.S.-Mexico border showcases the various factors influencing immigration through the interplay of human factors, social network, geography, and policy. According to the Migration Policy Institute's report (Bersin 2024), four key factors drive the decision to migrate to the U.S.-Mexico border: a mix of push and pull factors, cost to migrate, likelihood to reach border checkpoint and being admitted, and the consequences of being turned away. The push-pull theory states that an individual's decision to migrate is influenced by the dual factors: those that push them to leave their place of origin and those that pull them towards a new destination (Ravenstein 1885; Lee 1960). Economic pull factors predominantly influence Mexican migrants to the U.S., with family and social ties also playing significant roles (Passel and Suro 2005).

However, there has been a recent shift with a rise of humanitarian migrants arriving at the world's largest migration corridor with hopes of applying for asylum in the U.S. Over the last 20 years, Mexico has evolved to become a transit country for migrants further south and beyond, with the U.S. being the goal destination. In FY2013, there were approximately 100,000 transit migrants from non-Mexico countries encountered at the U.S.-Mexico border, as recorded by U.S. Border Patrol. This figure rose to approximately 685,000 in FY2019 and rose further to 1.5 million in FY2023 (Alba 2024; U.S. Customs and Border Protection). These migrants are predominantly driven by push factors such as food shortages, violence, systemic poverty, and persecution (Alba 2024).

While Mexico has become a transit country for migrants from Central America, South America, the Caribbean and beyond, this project focuses specifically on Mexican and Central American migrants. Due to political unrest and economic instability in the late 20th century, Central American countries have produced a record number of transit migrants. Given the range of human factors that influence decisions to migrate, agent-based modeling is most conducive to capturing the complexity of migration. Al-Khulaidy and Swartz (2020) developed an agent-based model (ABM) in NetLogo exploring factors that influence the movement of migrants from Mexico to the U.S., emphasizing the movement towards and between ports of entry. By building on this existing model that is focused on Mexican migrants, we include populations from Central America, specifically Belize, Guatemala, Honduras and El Salvador, to create a more comprehensive landscape of migration toward the southern border. Recent migration trends inform the following research question: Do migration patterns between Mexican and Central American migrants differ by enforced border restrictions, willingness to migrate, and risk aversion?

Willingness to migrate is further refined in the updated ABM model to be indexed by country of origin to capture the unique environmental factors pushing individuals to leave Mexico, Belize, Guatemala, Honduras and El Salvador. With a model that more accurately reflects the migrant population south of the U.S.-Mexico border, we can explore differences in migratory behaviors by countries of origin. We hypothesize more migrants from Central American countries than Mexico move toward the southwest border, regardless of different parameter levels.

Methodology

Model Description

Al-Khulaidy and Swartz's "ABM Migration SpringSim2020" (2020) in NetLogo models migrants from Mexico, and our updated Migration Movement ABM adds migrants originating from four additional Central American countries. The number of agents is initialized for each country based on 2015 population data (Instituto Nacional de Estadística) and is scaled by 100,000 (default) or 50,000; both options are available for selection on the user interface.

Table 1. 2015 Census Population per Country

Country Name	Population (2015)
Belize	415,789
El Salvador	6,348,795
Guatemala	18,255,216
Honduras	10,894,723
Mexico	130,739,927

Migrants are assigned randomly to an area in their home country when the model is set up, and then migrate using the following steps:

1. Migrants initially choose a port of entry (POE) closest to them. They update their desired POE based on information about successful migration and border crossing of other

migrants within their social network, particularly from their hometown or home country.
2. As migrants start to move, they update their POE choice as they encounter other migrants. More specifically, when encountering a caravan, migrants join the caravan to their POE of choice.
3. If Border Restriction is enforced, migrants who reach a closed POE choose a different POE nearest to them to migrate to.

The study focuses on three key drivers of migration: border restriction, willingness to migrate, and risk aversion. The latter two terms are defined in detail below. Border restriction refers to whether border restrictions into the U.S. are enforced or not.

Willingness to Migrate

The parameter willingness to migrate (WTM) is a combined index that captures an individual's push-pull factors based on an in-the-field experimental economics survey (Bah and Batista 2019). Within the Migration Movement ABM, users can set a value for average WTM, with a higher value associated with lower probability of dying en route. Conversely, a lower value of average WTM is associated with a higher probability of dying en route. Valid WTM values range from 0 to 100, with 0 representing complete lack of WTM and 100 being the greatest possible level of WTM. Within the model:

- X^w is the average willingness to migrate, which is set via the model interface slider
- M is the individual agent's willingness to migrate
- G^w is the global willingness to migrate

When $G^w \neq X^w$, then the following formula is used to calculate a new value for an individual agent's WTM which is denoted as M^{α}.

$$\mathrm{M}^{\alpha} = \text{random-normal}\left\{\text{round}\left(\frac{|X^w - \mathrm{M}|}{2}\right) + \mathrm{M}, 1.5\right\}$$

To better account for push factors, particularly for the Central American countries, the model was updated to include a "country-risk" global variable, which is informed by the European Union's INFORM Risk data (Marin-Ferrer and Poljansek 2017).

Table 2. Countries and Their INFORM Risk Index

Country Name	INFORM Risk Index	C
Belize	3.7	0.037
El Salvador	4.2	0.042
Guatemala	4.9	0.049
Honduras	4.2	0.042
Mexico	5.5	0.055

An agent's home country's risk (C) index scaled as a fraction is used to adjust WTM, where higher country risk increases an agent's WTM and lower risk decreases an agent's WTM. M^{β} is the adjusted individual WTM to account for country-risk:

$$\mathrm{M}^{\beta} = \mathrm{M}^{\alpha}(1 + C)$$

Risk Aversion

The theory underlying risk aversion (RA) is detailed by Huber and Nowotny (2018), who find that higher RA is negatively correlated with migration within source country as well as abroad. Moreover, Huber and Nowotny find that long-term risks have a greater impact on WTM than short-term economically motivated risks such wage work. "The strength of the impact of risk aversion on migration intentions is more strongly linked to, for example, political stability, government effectiveness and security risks than economic risks."

Within the model, users can set a value for average RA, with higher RA associated with lower WTM. Valid values range from 0 to 100, with 0 indicating complete lack of RA and 100 being the greatest possible level of RA. Within the model:

- X^r is the average risk aversion, which is set via the model interface slider
- R is the individual agen'ts risk aversion
- G^r is the global risk aversion

When $G^r \neq X^r$, then the following formula is used to calculate a new value for an individual agent's RA which is denoted as R^{α}.

$$\mathrm{R}^{\alpha} = \text{random-normal}\left\{\text{round}\left(\frac{|X^r - \mathrm{R}|}{2}\right) + \mathrm{R}, 1.5\right\}$$

Model Experiments

To examine the effects of border restriction, WTM and RA on migration among individuals from each country of interest, different values are applied to these parameters. A migrant moves when M^{β}>50 and R^{α}< Means, with Means referring to financial resources required to migrate. In other words, a migrant must have a willingness to migrant and the necessary means to migrate.

Central to this project is the examination of the number of migrants who leave their home country and migrate toward the U.S.-Mexico border. Here, migrants include those who are actively migrating, are at the border awaiting entry, and have crossed successfully. Because Mexico comprises a considerably larger population compared to Central American countries, the model and analyses utilize ratios and percentage of total migrants relative to home country populations to help normalize varying population sizes.

Results

Informed by exploratory analyses, the below parameter levels were established to analyze migration patterns between Mexico and Central American countries:

- Border restriction: On vs Off
- Average WTM: 50 (low) vs 60 (high)
- Average RA: 20 (low) vs 40 (high)

Using the Behavior Space, each combination of parameter levels was run 25 times with a time limit of 365 steps to represent one calendar year. Results below show the average of all runs to show the percentage of each country's total population who migrated.

By Region

To first understand the difference in migration patterns by region, Figure 2 provides the average percent of migrants from Mexico and Central America by each parameter level. These results provide the main effects of border restriction, WTM and RA. For example, when avg-WTM is 50 without factoring in border restriction or RA, the average percent of migrants for Mexico is 40% and for Central America is 36%. Table 3 outlines the data in further detail to examine the intersection of the various parameter settings and their influence on migration movement. Building on the example of Mexico when WTM is 50, we see that a lower value of RA and enforced border restriction resulted in 48% of the population migrating.

Figure 2. Average Percentage Who Migrated by Parameter and Region

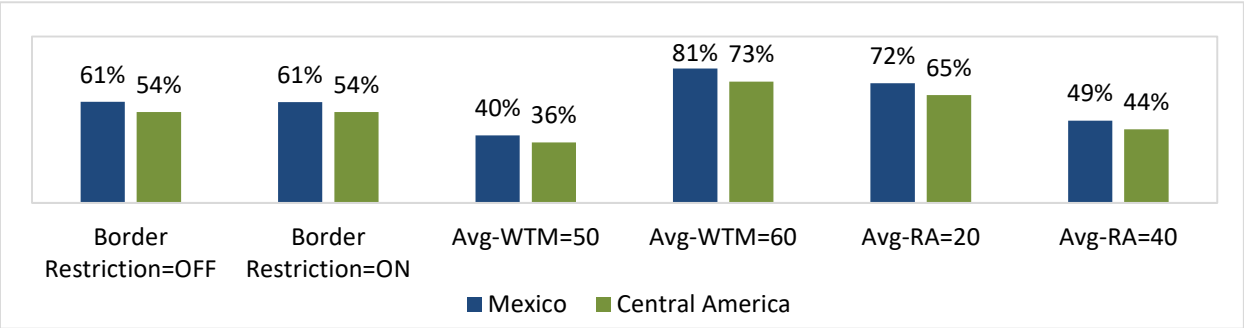

Table 3. Average Percentage Who Migrated by Region and Interaction of Parameters

	Border Restriction: Off	Border Restriction: On
Mexico		
WTM=50, RA=20	48%	48%
WTM=50, RA=40	33%	33%
WTM=60, RA=20	96%	96%
WTM=60, RA=40	66%	65%
Central America		
WTM=50, RA=20	43%	43%
WTM=50, RA=40	29%	29%
WTM=60, RA=20	86%	86%
WTM=60, RA=40	59%	59%

By Country

Given the unique political and economic states of each Central American country, model results were examined further by country. Table 4 presents the overall percentage of individuals who migrate by country as well as each main effect on the percent of migrants. For example, 5% of the total Belize population migrated toward the U.S.-Mexico border. Three percent of the Belize population migrated when WTM is low compared to 6% when WTM is high. To compare observed differences, we used Factorial ANOVA to examine the impact of border restriction, WTM, RA, and country of origin on migration. Results are noted in Table 4, with all main effects except for Border Restriction being statistically significant ($p<0.01$). For more detailed interaction effects, see Appendix A.

Table 4. Average Percentage Who Migrated by Parameter and Country of Origin

	Country *				
	Belize	El Salvador	Guatemala	Honduras	Mexico
Overall	5%	35%	48%	40%	61%
Border Restriction					
Off	5%	35%	48%	40%	61%
On	5%	35%	48%	40%	61%
Avg Willingness to Migrate *					
50 (low)	3%	23%	32%	27%	40%
60 (high)	6%	46%	64%	54%	81%
Avg Risk Aversion *					
20 (low)	5%	42%	57%	48%	72%
40 (high)	4%	28%	39%	33%	49%

* Main effect is statistically significant ($p<0.01$).

Analysis

Model results show that Mexico consistently had a higher percentage who migrated by 4 to 8 points compared to Central American countries, regardless of parameter setting (Figure 3). Overall, average WTM had the greatest main effect as evident in the 50% increase in migration when WTM rose from 50 to 60 (Table 3). Conversely, an increase in the average RA had a dampening effect on migration. When average RA increased from 20 to 40, the percent who decided to migrate decreased by approximately 30% for individuals from both Mexico and Central America.

These observed effects of WTM and RA hold true when comparing results by country. Here, average WTM and RA having significant main effects ($p<.01$) on percentage of migrants. Additionally, when comparing across the five countries, the differences in the overall percent who migrated were statistically significant ($p<.01$). Among the Central American countries, a very small percentage of the Belize population migrated (5%) compared to El Salvador (35%), Guatemala (48%) and Honduras (40%). This may be due to Belize's lower INFORM risk index and generally smaller population. Unsurprisingly, Mexico had the highest percentage who migrated. Under favorable conditions where WTM is high and RA is low, Mexico had notably high percentages of 81% and 72%, respectively. When examining interaction of these parameters

(Appendix A), Mexico had 96% of its population migrating toward the U.S.-Mexico border. Recognizing that an entire country cannot migrate en masse toward the U.S., initialization of migrants can be further improved to more accurately reflect migratory patterns,

Whether comparing by region or country, model results did not show any differences in migration patterns when border restrictions were turned on or off. Enforcement of border restriction does not fully restrict entry into the U.S. in the model, which allows 50% of migrants to cross the border at an official POE. Migrants who unsuccessfully cross at a POE subsequently migrate toward the nearest official POE, which means the model does not account for border crossings that occur illegally between POEs. This is a frequent occurrence documented by Customs and Border Protection, which provides an opportunity to further refine the model to more accurately reflect movement at the border. While border restriction in the model did not affect migration patterns for Mexico and Central American countries, results overall show significant differences between countries and with varying levels of WTM and RA.

Conclusion

By enhancing an existing ABM, we examined whether varying levels of border restriction, willingness to migrate and risk aversion affected migration among Mexicans and more recent migrant populations from Central America. However, contrary to our hypothesis that more Central American migrants would migrate to the southwest border, our model revealed that Mexico consistently had a greater percentage of total country population who decide to migrate compared to all Central American countries. These findings do not align with the latest data emerging from U.S. Customs and Border Protection. While the original model was validated against U.S. Customs and Border Protection data, the validation was for border encounters among Mexican migrants, particularly their movement between POEs (Al-Khulaidy and Swartz 2020). To make the model more realistic, additional refinement of the model's initialization of migrating populations would better reflect real-world migratory behaviors, to be validated against empirical data.

Both willingness to migrate and risk aversion have significant main effects on decision to migrate. Confirming observations by Bah and Batista (2019), increased willingness to migrate contributed to increased percentages who migrated. Increased risk aversion conversely resulted in decreased migration, as observed by Huber and Nowotny (2018). However, enforcement of border restrictions did not influence migration patterns in the model. These findings may be a result of enforced border restriction still allowing migrants to cross and the model starting all migrants in their home countries, which means Mexican migrants have less distance to travel and thus a greater chance of reaching and crossing the border. The model also did not account for the unique geography or topography of Mexico and Central American countries, which could influence migration routes. Our model represents a small step toward understanding the complex, multidimensional, and nuanced world of human migration. To develop a more comprehensive understand of migration, future model improvements could include empirical data validation, enforcement of complete border restriction, and incorporating a topography for agents to move along roads.

Appendix A. Average Percentage Who Migrated by Parameter and Country of Origin

	Border Restriction: Off			Border Restriction: On			Total
	avg-WTM: 50	avg-WTM: 60	Overall	avg-WTM: 50	avg-WTM: 60	Overall	
Belize	3%	6%	5%	3%	6%	5%	5%
avg-RA: 20	3%	7%	5%	3%	7%	5%	5%
avg-RA: 40	3%	5%	4%	3%	5%	4%	4%
El Salvador	24%	46%	35%	23%	47%	35%	35%
avg-RA: 20	29%	56%	42%	27%	56%	41%	42%
avg-RA: 40	19%	37%	28%	19%	38%	28%	28%
Guatemala	32%	65%	48%	32%	64%	48%	48%
avg-RA: 20	38%	77%	57%	38%	76%	57%	57%
avg-RA: 40	26%	53%	40%	26%	52%	39%	39%
Honduras	27%	54%	40%	27%	54%	40%	40%
avg-RA: 20	32%	64%	48%	32%	64%	48%	48%
avg-RA: 40	22%	44%	33%	22%	43%	33%	33%
Mexico	41%	81%	61%	40%	81%	61%	61%
avg-RA: 20	48%	96%	72%	48%	96%	72%	72%
avg-RA: 40	33%	66%	49%	33%	65%	49%	49%
Total	25%	50%	38%	25%	50%	38%	38%

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