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Shan Li*

Rainfall and self-selection patterns in Mexico-US migration

Abstract

This article studies the role of rainfall in determining the education composition of Mexico-US migration. Emphasizing the relationship between rainfall and migration costs, a revised Roy model indicates that rainfall affects selection on education through not only households' liquidity constraints but also the comparisons between changes in migration costs and wage differentials at different levels of education. With retrospective data on the migration history of male Mexicans, the empirical analysis shows that the inverted U-shaped relationship between migration probabilities and education is less dispersed with a higher vertex when rainfall decreases, suggesting higher migration costs and reinforced self-selection patterns. The impacts of rainfall on selection and education are stronger for the migrant stock than for migration flows. Studying how rainfall influences migrants' return decisions provides consistent results.

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1 Introduction

With large semi-arid areas, Mexico has a long history of drought. Its primary crop, which is maize, mainly grows on rain-fed land, and this characteristic leads to a high dependence on rainfall for agriculture. Given the fact that about 30% of male workers worked in the agricultural sector in the 1990s, Mexican household income is sensitive to precipitation anomalies historically. In drought, migration is one of the coping strategies. Literature finds that rainfall deficits increase the propensity of Mexicans to migrate to the United States, especially for farmers or rural residents in dry Mexican states (Munshi, 2003; Feng et al., 2010; Hunter et al., 2013; Fishman and Li, 2017). This drought-driven migration appears to relate low educational attainments to “climate refugees.” However, the real role of rainfall in determining the skill or education composition of migration flows has not been fully explored yet.

Studying whether Mexican migrants to the United States are composed of more highly educated individuals has important political and economic implications for both countries. The existing literature, nevertheless, offers conflicting findings regarding migration selection on education. Ambrosini and Peri (2012) and Moraga (2011) have found that Mexican migrants have less schooling than non-migrants, supporting the negative migration selection when the home country has more dispersed income distribution (Borjas, 1987). In contrast, Mishra (2007) found a positive selection on education, which is consistent with Chiswick’s (1999) model, which argues that high migration costs impede the migration movements of low-skill workers. Furthermore, Moraga (2011) also provided evidence for migrants’ lower wages, compared to non-migrants in Mexico, challenging Chiquiar and Hanson (2005) and Kaestner and Malamud (2014), who concluded that there is intermediate selection on wage earnings of Mexican migrants.

McKenzie and Rapoport (2010) explicitly provided one of the explanations for the absence of consensus on the direction of migration selection. They indicated that the selection on education tends to be positive or neutral in Mexican communities with weak networks in the US, but negative in communities with strong networks. Different data sets of communities yield different conclusions on selection. In addition to networks in communities, other potential determinants of selection include economic conditions, migrants’ networks at the household level, and border enforcement, as Orrenius and Zavodny (2005) displayed their significant influences on the skill level of illegal Mexican migrants to the US.

If “climate refugees” are less educated than other migrants as people may think, then rainfall affects migration selection as well. Data sets with different time lengths and geographic/atmospheric characteristics lead to different answers to the direction of selection.

Thinking of wage differentials between countries netting migration costs as demonstrated by Sjaastad (1962), conditions of insufficient rainfall, for example, drought, may hurt the income of Mexicans; people without liquidity constraints are more likely to migrate to the US due to larger wage differentials, while those who cannot afford upfront migration costs have to stay in Mexico. If less-educated people face tighter constraints in liquidity or ability as suggested by Angelucci (2015), drought-driven migration may not lead to higher possibilities of negative selection. This article demonstrates that the effects of rainfall on wage or income differentials and on migration costs differ by Mexicans’ educational attainments, resulting in changes in the selection on education.

Studies have suggested that decreases in rainfall lower the income of Mexicans differently at education levels. Poorly educated people are more likely to take agricultural jobs and are more vulnerable to climatic fluctuations. This results in more severe inequality in Mexico when rainfall decreases, although drought may negatively impact both crop income and non-farm income (Gathmann, 2008; Dell et al., 2014; Hunter et al., 2013; Fishman and Li, 2017).

However, relatively little is known about the possible effects of rainfall on migration costs. Rainfall may affect migration costs, including upfront monetary costs that may impede the movements of poorly educated people who cannot afford them. When decreases in rainfall lead to larger wage differentials and drive more Mexicans to migrate to the US as stated in Munshi (2003), there may be a higher and stronger demand for migration-related services, such as using coyotes, taking transportations, utilizing networks in the US, and borrowing to cover corresponding expenditures. In this article, a theoretical analysis of the seemingly constant supply of other migration-related services suggests a negative relationship between rainfall and migration costs. This is verified by empirical evidence on higher coyote (smuggler) prices, more difficulties in border crossing, and lower chances of using networks in drier years.

Considering the changes in wage differentials and migration costs caused by different rainfall levels, this article uses the models in Roy (1951), Borjas (1987), and Cattaneo and Peri (2016) to study the effects of rainfall on migration selection. Wage differentials net of migration costs determine migration decisions at different education levels. When individuals are indifferent between staying in Mexico and traveling to the US, the threshold levels of education for migration decisions can be derived. Rainfall affects these thresholds through liquidity constraints as well as the comparisons between changes in wage differentials and migration costs, thus influencing the selection on education.

Empirically, using retrospective data on male Mexicans' migration history from the Mexican Migration Project (MMP), the author finds that individuals from the middle of education distribution are more likely to be migrants, when compared to those from the tails of education distribution, suggesting intermediate selection. Lower rainfall levels reinforce this selection because the inverted U-shaped relationship between migration probabilities and education is less dispersed with a higher vertex when rainfall decreases. The least educated people without a primary school diploma lower their probabilities to migrate to the US in drier years because higher migration costs give them tighter liquidity constraints. Another possible explanation is that the increases in migration costs are larger than the increases in wage differentials or the decreases in income in Mexico in drier years, thus making migration less profitable. This latter explanation works better for the declined migration probabilities of most educated people with a college degree, whose income is less vulnerable to lower rainfall levels and whose wealth releases them from liquidity constraints. Opposite changes in migration probabilities are found in the case of people with some years of schooling, especially those who attended middle school and high school. Given their higher migration probabilities in drier years, if liquidity constraints are not binding, it is highly likely that they encounter larger changes in wage differentials than in migration costs. The role played by rainfall deficits in reinforcing original migration selection is more substantial for the migrant stock than for migration flows, supporting higher migration costs with lower rainfall levels. Analysis of return decisions of migrants in the US provides consistent results.

The structure of this article is as follows. In Section 2, the theoretical model underlying the effect of rainfall on migration selection is demonstrated. Section 3 provides a brief description of the MMP data and presents empirical strategies. Section 4 displays the main results showing how selection changes with rainfall. Robustness checks are also discussed. Section 5 concludes the article.

2 Climate shock and selection

The literature views the migration decision as an investment to maximize migrants' lifetime utility or earnings. Lower migration costs and larger wage differentials between the home and host countries imply higher migration intentions (Sjaastad, 1962; Borjas, 1987; Chiswick, 1999). A series of papers adopt Roy's (1951) model to analyze migration selection on education (Borjas, 1987; Chiquiar and Hanson, 2005; Orrenius and Zavodny, 2005; McKenzie and Rapoport, 2010).

Taking into account considerations of climate change, Cattaneo and Peri (2016) also extend Roy's model to indicate that higher temperatures, which negatively influence agricultural productivity, increase migration rates in middle-income economies while reducing migration rates in poor countries. The primary reason is that poor countries are facing binding liquidity constraints. Though they focus on migration rates in countries with different levels of wealth, a revised model sharing the spirit and allowing for changes in migration costs can be applied to examine how rainfall affects the migration propensity of people with different educational attainments.

2.1 Roy's model

Consider an individual living in the home country, Mexico, and deciding whether to migrate to the host country, the US. Suppose his labor market performance depends on his skills (education levels). The wage equations in Mexico (subscript 0) and the US (subscript 1) can be written as follows.

$$\text{Mexico: } \ln(w_0) = \mu_0 + \delta_0 s, \quad (1)$$

$$\text{The US: } \ln(w_1) = \mu_1 + \delta_1 s, \quad (2)$$

where w_i ($i = 0, 1$) is the wage, $\mu > 0$ denotes the wage level with no schooling, $\delta > 0$ is the return to schooling, s . The wage level with no schooling is higher in the US while Mexico has a higher return to schooling; thus I the author assumes $\mu_1 > \mu_0$ and $\delta_0 > \delta_1$ (Chiquiar and Hanson, 2005; McKenzie and Rapoport, 2010).

Earnings in Mexico are assumed to be affected by rainfall in Mexico through wage level with no schooling, μ , and return to schooling, δ , therefore, Eq. (1) becomes $\ln(w_0) = \mu_0(R) + \delta_0(R)s$, where R denotes rainfall in Mexico that the individual experiences.

The author assumes $\partial\mu_0/\partial R > 0$: decreases in rainfall hurt the income of people with no schooling. Without well-developed insurance markets, uneducated people suffer a monetary loss in drought due to lower crop yield and impaired non-farm income. Furthermore, a higher return to schooling in drier years is assumed: $\partial\delta_0/\partial R < 0$. People who are more

educated may self-select into job positions which are less vulnerable to natural disasters and diversify their income packages to avoid substantial losses arising which arise from climate fluctuations.¹

2.2 Migration costs

When regional rainfall in Mexico has no effects on migrants' income in the US, an individual in Mexico will migrate to the US if

$$\ln(w_1) - \ln(w_0 + C) \approx \ln(w_1) - \ln(w_0) - \pi > 0 \quad (3)$$

where C denotes migration costs. Migration costs in time equivalent units, $\pi = C/w_0$, are assumed to decrease with schooling (Chiswick, 1999; Chiquiar and Hanson, 2005; McKenzie and Rapoport, 2010). Without enough money, either from savings or credits, to pay for the upfront migration costs, Mexicans are not able to afford the migration trip even if condition (3) above is satisfied.

Migration costs mainly include upfront costs, such as transportation costs and coyote (smuggler) prices, and other costs, such as seeking help from networks and finding lodgings in the US. How rainfall influences these migration costs depends on its impacts on both the demand and supply in the market. In drier years, the lower-income of Mexicans suggests larger wage differentials and therefore stronger demand for migration services. More potential migrants and their higher willingness to pay for the movement lead to a higher and steeper downward sloping demand curve.

However, the manner by which the supplies of different migration costs change is ambiguous. The supplies of transportation services and existing networks in the US seem not to be affected by rainfall in the short run, since international train or flight services do not change greatly while networks in the US are mainly determined by historical migration. Stronger demand for them in drought may lead to higher prices of these services. Section 4 empirically shows that migrants traveling in drier years are less likely to contact and lodge from relatives in the US, implying not only higher monetary costs but also higher psychological costs. Besides, though the changes in the supply of coyote services are not clear, Section 4 also provides some evidence on higher coyote costs for illegal migrants who face lower rainfall levels.

Therefore, migration costs, C , are assumed to increase in drier years, yielding

$$\ln(\pi) = \mu_\pi - \gamma_1 s - \gamma_2 R, \quad (4)$$

where $\mu_\pi > 0$, $\gamma_1 > 0$, $\gamma_2 > 0$. For simplicity, the effects of rainfall on migration costs are assumed to be identical across education levels. However, these effects would be larger for those who are less educated, since less-educated people are willing to pay more for the migration trips due to their larger changes in wage differentials in drought.

¹ When $|\partial\mu_o/\partial R| \gg |\partial\delta_o/\partial R|$, Mexican people at different education levels all suffer a decrease in income in Mexico in a dry year. When $|\partial\mu_o/\partial R| > |\partial\delta_o/\partial R|$, poorly educated people still experience an income loss as rainfall decreases, while it is possible that the most educated people are not negatively affected.

2.3 Decision and selection

If the values of s satisfy

$$\ln(w_1) - \ln(w_0) - \pi = \mu_1 + \delta_1 s - \mu_0(R) - \delta_0(R)s - e^{\mu_1 - \gamma_1 s - \gamma_2 R} = 0, \quad (5)$$

then individuals with s years of schooling are indifferent between staying in Mexico and migrating to the US. Viewing migration as an investment, the author sets $A = \ln(w_0) + \pi = \mu_0(R) - \delta_0(R)s + e^{\mu_1 - \gamma_1 s - \gamma_2 R}$ to capture the entire costs of the investment, including opportunity costs (income in Mexico); set $B = \mu_1 + \delta_1 s$ to denote the monetary return to the investment, namely migrants' earnings in the US. To show the difference between them graphically, Figure 1 uses curved lines and straight lines to denote A and B , respectively.² The interactions indicate the threshold values. In line with Chiquiar and Hanson (2005), McKenzie and Rapoport (2010), and Moraga (2013), the least educated Mexicans ($s < s_L$) choose not to migrate due to unaffordable migration costs, while the most educated people ($s > s_U$) with low migration costs would stay in Mexico to enjoy the high return to education in Mexico. Mexicans with years of schooling between two threshold values in Figure 1, s_L and s_U , prefer to migrate to the US.

The relationship between threshold values and rainfall is defined by $\partial s / \partial R$. Taking the derivative of R on both sides of Eq. (5), we can get

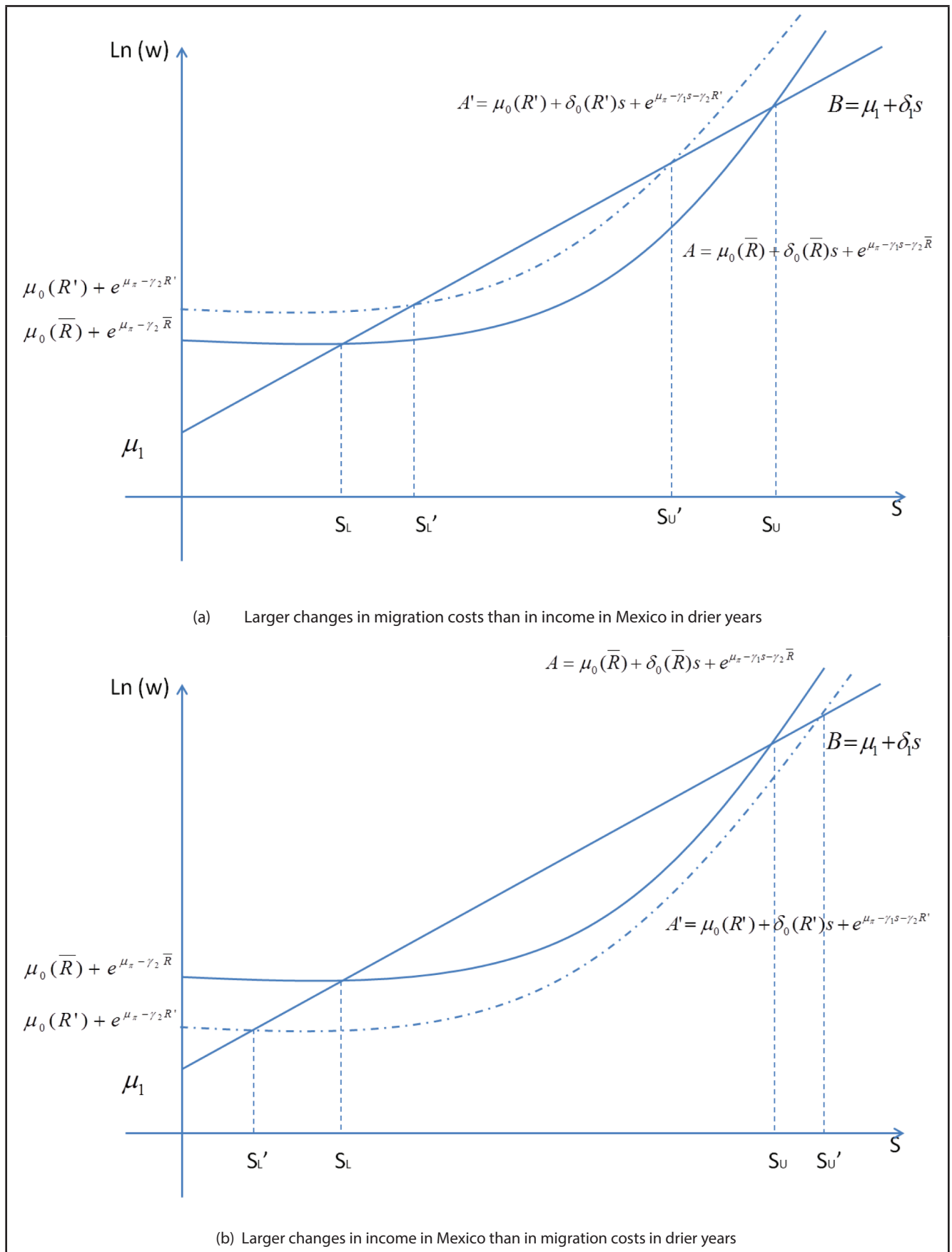
$$(\delta_1 - \delta_0 + \pi\gamma_1) \times \partial s / \partial R = \partial \mu_0 / \partial R + s \times \partial \delta_0 / \partial R - \pi\gamma_2, \quad (6)$$

where $(\delta_1 - \delta_0 + \pi\gamma_1)$ captures the increase in net benefits (wage differentials net of migration costs: $B - A$) from a migration trip when schooling increases by one unit. The right-hand side of Eq. (6), Δ , presents the decrease in net benefits ($B - A$) or the increase in the entire costs (A) of a migration trip when rainfall increases by one unit.

Mexicans with educational attainment around s_L may have high migration costs especially when π is sensitive to education levels. If migration costs and their dependency on education (γ_1) are large enough to make $(\delta_1 - \delta_0 + \pi\gamma_1) > 0$, more years of schooling give larger net benefits from migration, which is consistent with positive selection around s_L . Under these circumstances, it is very likely that $\partial s / \partial R < 0$ when rainfall causes larger changes in migration cost ($\pi\gamma_2$) than in income in Mexico, in other words, $\Delta < 0$. s_L moves to the right in drier years as shown in Figure 1(a). The effects of decreased rainfall on selection through higher migration costs outweigh the effects occasioned through lower Mexican income; then therefore, only those people who have more educated educational credentials with years of schooling greater than s'_L will stick to their original decision because of their larger net benefits from migration. However, people with education levels between s_L and s'_L change their decision because they lack enough adequate net benefits from migration to offset the negative effects of larger changes in migration costs than in income in Mexico. If income in Mexico is more sensitive to rainfall than migration costs, having $\Delta > 0$ and $\partial s / \partial R > 0$, s_L moves to the left in drier years as shown in Figure 1(b). When the decreases in income in Mexico outweigh the increases in migration costs in dry years, people with education levels between s_L and s'_L switch from staying in Mexico to migrating to the US.

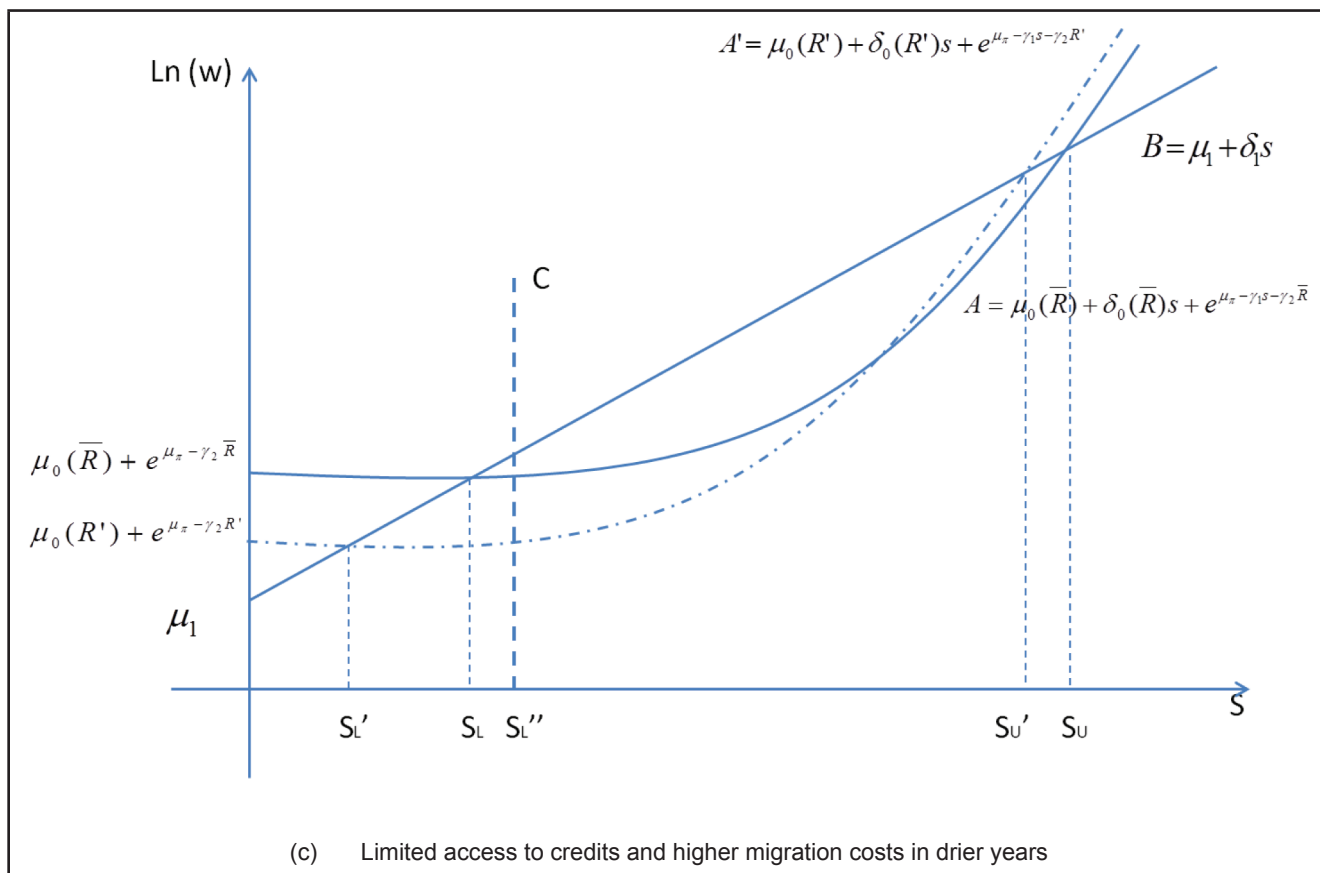
² Figure 1 does not follow the convention in the literature as the straight line in the figure denotes the earnings in Mexico.

Figure 1 Migration selection, schooling, and rainfall.



continued

Figure 1 (Continued)



A denotes the entire costs of migration, including opportunity costs; B denotes the monetary return to the investment, namely migrants' earnings in the US. When $A < B$, people migrate to the US. With lower rainfall, A shifts to A'. The effects of rainfall on selection depend on liquidity constraints and the comparisons between changes in income in Mexico and migration costs.

Unlike Cattaneo and Peri (2016)'s model that assumes higher temperature lowering savings, the author's model here displays a possibility that rainfall affects migration costs, since savings are generally accumulated in previous years. As the failure of the credit and financial markets has plagued Mexico (Hanson, 2010), some people around s_L face tighter liquidity constraints in drier years. Even if the decreases in income in Mexico are larger than the increases in migration costs in drier years as shown in Figure 1(b), the actual threshold value of education may shift to the right as illustrated in Figure 1(c) when increased migration costs exceed savings. In Figure 1(c), people with education levels between s_L and s_L'' may prefer and be able to make a migration trip in normal years, while in drier years they have to stay in Mexico because of higher upfront migration costs.

Similar reasoning can be applied to people with educational attainment around s_U , where a negative selection pattern is demonstrated. Their low migration costs suggest a high possibility that $(\delta_1 - \delta_0 + \pi\gamma_1) < 0$. It is very likely that income in Mexico for them is not significantly affected by rainfall, especially when $|\partial\mu_0/\partial R| > |\partial\delta_0/\partial R|$. Then, $\Delta \approx -\pi\gamma_2 < 0$ and $\partial s/\partial R > 0$. Decreases in rainfall only bring higher migration costs, then s_U moves to the left in drier years as shown in Figure 1(a), as more years of schooling imply lower net benefits from migration. When rainfall has larger effects on income in Mexico than on migration costs, Δ tends to be positive and $\partial s/\partial R$ tends to be negative. s_U may move to the right in drier years as shown in Figure 1(b). People between s_U and s_U' change migration decisions and prefer to move to the US in drier years.

3 Data and empirical strategies

The data used in this article are from the MMP, which randomly sampled households from 3–5 Mexican communities every year since 1982. To include potential permanent migrants' information, the MMP also surveyed some migrating households that have settled down in the US or have not returned to Mexico. Recording detailed migration history of household heads and their spouses, the MMP provides retrospective data on migration trips to the US for temporary migrants (seasonal migrants), permanent migrants, and non-migrants. With demographic and economic information on Mexican households and their members, the MMP has formed the foundation of numerous studies (Durand and Massey, 2004).³

The author's samples are from the 1982 to 2015 MMP surveys, which include 154 communities covering all states in Mexico. Since males are the main financial support in Mexican families while females have a low labor force participation rate, the author's samples only include males who are household heads and are aged from 18 to 70 years. Since an average male household head has about 5 years of schooling, most of the individuals in the author's sample have finished their education and entered the labor market. They are more likely to be economic migrants who are concerned about wage differentials and migration costs in case of travel abroad. A small sample of people who were born in the US has been dropped.⁴

3.1 Rainfall, schooling, and migration probability

Though investigating how the gap in average education levels between migrants and non-migrants changes with rainfall sheds light on selection, it is not quite appropriate to reveal how threshold values in the model and the education composition of migration flows change. Because rainfall tends to affect the migration decisions of people at margin, it is likely that changes in average education levels of migrants and non-migrants in the same direction will occur. For example, in Figure 1(c), people with years of schooling between s_L and s_L'' do not have enough savings and consequently change their original migration decisions and stay in Mexico in dry years, leading to increases in the average level of education of both migrant and non-migrants groups, if we hold s_U unchanged. The gap in average education levels can be either enlarged or narrowed.

Therefore, using person-year unbalanced panels, the author examines whether the effects of rainfall on migration probabilities differ by education levels. To provide more solid analysis, two separate samples for movement decision and migration status are used for the regression below

$$M_{i,c,s,y} = \alpha R_{s,y} + \beta E_{i,y-1} + \gamma E_{i,y-1} \times R_{s,y} + \varphi X_{i,y-1} + A_s + B_y + C_c + e_{i,c,s,y} \quad (7)$$

where $M_{i,c,s,y}$ denotes movement decision or migration status in year y of individual i who is interviewed in community c and resides in state s in year y . Empirically, movement decision refers to the question of whether any actual migration trip to the US, longer than 1 month, in year y is made conditional on no migration experience in year $y-1$. If yes, then this dichotomous

3 The MMP is a bi-national research project co-directed by Jorde Durand (University of Guadalajara) and Douglas Massey (Princeton University). Durand and Massey (2004) also provide evidence for the close correspondence between the MMP and nationally representative surveys regarding migrants' characteristics. I use MMP154 data.

4 Although climate change may also influence Mexicans' trips to Canada, this paper only focuses on migrants' trips to the US, because only 51 household heads ever traveled to Canada in the original dataset.

variable, $M_{i,c,s,y}$, is equal to unity; zero otherwise. Therefore, tourism trips are not regarded as migration experience. Since return trips are not clearly recorded in the MMP, the condition of no US experience in year $y-1$ is set to distinguish migration trips to the US from return trips to Mexico.⁵ In the corresponding sample, except for traveling years in which migrants move to the US, migrants' years in the US have been dropped for not experiencing rainfall in Mexico. However, these years imply migrants' preference for staying in the US. To include them in the analysis, a second sample and a differently defined dependent variable, migration status, is used. Employing individuals' annual location information provided by the MMP and regarding location choices as migration status decisions, the dichotomous dependent variable, $M_{i,c,s,y}$, is set equal to unity if the individual spends at least 1 month in the US in year y , zero otherwise. The corresponding sample for migration status includes all years of individuals no matter where they stay and how frequently they travel.

The movement decision sample focuses on migration flows, while the migration status sample focuses on the migrant stock in the US. Both of them are worth studying. The difference between these two samples is mainly migrants' years in the US, except for their traveling years. Conditional on staying in the US already, migrants make their location decisions without considering upfront migration costs. Therefore, switching from the movement decision sample to the migration status sample, the effects of rainfall through upfront migration costs should be smaller. As discussed above, rainfall may decrease savings to cover upfront migration costs or increase those costs. If migration costs never change, then lower rainfall levels strengthen liquidity constraints only through savings. In the migration status sample, more observations are not troubled by upfront migration costs or liquidity constraints; thus, the negative rainfall-driven effects of migration costs for poorly educated people on their migration decisions should be smaller than that in the movement decision sample. If rainfall deficits increase migration costs, especially those costs after arriving in the US, the rainfall-driven effects of migration costs should be larger in the migration status sample. In other words, migrants who are in the US and sensitive to migration costs may increase their return propensity in drier years if the costs of return trips to Mexico are trivial.

Though two definitions of dependent variables and two samples are used, independent variables are the same. $E_{i,y-1}$ denotes education-related variables. Generally, the author has years of schooling and its squared term in year $y-1$. In specifications that the author groups people based on their years of schooling, $E_{i,y-1}$ presents different educational categories. Coefficients on $E_{i,y-1}$ explain the relationship between migration probability and education, suggesting a selection pattern in migration.

Following Fishman and Li (2017), $R_{s,y}$ is the rainfall in the main agricultural season, spring-summer season, in year y in the individual's home state s in Mexico, measured in 100 mm units.⁶

5 The MMP does not record migrants' return trips to Mexico as clearly as their migration trips to the US. Using individuals' location information in each life year makes it difficult to define migrants returning years. If migrants stay in the US in year $y-1$ but make a new migration trip to the US in year y , it is very likely that migrants firstly return to Mexico in year y and then travel to the US again in the same year. Therefore, with the condition of no US experience in year $y-1$, when migrants make new migration trips to the US every year continuously, those years are dropped in the corresponding sample.

6 Mexico's main agricultural outcome, Maize, has two major agricultural seasons: Spring-Summer (78.5% of total production) and Autumn-Winter (21.5%) (Secretariat of Agriculture, Livestock, Rural Development, Fisheries and Food (SAGARPA) 2008). The Spring-Summer season includes (i) planting period (April–June), (ii) growing period (July–August), and (iii) maturation and harvesting period (September–November).

Table 1 Summary statistics for state level rainfall in Mexico from 1941 to 2012.

	Annual		Rain spring		Rain winter		Drought spring*	
	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
Rainfall (100 mm)	8.81	5.11	7.91	4.39	0.91	1.16	0.14	0.35
Observations	2,291 (32 states in Mexico)							

Source: Rainfall data from the MMP and INEGI. *Drought Spring: a dichotomous variable which is unity if *Rain Spring* in a state is one standard deviation below the historical average of that state; zero otherwise.

The annual seasonal rainfall data from 1941 to 2012 at the state level are from the MMP and Comisin Nacional del Agua (Conagua).⁷ Although the effects of rainfall may last years, the author follows the literature and focuses exclusively on the effects in the short run (Feng et al., 2010; Cattaneo and Peri, 2016; Nawrotzki et al., 2013). In the robustness checks, controlling for rainfall in previous years yields consistent results. Table 1 displays the summary statistics of rainfall in Mexico at the state level. An average Mexican state has 791 mm rainfall in the spring (spring-summer season). Its probability of suffering drought is 14% when drought in each state is defined as one standard deviation below the historical average of that state.

In line with Orrenius and Zavodny (2005) and Cattaneo and Peri (2016), the interaction term between education and rainfall, $E_{i,y-1} \times R_{s,y}$, illustrates how the effects of rainfall on migration decision change with years of schooling and how rainfall shapes the relationship between migration probability and education.

$X_{i,y-1}$ consists of time-varying individual controls including age, marital status, number of children, and a dichotomous variable for previous migration experience. A dichotomous variable for agricultural jobs is also controlled for in some specifications. These individual characteristics, as well as years of schooling, are measured in year $y-1$ to avoid their causal relationship with rainfall.

A_s , B_y , and C_c capture state fixed effects (FE), year FE, and community FE, respectively. They control for economic conditions and border enforcement studied by Orrenius and Zavodny (2005), community-level networks discussed by McKenzie and Rapoport (2010), migration policy changes, such as the Immigration Reform and Control Act (IRCA),⁸ and other state/community characteristics. Community FE does not subsume state FE because of domestic migration. About 35% of individuals in the sample had domestic trips.

Errors are clustered at the state \times year level.

Table 2 displays the summary statistics of characteristics of observations, person-years, in both the movement decision (travel) and migration status (in the US) samples. These two samples give similar facts. Regarding years of schooling, migrants are largely from the category "Primary." The frequencies of people from *Primary*, *Middle*, and *High* categories are larger for migrants, suggesting intermediate selection. In addition, migrants tend to be unmarried, younger, and experienced with migration. Above 50% of migrants hold illegal documents.

⁷ The rainfall database has a few missing values. Corresponding observations are dropped. More localized rainfall indicators are not used due to the limitation and confidentiality requirements of the MMP data.

⁸ For more details about IRCA, see Li (2016).

Table 2 Summary statistics of individual-year characteristics of male household heads from 1941 to 2012.

	Movement decision (travel)			Migration status (in the US)		
	Mean	Std. Dev.	Migrants (2%)	Mean	Std. Dev.	Migrants (9%)
	All males			All males		
Travel/In US (%)	2	15		9	28	
School (Years)	5.37	4.50	4.89	5.35	4.44	5.22
No school (0) (%)	17	38	14	17	37	12
Primary (1–5 years) (%)	33	47	39	33	47	38
Middle (6–8 years) (%)	26	44	27	26	44	29
High (9–11 years) (%)	12	32	13	12	32	13
College (12–15 years) (%)	7	26	5	7	26	6
Grad (16–25 years) (%)	5	22	2	5	21	2
Married (%)	68	47	63	68	47	66
Age (years)	34.78	12.90	29.39	34.62	12.76	32.47
Child (number of children)	2.07	2.30	1.94	2.07	2.29	2.06
Migrated before (%)	18	38	49	25	43	88
Illegal (%)			69			54
Number of Observations	574,779		12,829	627,777		54,442

Source: Retrospective data from 1941 to 2012 on the migration history of male household heads in the MMP. The number of observations for the variable *Illegal* is 12,736 and 54,137 for the travel and in the US samples, respectively.

3.2 Return decisions

Many migrants may return to Mexico or transit back and forth across the Mexico-US border. Analysis of return decisions of migrants who already stay in the US should provide some information on changes in wage differentials and migration costs other than upfront costs as rainfall changes.

To study migrants' return decisions, the author replaces the dependent variable in Eq. (7) with a dichotomous variable for migrants' return trips to Mexico and expect opposite signs of coefficients on rainfall related variables. Return decision ($Return_{i,c,s,y}$) is unity if migrant i from Mexican community c and state s returns from the US to Mexico in year y ; zero otherwise. Since the MMP only has individuals' annual location information but no precise records on migrants' return trips, the author constructs two samples using different definitions of a return trip. In the first sample, the dichotomous variable for return in year y is unity if the migrant's location is in the US in year y but is in Mexico in year $y + 1$, zero for locations in the US for continuous years. In the second sample, $Return_{i,c,s,y}$ has the value of unity in year y if the migrant's location is in the US in year $y - 1$ while is in Mexico in year y , conditional on no new migration trips to the US in year $y - 1$; zero if migrants have locations in the US for continuous years. The "Return (Leave)" and "Return (Arrive)" are used to denote the corresponding samples for these two different dependent variables, respectively. Both samples drop migrants' years when (1) migrants' locations are in Mexico but return trips are not found, or when (2) migrants make new migration trips to the US every year continuously. The second sample has a larger sample size.⁹

4 Results

4.1 Migration costs

Before presenting the relationship between selection on schooling and rainfall, the author studies the increasing migration costs in drier years as given in Tables 3 and 4. Using limited data in the MMP on migration costs, Table 3 displays a strong negative correlation between rainfall and illegal migration costs; Table 4 suggests fewer benefits from networks in the US and tighter liquidity constraints in years with lower rainfall levels.

Illegal migration costs in Table 3 include (1) monetary costs of hiring a coyote (smuggler) to lower apprehension probability and (2) extra costs associated with unpopular border crossing sectors. Controlling for community FE, state FE, and year FE, column (1) in the first panel regresses non-zero coyote costs of illegal trips to the US on rainfall ($R_{s,y}$) in migrants' hometowns. When rainfall decreases by one standard deviation (439 mm), coyote costs increase by about 35 dollars, 7% of the average coyote costs.¹⁰ Results do not change greatly after controlling for years of schooling in columns (2)–(5), thus changes in selection on schooling should not be the reason for higher individual coyote costs in drier years. Controlling for individual FE, columns (4) and (5) imply that changes in selection on unobserved abilities are not the reason

⁹ For example, if the location information for a migrant is the US in year 2000 and 2001 but Mexico in year 2002: (1) the first sample has $Return_{2000}=0$ and $Return_{2001}=1$, while year 2002 is dropped; (2) the second sample has $Return_{2000}=0$, $Return_{2001}=0$, and $Return_{2002}=1$.

¹⁰ For illegal migrants who cross the border several times in 1 year, their coyote costs of the latest cross are used. Considering the possible effects of rainfall on exchange rates, using coyote costs in pesos give consistent results.

Table 3 Male migrants' coyote costs and sector choices change with rainfall.

	Coyote costs in USD				
	(1)	(2)	(3)	(4)	(5)
Rainfall	-7.7718** (3.4833)	-7.7860** (3.4893)	-11.7426*** (4.3320)	-7.6126* (4.3557)	-7.6126 (5.2118)
School		-4.8631*** (1.6115)	-9.9031*** (3.7678)	-26.8254 (19.4667)	-26.8254 (27.7395)
School × Rainfall			0.6594 (0.4270)		
Married		28.8064** (11.2538)	28.6928** (11.2578)	4.4146 (18.7946)	4.4146 (27.0166)
Age		-2.1656*** (0.5972)	-2.2260*** (0.5996)		
Child		0.8596 (2.1556)	0.7900 (2.1517)	0.9558 (4.2650)	0.9558 (6.5539)
Fixed effects	Community FE	Community FE	Community FE	Individual FE	Individual FE
State FE & Year FE	Yes	Yes	Yes	Yes	Yes
Cluster	State × Year	State × Year	State × Year	State × Year	Individual
R ²	0.45	0.45	0.45	0.91	0.91
Number of observations	5,937	5,937	5,937	5,937	5,937
Mean (Coyote)	494.83				
Std. Dev. (Coyote)	400.48				
	Cross-Sector (Selected Coefficients)				
Rainfall	0.0036 (0.0038)	0.0041 (0.0038)	0.0079* (0.0047)	-0.0037 (0.0066)	-0.0037 (0.0083)
School		-0.0004 (0.0018)	0.0045 (0.0039)	-0.0475 (0.0642)	-0.0475 (0.0523)
School × Rainfall			-0.0007 (0.0005)		
Fixed effects	Community FE	Community FE	Community FE	Individual FE	Individual FE
State FE & Year FE	Yes	Yes	Yes	Yes	Yes
Cluster	State × Year	State × Year	State × Year	State × Year	Individual
R ²	0.31	0.31	0.31	0.84	0.84
Number of observations	7,839	7,839	7,839	7,839	7,839
Mean (Sector)	0.40				
Std. Dev. (Sector)	0.49				

Note: Dependent variable: Panel (1): Coyote costs (dollars) (adjusted for CPI (1982–1984)); Panel (2): Dichotomous variable for crossing the border in Tijuana. Independent variable: individual characteristics and rainfall in the home state. Sample: Migrants' traveling years with illegal crossings.

Source: The MMP. Standard errors are reported in parentheses. Stars signify the following: ***significant at 0.01, **significant at 0.05 level, and *significant at 0.1 level.

either. Furthermore, the negative effects of rainfall on migration costs might be smaller for people with more years of schooling, although the positive coefficient on the interaction term between *School* and *Rainfall* in column (3) is barely significant.

Table 4 Male migrants' migration costs (networks) change with rainfall.

	Lodging from relatives	Contacting relatives	Receiving financial help
	(1)	(2)	(3)
Rainfall	0.0086** (0.0042)	0.0056 (0.0045)	-0.0001 (0.0045)
School	0.0022 (0.0018)	0.0025 (0.0019)	-0.0041** (0.0018)
Married	0.0410*** (0.0147)	0.0431*** (0.0151)	-0.0000 (0.0139)
Age	-0.0025*** (0.0007)	-0.0049*** (0.0007)	-0.0053*** (0.0007)
Child	-0.0102*** (0.0032)	-0.0038 (0.0032)	0.0008 (0.0032)
R^2	0.17	0.13	0.21
Rainfall	0.0141*** (0.0051)	0.0106** (0.0050)	-0.0089* (0.0050)
School	0.0090** (0.0043)	0.0086** (0.0041)	-0.0148*** (0.0040)
School × Rainfall	-0.0009* (0.0006)	-0.0008* (0.0005)	0.0015*** (0.0005)
Married	0.0414*** (0.0147)	0.0434*** (0.0151)	-0.0006 (0.0138)
Age	-0.0025*** (0.0007)	-0.0049*** (0.0008)	-0.0054*** (0.0007)
Child	-0.0100*** (0.0032)	-0.0037 (0.0032)	0.0006 (0.0032)
R^2	0.17	0.13	0.21
Number of observations	6,855	6,874	6,983
Fixed effects	Community FE	Community FE	Community FE
State FE & Year FE	Yes	Yes	Yes
Cluster	State × Year	State × Year	State × Year
Mean (dependent Var)	0.44	0.50	0.59
Std. Dev. (dependent Var)	0.50	0.50	0.49

Note: Dependent variable: Column (1): Dichotomous variable for lodging from relatives upon arriving in the US; Column (2): Dichotomous variable for contacting relatives after arriving in the US; Column (3): Dichotomous variable for receiving financial help for US trips. Independent variable: individual characteristics and rainfall in the home state. Sample: Male household heads' first or last trips to the US (Surveys before 2012 only asked either migrants' first or last US trip. Surveys after 2012 recorded both the first and last trips for migrants traveled multiple times.). State FE, Year FE, and Community FE are included. Errors are cluster at State × Year level.

Source: The MMP. Standard errors are reported in parentheses. Stars signify the following: ***significant at 0.01, **significant at 0.05 level, and *significant at 0.1 level.

Conducting a similar analysis in the second panel in Table 3, the dependent variable is changed to a dichotomous variable for the most common cross sector for illegal crossings. It is set at unity if migrants choose Tijuana in Baja California del Norte to cross the border, zero

otherwise.¹¹ Regressions of this choice of sectors for illegal trips on rainfall ($R_{s,y}$) in columns (1)–(3) show that illegal migrants are more likely to switch to unfavorable sectors as rainfall decreases, although only column (3) presents a significant coefficient. Since crossing in remote or unpopular areas requires more time and higher payments to coyotes (Gathmann, 2008), illegal migrants may face extra costs in drier years, supporting the results in the first panel in a degree. People may argue that rainfall may influence migrants' intentions for illegal trips and using coyotes. However, the first panels of Tables A1 and A2 in Appendix show that on average the effects of rainfall on the probability of choosing to be illegal or hiring a coyote are not significant.¹²

Furthermore, focusing on migrants' interactions with their connections or relatives, Table 4 also suggests higher migration costs in drier years for both legal and illegal migrants. The dependent variables in columns (1)–(3) are dichotomous variables for lodging from relatives during their stays, contacting relatives in the US, and receiving financial help for their US trips, respectively. Regressing them on rainfall in Mexico, columns (1) and (2) indicate that lower rainfall levels decrease migrants' possibilities to lodge from or contact their relatives in the US. Migrants travel in drier years, especially those less educated, experience more difficulties in utilizing networks in the US and hence higher migration costs, such as rental, information, and job search costs. Column (3) reveals tighter liquidity constraints since lower rainfall levels increase the probabilities that less-educated migrants receive financial help from friends, relatives, and community members.¹³ Liquidity constraints are mainly associated with upfront costs while taking advantages of networks in the US involves other migration costs.

However, the author admits that it is difficult to identify a solid relationship between migration costs and rainfall in the absence of availability of more detailed data on total migration costs, including money spent on legitimate procedures and transportation. If total migration costs, rather than just coyote costs in illegal migration trips, increase by 7% as rainfall decreases by one standard deviation as shown in Table 3, migration trips become less profitable and more difficult if liquidity constraints bind. Therefore, the costs channel through which rainfall affects migration decision and selection cannot be ignored.

4.2 Rainfall and selection

Regarding the relationship between rainfall and selection on schooling, Eq. (7) has been fitted to the MMP data. Results are reported in Table 5. The first three columns are from the movement decision (travel) sample, while the remaining three columns are from the migration status (in the US) sample.¹⁴

In column (1) of Table 5, the inverted-U-shaped relationship between migration probability and years of schooling suggests that migrants are more likely to be from the middle of the

¹¹ About 40% of illegal crossings in the sample took place in Tijuana. In addition, migrants usually would not change their cross sectors within a year.

¹² Table A1 and A2 in Appendix focus on migrants' choices, while the statement holds even if we include all nonmigrants in the sample.

¹³ In the MMP, about 90% of migrants with financial help report that friends, relatives, and community members are the sources, while the rest of them receive help from employers or banks.

¹⁴ Unweighted specifications are used because sample weights are at the community level, while community FE are controlled for. Weighted regressions give consistent results.

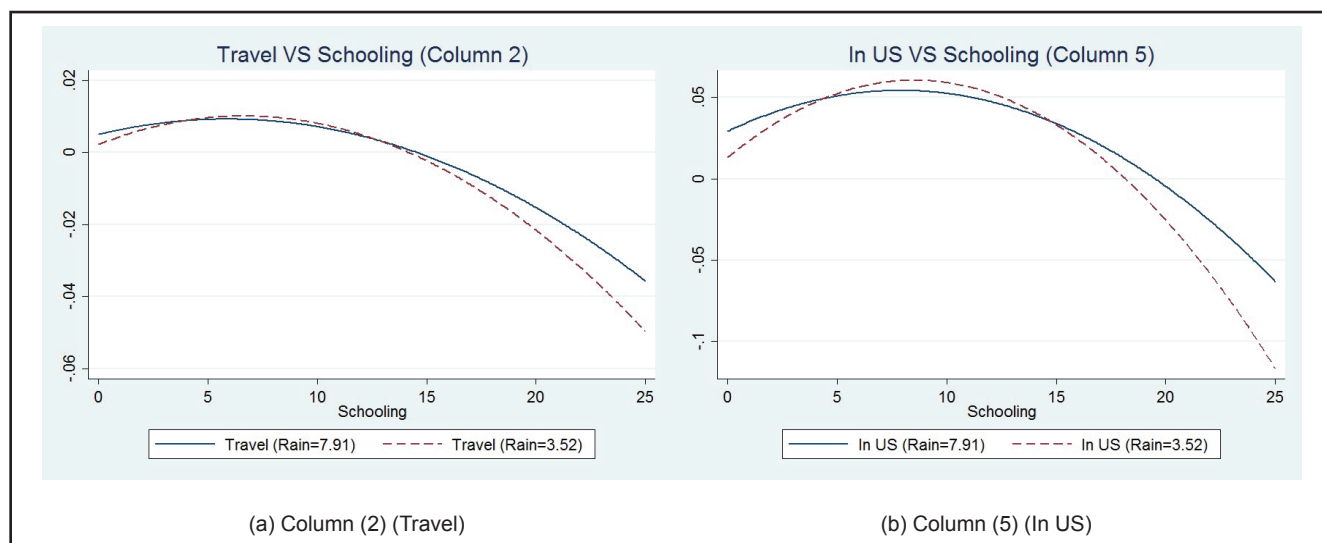
Table 5 Selection on schooling varies by rainfall (selected coefficients).

Dependent variable	Movement decision (travel)			Migration status (in the US)		
	(1)	(2)	(3)	(4)	(5)	(6)
Rainfall	0.0001 (0.0002)	0.0006*** (0.0002)	0.0001 (0.0002)	0.0003 (0.0003)	0.0037*** (0.0004)	0.0009*** (0.0003)
School	0.0014*** (0.0001)	0.0031*** (0.0004)		0.0065*** (0.0003)	0.0150*** (0.0008)	
School × Rainfall		-0.0002*** (0.00004)			-0.0011*** (0.0001)	
School squared	-0.0001*** (0.000001)	-0.0002*** (0.00002)		-0.0004*** (0.00002)	-0.0009*** (0.00005)	
School squared × Rainfall		0.00001*** (0.000002)			0.0001*** (0.000005)	
No school			-0.0092*** (0.0016)			-0.0389*** (0.0031)
Middle			0.0025* (0.0014)			0.0177*** (0.0024)
High			0.0004 (0.0018)			0.0206*** (0.0034)
College			-0.0099*** (0.0017)			0.0082*** (0.0030)
Grad			-0.0163*** (0.0017)			-0.0304*** (0.0029)
No school × Rainfall			0.0005*** (0.0002)			0.0028*** (0.0003)
Middle × Rainfall			-0.0003** (0.0001)			-0.0015*** (0.0003)
High × Rainfall			-0.0003* (0.0002)			-0.0023*** (0.0003)
College × Rainfall			-0.0001 (0.0002)			-0.0020*** (0.0003)
Grad × Rainfall			0.0005*** (0.0002)			0.0009*** (0.0003)
R ²	0.036	0.036	0.036	0.25	0.25	0.25
Number of observations	574,779	574,779	574,779	627,777	627,777	627,777

Note: Dependent variable (Columns (1)–(3)): Travel=1 for actual migration trips, zero otherwise. Dependent variable (Columns (4)–(6)): In US=1 if migrants spend more than 1 month in the US, 0 otherwise. Independent variables: Rainfall in Mexico (state level) and its interactions with education-related variables. Sample (Columns (1)–(3)): male household heads' years in Mexico and traveling years to the US (unbalanced panels). Sample (Columns (4)–(6)): male household heads' life years (unbalanced panels). State FE, Year FE, and Community FE are included. Errors are cluster at State × Year level.

Source: The MMP. Standard errors are reported in parentheses. Stars signify the following: ***significant at 0.01, **significant at 0.05 level, and *significant at 0.1 level.

Figure 2 The inverted U relationship between years of schooling and migration probabilities changes with rainfall.



Setting the values of all control variables to zero and ignoring the constant terms, these figures show the expected migration probabilities versus individuals' years of schooling based on coefficients in Table 5. (a) and (b) are from the movement decision (Travel) sample and the migration status (in the US) sample, respectively. The inverted U curves in droughts are sharper with higher vertexes than curves in normal years. Facing droughts, people with about 5–13 years of schooling increase their migration probabilities, while people with years of schooling fewer than 5 years or more than 15 years decrease their probabilities of migrating

education distribution. This relationship is affected by rainfall as the interaction terms have significant coefficients in column (2). Graphically presenting these results in Figure 2(a), the solid line and dashed line show individuals' probabilities of migrating versus years of schooling at average (791 mm) rainfall level and at one-standard-deviation below average (352 mm) rainfall level, respectively.¹⁵

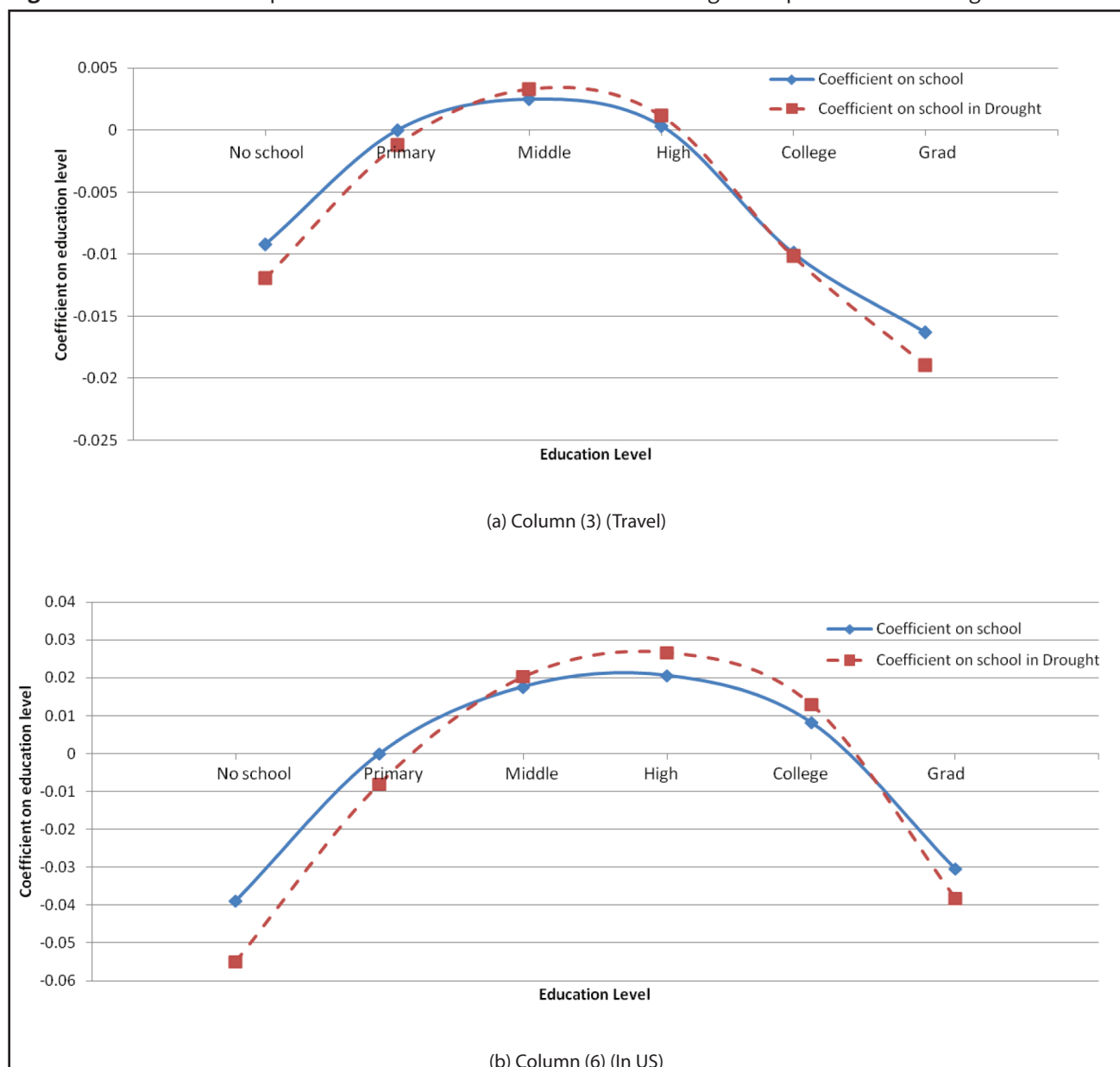
The selection on education in a normal year with average rainfall level tends to be intermediate toward negative since the inverted-U shape shows higher migration probability for relatively poor people. When rainfall decreases, the less dispersed curve indicates increased migration probabilities of people with about 5–12 years of schooling, but decreased migration probabilities of others.

Column (3) of Table 5 provides consistent results by grouping people into different educational categories. Results are transformed into solid and dashed lines in Figure 3(a), which represent the coefficients on educational categories and their changes caused by *Rainfall* decreasing by one standard deviation, respectively. Compared to *Primary*, which is the benchmark, people in categories *Middle* and *High* are more likely to migrate, while people in categories *No school*, *College*, and *Grad* are less likely to migrate. In drier years, people in categories *Middle* and *High* increase their migration probabilities, while those in categories *No school*, *Primary*, and *Grad* lower their probabilities. The dashed line provides a less dispersed curve.

These changes in the selection are consistent with Figure 1(c). Decreases in rainfall lead to lower migration probabilities of the least educated people. In drier years, these people may experience larger increases in migration costs than increases in wage differentials. As

¹⁵ For simplicity, the values of other control variables are set to zero in Figure 2, since they only contribute to the parallel movements of lines.

Figure 3 The relationship between educational attainments and migration probabilities changes with rainfall.



Points on the solid line represent the coefficients on educational categories based on the migration regression results in Table 5. Points on the dashed line represent the changed coefficients on educational categories caused by a decrease in rainfall (439 mm). Both (a) and (b) show an inverted U relationship between migration probabilities and educational attainments. When rainfall decreases, people in categories Middle and High have higher probabilities to travel to or stay in the US, while people in categories No school, Primary, and Grad reveal lower migration probabilities.

migration becomes less attractive to them, they may give it up voluntarily. When the opposite happens, tighter liquidity constraints should be the main factor impeding their movement. If migration costs, including upfront costs, are not affected by rainfall, only declines in savings could lead to the reinforced positive selection on education among those identified as poorly educated people, as shown in Table 5, and Figures 2 and 3. However, if we believe that rainfall in the spring does not affect Mexicans' savings, which are largely likely to have been accumulated in previous years, in Table 5, higher upfront costs as shown in Table 3 are the only reason for tighter liquidity constraints as shown in column (3) of Table 3.

In addition, given the fact that people in the *Middle* and *High* categories are more likely to migrate in drier years, we know that at least some people have larger increases in wage differentials than increases in migration costs. Besides, liquidity constraints are not hindering their movement.

As for people who are highly educated, such as those with graduate degrees, their lower migration propensities in drier years may mainly result from higher migration costs, especially those do not decline as education levels increase since their income in Mexico may not be sensitive to rainfall. Another possible explanation is that their income in Mexico may increase as rainfall decreases since the prices of unskilled labor may decline.

Using the migration status sample to study people's location choices every year, columns (3)–(5) of Table 5 and corresponding figures give stronger results than the movement decision sample. Both the magnitudes of coefficients on variables of interests and the magnitudes of gaps between solid and dashed lines in Figures 2 and 3 are larger for the migration status sample. If the costs of migrants in the US returning to Mexico are negligible, the difference between these two samples mainly represents years spent by migrants in the US, during which upfront migration costs or liquidity constraints should be excluded from their concern. Assuming other migration costs do not change by rainfall, in drier years at least those poorly educated migrants in the US should have stronger intentions to stay and present smaller gaps between lines for the migration status sample. However, this contradicts the fact that larger gaps between lines in Figures 2 and 3, implying their higher return rate. A good explanation is that migration costs, other than upfront costs, increase as rainfall decreases. It is quite possible that upfront costs only make up a small portion of total migration costs, while the rest are more sensitive to rainfall.

Migrants in the US who are from the *High* category prefer to stay in the US when there is a reduction in rainfall probably because they benefit more from migration as rainfall decreases.

People in this category display higher incentives to migrate as rainfall decreases in the movement decision sample. As upfront costs being absent, the trend is stronger due to smaller changes in migration costs for migrants in the US than migrants traveling with upfront costs.

The comparison between results from those two samples for people with graduate degrees is unclear because of their small proportion in samples. Migrants in the US increasing their intention to return in drier years may reflect that upfront costs are not significant compared to other costs, such as money and time on searching jobs.

The analysis mentioned above shows that the intermediate selection pattern is reinforced when rainfall decreases. Furthermore, this is more obvious for the migrant stock than migration flows, suggesting higher migration costs as rainfall decreases. The return analysis mentioned in Section 4.3 uses migrants' years in the US and provides supporting results.

4.3 Return

Table 6 presents how migrants' return decisions are determined by rainfall levels in Mexico. Two definitions for migrants' returns and corresponding samples are used as mentioned in the data section. They give consistent results. In columns (1) and (3), coefficients on *School*, *School Squared*, and their interaction terms with *Rainfall* have expected signs, which are the opposite of the signs of coefficients in the migration decision regressions in Table 5. Figure 4 uses two

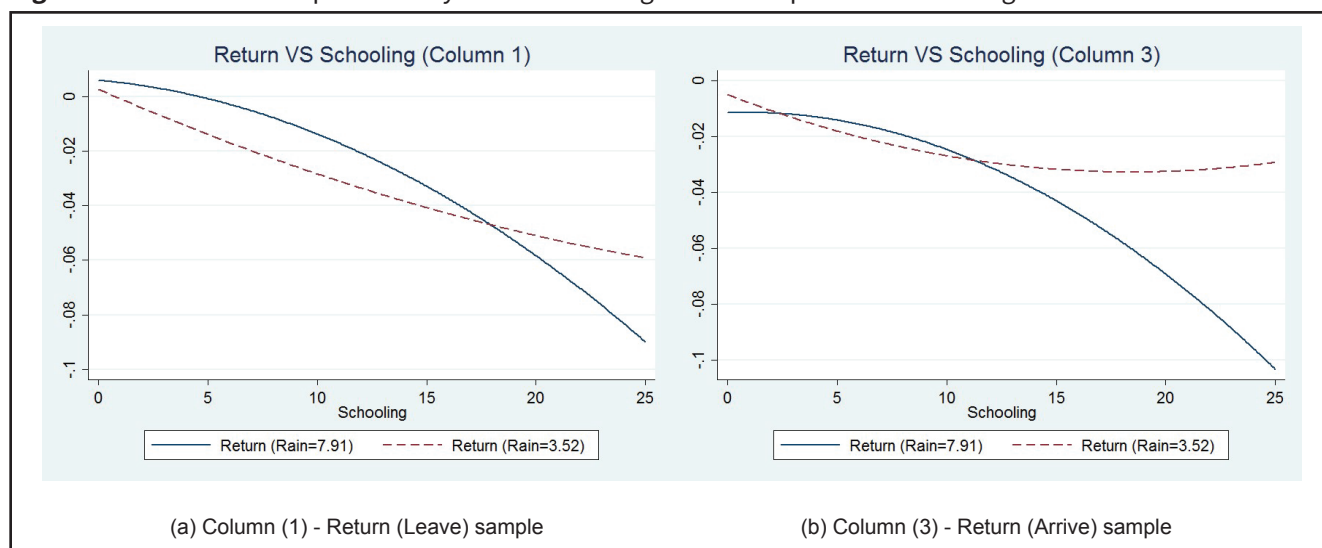
Table 6 Return decision varies with rainfall by schooling (selected coefficients).

Dependent variable	Return (leave)		Return (arrive)	
	(1)	(2)	(3)	(4)
Rainfall	0.0007 (0.0021)	0.0024 (0.0019)	-0.0015 (0.0020)	0.0004 (0.0016)
School	-0.0058* (0.0033)		-0.0056* (0.0030)	
School × Rainfall	0.0006 (0.0004)		0.0007* (0.0004)	
School squared	0.0002 (0.0002)		0.0003 (0.0002)	
School squared × Rainfall	-0.00004 (0.00002)		-0.0001** (0.00002)	
No school		0.0100 (0.0184)		0.0109 (0.0160)
Middle		0.0042 (0.0109)		0.0017 (0.0101)
High		-0.0397*** (0.0130)		-0.0233** (0.0117)
College		-0.0374*** (0.0143)		-0.0239* (0.0132)
Grad		0.0267 (0.0229)		0.0382* (0.0223)
No school × Rainfall		-0.0009 (0.0024)		-0.0015 (0.0021)
Middle × Rainfall		-0.0007 (0.0015)		-0.0003 (0.0014)
High × Rainfall		0.0035** (0.0018)		0.0016 (0.0015)
College × Rainfall		0.0009 (0.0020)		-0.0002 (0.0018)
Grad × Rainfall		-0.0066** (0.0027)		-0.0082*** (0.0026)
R^2	0.059	0.06	0.043	0.044
Number of observations	36,340	36,340	39,749	39,749
Mean (return)		13%		12%
Std. Dev. (return)		0.34		0.33

Note: Dependent variable: Return = 1 if migrants return to Mexico, 0 if migrants stay in the US. Independent variables: Rainfall in Mexico (state level) and its interactions with education-related variables. State FE, Year FE, and Community FE are included. Errors are cluster at State × Year level.

Source: The MMP. Standard errors are reported in parentheses. Stars signify the following: ***significant at 0.01, **significant at 0.05 level, and *significant at 0.1 level.

Figure 4 The relationship between years of schooling and return probabilities changes with rainfall.



Setting the values of all control variables to zero and ignoring the constant terms, these figures show the expected or predicted return probabilities versus individuals' years of schooling based on coefficients in Table 6. Facing droughts, migrants with some years of schooling lower their return probabilities, while the least educated migrants and the most educated migrants increase their probabilities of return to Mexico.

lines to display the relationship between return decisions and years of schooling at different rainfall levels. In a normal year with an average rainfall level (791 mm), migrants with fewer years of schooling are more likely to return. However, in a drier year, migrants with about 4–12 years of schooling tend to stay, while migrants with no years of schooling (Figure 4(b)) or more than 12 years of schooling are more likely to return to Mexico. Columns (2) and (4) of Table 6 confirm that by using different educational categories. The original selection on education in return migration is also reinforced in drier years.

4.4 Robustness

The following robustness checks provide consistent results, though some of the result tables are not reported in the present article.

Mexicans who work in the agriculture sector may be more sensitive to rainfall. Controlling for the occupational dichotomous variable, *Agriculture*, and dropping observations without a job does not bring about any significant change in results. Agricultural workers may experience larger changes in wage differentials as well as migration costs when rainfall levels change. Distinguishing agricultural workers from nonagricultural workers, Tables A4 and A5 in Appendix show how rainfall affects migration selection on education in those subsamples, respectively.¹⁶ Both tables show reinforced migration selection patterns on education in drier years.

Rainfall in previous years may have continuous effects on later migration decisions. Controlling for rainfall in previous years, for example, comparison of rainfall in the last year with rainfall during the preceding 8 years, provides consistent results.

Applying the Cox proportional hazard model to conduct migration duration analysis, Table A6 in Appendix indicates that migrating in drier years results in longer durations of stay in the US. This is consistent with higher migration costs as rainfall decreases.

¹⁶ The corresponding summary statistics are shown in Table A3 in Appendix.

Since the MMP asks respondents about their migration history to get retrospective data, recall errors may bias results. Limiting the author's samples within the most recent 10 years, or 5 years, or from years after 1987 when Immigration Reform and Control Act (IRCA) was in the act in the US, regressions provide highly consistent results.

One may be concerned about the possible causal effects of rainfall on education, though most of the people in the sample finish their education, owing to the fact that the average years of schooling is about 5. Using the main samples and regressing years of schooling ($E_{i,y-1}$) on rainfall ($R_{s,y}$), Table A7 in Appendix shows that rainfall levels in the current year have no significant effects on education levels in the previous year when individual characteristics and different types of FE are controlled according to different specifications. In addition, limiting the study to people with a job or people whose ages are above 6 years combined with their years of schooling creates subsamples consisting of individuals who barely change their education levels. Employing those subsamples and repeating the empirical analysis give consistent results.

Though controlling for temperature may give a good robustness check, availability of data on state-level temperature is quite limited. The Conagua only provides data on temperature after 1985, while the main samples of the author cover years 1941–2012. National Oceanic and Atmospheric Administration (NOAA) has earlier records from different temperature stations, which were established in different years, presenting too many missing values for some states in Mexico. Using the temperature records from the stations, which are closest to capitals of states, brings measurement errors as well. With the limited data from NOAA, controlling for state-level temperature in regressions does not significantly alter the author's results.

5 Conclusion and discussion

To summarize, a revised Roy model demonstrates that the relationship between rainfall and selection on education is determined by household liquidity constraints and the comparisons between changes in migration costs and wage differentials caused by rainfall fluctuations. People from different educational attainment groups respond differently when faced with climate shocks. Employing retrospective data on Mexican individuals' US migration history, which is provided by the MMP, the inverted U-shaped relationship between migration probability and years of schooling becomes less dispersed with a higher vertex when rainfall levels fall. Specifically, faced with insufficient rainfall, those people who are least educated, with less than 5 years of schooling, have lower migration probabilities, probably due to their tighter household liquidity constraints. Focusing on coyote costs, difficulties of illegal crossings, and utilizing networks in the US, higher migration costs in drier years result in those tighter liquidity constraints. Comparing the increases in both wage differentials and migration costs, in drier years highly educated people with more than 15 years of schooling decrease their migration probabilities, while people from the middle spectrum of education distribution increase their migration probabilities. Declines in rainfall levels reinforce the original selection pattern with a stronger effect for migrant stock than migration flows. Return analysis for migrants in the US supports the conclusion mentioned above.

Though changes in wage differentials and migration costs determine the direction of selection on education, empirical estimation of the effects of rainfall on them is difficult, since panel data on individuals' earnings in both countries and migration costs of all migration

trips are required. In addition, regarding the reasons for liquidity constraints, it is not easy to distinguish the effects of savings from those of upfront migration costs unless more detailed information is available on both. With limited data, studying the effects of rainfall on selection still provides some information.

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Appendix

A.1 Migration behavior

Tables A1 and A2 in Appendix explore how rainfall affects migration behavior related indicators.

In Table A1 in Appendix, the sample includes all migrants' trips (traveling years) to the US. Dependent variables for columns (1)–(3) are dichotomous variables for being illegal migrants,

Table A1 Relationship between rainfall and migration behavior.

	Illegal (1)	Using coyote (2)	Cross alone (3)	Migrated before		
				Mother (4)	Father (5)	Siblings (6)
Rainfall	0.0023 (0.0027)	0.0043 (0.0031)	-0.0028 (0.0030)	0.0006 (0.0010)	0.0000 (0.0021)	-0.0033 (0.0032)
School	-0.0182*** (0.0013)	-0.0161*** (0.0014)	-0.0063*** (0.0011)	0.0042*** (0.0007)	0.0093*** (0.0012)	0.0094*** (0.0014)
Married	-0.0283*** (0.0087)	-0.0120 (0.0099)	-0.0081 (0.0086)	-0.0071* (0.0038)	-0.0118 (0.0079)	-0.0015 (0.0094)
Age	-0.0086*** (0.0005)	-0.0086*** (0.0006)	-0.0014*** (0.0004)	-0.0002 (0.0002)	-0.0045*** (0.0004)	-0.0014*** (0.0005)
Child	0.0162*** (0.0019)	0.0118*** (0.0023)	0.0051*** (0.0019)	-0.0006 (0.0007)	-0.0017 (0.0017)	0.0050** (0.0023)
Migrated before	-0.0660*** (0.0080)	-0.1025*** (0.0090)	-0.0280*** (0.0076)	0.0204*** (0.0035)	0.0522*** (0.0074)	0.1422*** (0.0088)
R^2	0.38	0.33	0.16	0.07	0.27	0.23
Rainfall	-0.0033 (0.0033)	-0.0006 (0.0036)	-0.0059* (0.0033)	0.0038*** (0.0014)	0.0052* (0.0027)	-0.0039 (0.0036)
School	-0.0256*** (0.0029)	-0.0227*** (0.0031)	-0.0104*** (0.0024)	0.0084*** (0.0015)	0.0160*** (0.0026)	0.0086*** (0.0030)
School × Rainfall	0.0010*** (0.0003)	0.0009** (0.0004)	0.0006* (0.0003)	-0.0006*** (0.0002)	-0.0009*** (0.0003)	0.0001 (0.0004)
Married	-0.0286*** (0.0086)	-0.0122 (0.0099)	-0.0082 (0.0085)	-0.0069* (0.0038)	-0.0115 (0.0079)	-0.0016 (0.0094)
Age	-0.0087*** (0.0005)	-0.0086*** (0.0006)	-0.0014*** (0.0004)	-0.0002 (0.0002)	-0.0045*** (0.0004)	-0.0014*** (0.0005)
Child	0.0162*** (0.0019)	0.0118*** (0.0023)	0.0051*** (0.0019)	-0.0006 (0.0007)	-0.0017 (0.0017)	0.0050** (0.0023)
Migrated before	-0.0661*** (0.0080)	-0.1026*** (0.0090)	-0.0280*** (0.0076)	0.0204*** (0.0035)	0.0523*** (0.0074)	0.1422*** (0.0088)
R^2	0.38	0.33	0.16	0.072	0.27	0.23
Number of observations	12,736	12,826	12,826	12,652	12,077	12,826

Note: Dependent variable: Dichotomous variables for illegal trips, using coyotes, crossing alone, and migrated family members. Sample: All migrants' trips to the US. State FE, Year FE, and Community FE are included. Errors are cluster at State × Year level.

Source: The MMP. Stars signify the following: ***significant at 0.01, **significant at 0.05 level, *significant at 0.1 level.

dichotomous variables for hiring coyotes, and dichotomous variables for illegally crossing the border alone, respectively. Controlling for education level, rainfall has no significant effects on them in the first panel. The fact that Table A2 in Appendix limits the sample to illegal trips verifies that. In the second panel in Table A1 in Appendix, the interaction terms between *School* and *Rainfall* suggest that less-educated people in drier years are more likely to be illegal, use coyote, and cross alone. This conclusion would not affect the migration costs analysis in the article since education is controlled for in regression. However, it is not clear whether those behaviors are associated with higher migration costs.

Columns (4)–(6) of Table A1 in Appendix study the relationship between rainfall and family members' migration experience to see whether lower rainfall levels encourage

Table A2 Relationship between rainfall and illegal migration behavior.

	Using coyote	Cross alone
	(1)	(2)
Rainfall	0.0039 (0.0036)	−0.0044 (0.0042)
School	−0.0033* (0.0018)	0.0018 (0.0018)
Married	0.0015 (0.0117)	0.0061 (0.0127)
Age	−0.0039*** (0.0007)	0.0018*** (0.0007)
Child	0.0030 (0.0028)	0.0019 (0.0027)
R^2	0.22	0.2
Rainfall	0.0021 (0.0048)	−0.0017 (0.0050)
School	−0.0057 (0.0043)	0.0053 (0.0041)
School × Rainfall	0.0003 (0.0005)	−0.0005 (0.0005)
Married	0.0013 (0.0117)	0.0063 (0.0127)
Age	−0.0039*** (0.0007)	0.0018*** (0.0007)
Child	0.0030 (0.0028)	0.0019 (0.0027)
R^2	0.22	0.2
Number of observations	7,837	7,837

Note: Dependent variable: Dichotomous variables for using coyotes and crossing alone. Independent variable: Rainfall in Mexico in migrants' traveling year. Sample: All illegal migrants' trips to the US. State FE, Year FE, and Community FE are included. Errors are cluster at State × Year level.

Source: The MMP. Stars signify the following: ***significant at 0.01, **significant at 0.05 level, *significant at 0.1 level.

Table A3 Summary statistics of male household heads (agriculture versus. non-agriculture).

	Migration decision sample			
	Agriculture		Non-agriculture	
	Mean	Std. Dev.	Mean	Std. Dev.
Travel (%)	3	17	2	13
School (Year)	3.25	3.04	6.78	4.67
No school (0) (%)	27	44	10	29
Primary (1–5 years) (%)	43	50	25	44
Middle (6–8 years) (%)	22	41	30	46
High (9–11 years) (%)	6	23	17	37
College (12–15 years) (%)	2	13	10	31
Grad (16–25 years) (%)	0	6	8	28
Married (%)	70	46	70	46
Age (Years)	35.62	13.41	34.14	11.79
Child (number of children)	2.23	2.46	2.06	2.18
Migrated before (%)	21	41	15	36
Number of observations	234,816		308,411	
	Migration status sample			
In the US (%)	8	28	9	29
School (Year)	3.27	3.04	6.73	4.61
No school (0) (%)	27	44	9	29
Primary (1–5 years) (%)	44	50	26	44
Middle (6–8 years) (%)	22	41	30	46
High (9–11 years) (%)	6	23	17	37
College (12–15 years) (%)	2	13	10	30
Grad (16–25 years) (%)	0	6	8	27
Married (%)	70	46	69	46
Age (Years)	35.38	13.27	34.02	11.69
Child (number of children)	2.24	2.46	2.05	2.17
Migrated before (%)	28	45	23	42
Number of observations	254,594			

Source: Retrospective data from 1941 to 2012 on the migration history of male household heads in the MMP.

better-connected migrants to move, because with parents or siblings migrated before, migrants may have more information and connections in the US and therefore lower migration costs. Results show that lower rainfall levels drive migrants with no migrating parents to travel to the US. In other words, migrants who travel in drier years have higher migration costs.

A.2 Duration analysis

The author applies the Cox proportional hazard model to examine the effects of rainfall in migrants' traveling years to study migrants' durations in the US. Income effects of larger wage

differentials in dry years encourage migrants to return sooner when drought-driven migrants have lower financial targets. Substitution effects suggest migrants to stay longer in the US to obtain the relatively high wages. If migration costs increase in drier years, migrants traveling in those years may stay longer in the US to recoup their higher costs. Following Orrenius and Zavodny (2005) and Li (2016), the author provides a brief explanation for the Cox proportional hazard model employed to study durations of all migration trips to the US.

The hazard function that depends on a vector of explanatory variables Z with unknown coefficients β is factored as

$$h(t|Z) = h(t)\exp(\beta'Z), \quad (\text{A1})$$

where $h(t)$ is the base hazard function. The possibility of return is allowed to vary with exogenous variables Z which include R and X in Eq. (7). Differently, all these variables are time-invariant for each trip and measured one year before migrants' trips to the US. Taking all migrants' trips to the US as observations, this Cox model controls for traveling year FE, state FE, and community FE. Errors are clustered at state X year level.

The sign of each coefficient (β) indicates how an explanatory variable affects the hazard rate. The Hazard Ratio (HR) is calculated as $\exp(\beta)$. When $HR > 1$ ($HR < 1$), one unit increase in variable Z raises (reduces) the hazard by $HR-1$ ($1-HR$) and therefore shortens (lengthens) the migration duration.

Table A6 in Appendix indicates that migrants who migrate in drier years tend to stay longer in the US, given hazard ratios for *Rain Spring* being greater than one across specifications. This is consistent with the hypothesis of higher migration costs in the drier year, since migrants may want to stay longer in the US to recoup the costs associated with migration. Columns (2) and (3) of Table A6 in Appendix explore how the inverted U function of migrants' durations and their years of schooling changes with rainfall. In column (3), traveling in drier years, migrants from category *Primary* will stay longer in the US, while other migrants, especially those from category *Grad*, may return sooner.

Table A4 Selection on schooling varies by rainfall - agriculture (selected coefficients).

Dependent variable	Movement decision (travel)			Migration status (in the US)		
	(1)	(2)	(3)	(4)	(5)	(6)
Rainfall	-0.0003 (0.0003)	0.0008*** (0.0003)	0.0001 (0.0003)	0.0007* (0.0004)	0.0052*** (0.0005)	0.0014*** (0.0005)
School	0.0030*** (0.0003)	0.0066*** (0.0008)		0.0089*** (0.0005)	0.0225*** (0.0015)	
School × Rainfall		-0.0004*** (0.0001)			-0.0017*** (0.0002)	
School squared	-0.0002*** (0.00002)	-0.0004*** (0.0001)		-0.0006*** (0.00004)	-0.0012*** (0.0001)	
School squared × Rainfall		0.00002*** (0.000006)			0.0001*** (0.00001)	
No school			-0.0112*** (0.0025)			-0.0473*** (0.0043)
Middle			0.0115*** (0.0029)			0.0356*** (0.0042)
High			0.0183*** (0.0049)			0.0421*** (0.0065)
College			-0.0022 (0.0078)			0.0260** (0.0106)
Grad			-0.0272** (0.0111)			-0.0247 (0.0205)
No school × Rainfall			0.0006** (0.0003)			0.0033*** (0.0004)
Middle × Rainfall			-0.0011*** (0.0003)			-0.0033*** (0.0004)
High × Rainfall			-0.0015*** (0.0005)			-0.0049*** (0.0006)
College × Rainfall			-0.0001 (0.0008)			-0.0037*** (0.0010)
Grad × Rainfall			0.0014 (0.0012)			0.0018 (0.0022)
R^2	0.044	0.044	0.044	0.22	0.23	0.23
Number of observations	234,816	234,816	234,816	254,594	254,594	254,594
Mean (dependent Var)		3%			8%	
Std. Dev. (dependent Var)		0.17			0.28	

Note: Dependent variable (Columns (1)– (3)): Travel=1 for actual migration trips, zero otherwise. Dependent variable (Columns (4)– (6)): In US=1 if migrants spend more than one month in the US, zero otherwise. Independent Variables: Rainfall in Mexico (state level) and its interactions with education-related variables. Sample (Columns (1)– (3)): male household heads' years in Mexico and traveling years to the US (unbalanced panels). Sample (Columns (4)– (6)): male household heads' life years (unbalanced panels). State FE, Year FE, and Community FE are included. Errors are cluster at State × Year level.

Source: The MMP. Standard errors are reported in parentheses. Stars signify the following: ***significant at 0.01, **significant at 0.05 level, *significant at 0.1 level.

Table A5 Selection on schooling varies by rainfall - non-agriculture (selected coefficients).

Dependent variable	Movement decision (travel)			Migration status (in the US)		
	(1)	(2)	(3)	(4)	(5)	(6)
Rainfall	0.0002 (0.0002)	0.0008*** (0.0002)	0.0001 (0.0002)	-0.0002 (0.0004)	0.0031*** (0.0005)	0.0006 (0.0005)
School	0.0007*** (0.0002)	0.0021*** (0.0003)		0.0054*** (0.0004)	0.0120*** (0.0008)	
School × Rainfall		-0.0002*** (0.00004)			-0.0009*** (0.0001)	
School squared	-0.0001*** (0.000001)	-0.0001*** (0.00002)		-0.0003*** (0.00002)	-0.0007*** (0.00004)	
School squared x Rainfall		0.00001*** (0.000002)			0.00004*** (0.000004)	
No school			-0.0097*** (0.0022)			-0.0371*** (0.0043)
Middle			0.0003 (0.0015)			0.0117*** (0.0027)
High			-0.0006 (0.0018)			0.0180*** (0.0038)
College			-0.0074*** (0.0018)			0.0132*** (0.0037)
Grad			-0.0126*** (0.0018)			-0.0270*** (0.0036)
No school × Rainfall			0.0009*** (0.0003)			0.0029*** (0.0005)
Middle × Rainfall			-0.00004 (0.0002)			-0.0011*** (0.0003)
High × Rainfall			-0.0001 (0.0002)			-0.0021*** (0.0004)
College × Rainfall			0.0001 (0.0002)			-0.0021*** (0.0004)
Grad × Rainfall			0.0005*** (0.0002)			0.0005 (0.0004)
R^2	0.03	0.03	0.03	0.3	0.3	0.3
Number of observations	308,411	308,411	308,411	340,364	340,364	340,364
Mean (dependent Var)		2%			9%	
Std. Dev. (dependent Var)		0.13			0.29	

Note: Dependent variable (Columns (1)– (3)): Travel=1 for actual migration trips, zero otherwise. Dependent variable (Columns (4)– (6)): In US=1 if migrants spend more than one month in the US, zero otherwise. Independent Variables: Rainfall in Mexico (state level) and its interactions with education-related variables. Sample (Columns (1)– (3)): male household heads' years in Mexico and traveling years to the US (unbalanced panels). Sample (Columns (4)– (6)): male household heads' life years (unbalanced panels). State FE, Year FE, and Community FE are included. Errors are cluster at State × Year level.

Source: The MMP. Standard errors are reported in parentheses. Stars signify the following: ***significant at 0.01, **significant at 0.05 level, and *significant at 0.1 level.

Table A6 Cox model results: migration duration changes with rainfall (selected coefficients).

	(1)	(2)	(3)
Rainfall	1.0104 (0.0071)	1.0083 (0.0102)	1.0149* (0.0084)
School		0.9371*** (0.0169)	
School × Rainfall		1.0025 (0.0023)	
School squared		1.0041*** (0.0013)	
School squared × Rainfall		0.9997* (0.0002)	
No school			1.0737 (0.0894)
Middle			0.9154 (0.0508)
High			0.8678* (0.0675)
College			0.8163** (0.0838)
Grad			1.6970*** (0.3438)
No school × Rainfall			0.9926 (0.0110)
Middle × Rainfall			0.9961 (0.0074)
High × Rainfall			0.9828* (0.0100)
College × Rainfall			0.9972 (0.0130)
Grad × Rainfall			0.9467** (0.0228)
Number of observations	22,883	22,883	22,883
Mean (duration)	21.41 months		
Std. Dev. (duration)	46.28		

Note: Dependent variable: Duration (months) in the US. Independent Variable: Rainfall in Mexico in migrants' traveling year. Sample: All male migrants' trips to the US. State FE, Year FE, and Community FE are included. Errors are cluster at State × Year level.

Source: The MMP. Hazard ratios are reported in the table. Standard errors for coefficients, rather than hazard ratios, are reported in parentheses. Stars signify the following: ***significant at 0.01, **significant at 0.05 level, and *significant at 0.1 level.

Table A7 The insignificant effects of rainfall on years of schooling.

	Movement decision (travel)				Migration status (in the US)			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Rainfall	-0.0026 (0.0030)	-0.0026 (0.0030)	0.0002 (0.0004)	0.0002 (0.0004)	-0.0015 (0.0027)	-0.0015 (0.0027)	0.0002 (0.0004)	0.0002 (0.0004)
Married	0.0465 (0.0299)	0.0468 (0.0299)	0.1135*** (0.0040)	0.1134*** (0.0040)	0.0476* (0.0289)	0.0478* (0.0288)	0.1050*** (0.0037)	0.1050*** (0.0037)
Age	-0.1241*** (0.0011)	-0.1244*** (0.0011)	0.0009*** (0.0001)	0.0009*** (0.0001)	-0.1234*** (0.0011)	-0.1234*** (0.0011)	0.0009*** (0.0001)	0.0009*** (0.0001)
Child	-0.1366*** (0.0046)	-0.1367*** (0.0046)	0.0009*** (0.0003)	0.0008*** (0.0003)	-0.1403*** (0.0044)	-0.1402*** (0.0044)	0.0007*** (0.0003)	0.0007*** (0.0003)
Migrated before	-0.3278*** (0.0156)	-0.3150*** (0.0155)	-0.0284*** (0.0051)	-0.0281*** (0.0052)	-0.2970*** (0.0163)	-0.3036*** (0.0152)	-0.0200*** (0.0043)	-0.0212*** (0.0043)
Movement decision (travel)		-0.2916*** (0.0315)		0.0034 (0.0028)				
Migration status (in the US)					0.0231 (0.0180)			0.0064** (0.0031)
Rainfall	-0.0043 (0.0089)	-0.0044 (0.0089)	0.0002 (0.0012)	0.0002 (0.0012)	0.0002 (0.0084)	0.0002 (0.0084)	-0.0000 (0.0011)	-0.0000 (0.0011)
Rainfall squared	0.0001 (0.0004)	0.0001 (0.0004)	-0.0000 (0.0000)	-0.0000 (0.0000)	-0.0001 (0.0004)	-0.0001 (0.0004)	0.0000 (0.0000)	0.0000 (0.0000)
Fixed effects	Community	Community	Individual	Individual	Community	Community	Individual	Individual
State FE & Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Cluster	State × Year	State × Year	Individual	Individual	State × Year	State × Year	Individual	Individual
R ²	0.37	0.37	0.99	0.99	0.37	0.37	1	1
Number of observations	574,779	574,779	574,779	574,779	627,777	627,777	627,777	627,777

Note: Dependent variable: School (Years of schooling). Independent variable: individual characteristics and rainfall in home state. Sample (Columns (1)–(4)): male household heads' years in Mexico and traveling years to the US (unbalanced panels). Sample (Columns (5)–(8)): male household heads' life years (unbalanced panels). State FE, Year FE, and Community FE (or Individual FE) are included. Errors are cluster at State × Year or Individual level.

Source: The MMP. Standard errors are reported in parentheses. Stars signify the following: ***significant at 0.01, **significant at 0.05 level, *significant at 0.1 level.