Migration Dynamics, Strategy, and Policy*

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Abstract

Dynamic behavior and strategic interactions are important features of migration decisions. When households make decisions about whether to engage in migration, they take into account dynamic considerations about the future and strategic considerations about what neighboring households are doing. We develop and estimate a structural econometric model of the dynamic migration game among households in rural Mexico. We use the estimated parameters to simulate the effects of counterfactual scenarios, including those regarding wages and migration policy, on migration decisions and welfare. Results show that increases in the wage in Mexico not only increase migration within Mexico, but also increase migration to the US. In addition, owing in part to strategic interactions and dynamic behavior, policies that restrict migration from rural Mexico to the US decrease migration not only to the US but also within Mexico as well, cause migration to the US to decrease by more than what is required by the policy, and decrease average welfare per household-year. We find that analyses that ignore the possibility of strategic interactions or dynamic behavior lead to misleading results.

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1 Introduction

According to estimates from the World Bank (2010a), around 3 percent of the world population live in a country different from the one in which they were born. The US is the country with the highest immigrant population in the world, with more than 46 million people who were foreign born (United Nations, 2013), of which about 11 million are from Mexico (World Bank, 2010b). Given the economic significance of migration and its relevance for policy (Rojas Valdés, Lin Lawell and Taylor, 2020b), it is important to understand the factors that cause people to migrate. We add to the literature on the determinants of migration by incorporating two important features of migration decisions: strategic interactions and dynamic behavior.

Migration decisions are dynamic because households consider the future when making these decisions, basing them not only on the current state of economic factors, but also on the prospects of economic opportunities in other areas and the potential streams of net benefits (or payoffs) from migrating. Migration decisions are also dynamic because these decisions can be viewed as forms of investment that are made under uncertainty. Migration decisions are at least partially irreversible, there is leeway over the timing of these decisions, and the payoffs from these decisions are uncertain; as a consequence, there may be an option value to waiting before making these decisions that makes these decisions dynamic rather than static (Dixit and Pindyck, 1994).

In addition to being dynamic, migration decisions are also strategic. We define 'strategic interactions' as arising whenever the migration decisions of other households in the village affect a household's payoffs from migration and therefore its decisions to have a member migrate. There are several reasons why a household's migration decisions may depend on the migration decisions of its neighbors, including migration networks (Massey and Espionsa, 1997; Munshi and Rosenzweig, 2016), information externalities (Massey, Goldring and Durand, 1994), relative deprivation (Taylor, 1987; Stark and Taylor, 1989; Stark and Taylor, 1991), risk sharing (Chen, Szolnoki and Perc, 2012; Morten, 2019), competition effects (Rojas Valdés, Lin Lawell and Taylor, 2020a), a limited number of employers at the destination site who do not discriminate against migrants from elsewhere (Carrington, Detragiache and Vishwanath, 1996), the marriage market (Riosmena, 2009), and cultural norms (Kandel and Massey, 2002; Rojas Valdés, Lin Lawell and Taylor, 2020b). Our structural model is general enough to capture multiple possible sources of strategic interactions, and enables us to analyze their net effect.[1]

[1]We choose to use the term 'strategic interactions' instead of 'peer effects' for two main reasons. First, the term 'peer' often connotes an individual; in contrast; the decision-makers we examine are households rather than individuals. Second, a possible source of strategic interactions we allow for in our analysis is a

Owing to strategic interactions and dynamic behavior, the migration decisions of households in a village can be thought of as a dynamic game in which each household makes decisions about whether to engage in migration, taking into account dynamic considerations about the future and strategic considerations about what other households in the village are doing. We develop and estimate a structural econometric model of the dynamic migration game among households in rural Mexico.

While strategic interactions and dynamic behavior are features of migration that have been considered in previous reduced-form, structural, and calibrated models (see e.g., Munshi, 2003; Kennan and Walker, 2011; Munshi and Rosenzweig, 2016; Kaplan and Schulhofer-Wohl, 2017; Lessem 2018; Morten, 2019; Liao et al., 2020; Rojas Valdés, Lin Lawell and Taylor, 2020a), we build on the previous literature on the determinants of migration by estimating a structural econometric model that jointly incorporates both strategic interactions and dynamic behavior, and that enables us to calculate welfare and to analyze the effects of counterfactual scenarios on decisions and welfare. A methodological innovation we make to the estimation of structural econometric models of dynamic games is that we address the endogeneity of neighbors' actions by using an exclusion restriction combined with a fixed point algorithm.

There are several advantages to using a structural econometric model. First, our structural econometric model enables us to estimate structural parameters of the underlying dynamic game with direct economic interpretations. These structural parameters include parameters that measure the effects of state variables on household payoffs (utility) and the net effect of the strategic interactions. Unlike parameters from a reduced-form model of strategic interactions (see e.g., Rojas Valdés, Lin Lawell and Taylor, 2020a), our structural parameters account for continuation values that explicitly model how expectations about future affect current decisions. A second advantage to using a structural econometric model is that the parameter estimates can be used to calculate welfare. A third advantage is that the parameter estimates can be used to simulate the effects of counterfactual scenarios on decisions and welfare.[2]

competition effect, which is an effect that is potentially more accurately described as a 'strategic interaction' rather than a 'peer effect'. Nevertheless, our concept of 'strategic interactions' is very similar to that of 'peer effects'.

[2]A potential drawback of structural econometric models is that they require sources of structure (e.g., from economic theory), and the assumptions underlying these sources of structure may or may not hold in reality. We mitigate these concerns by imposing minimal, parsimonious assumptions in our structural econometric model of the dynamic migration game. As we explain in more detail in our description of our model, the primary sources of economic structure in our structural econometric model of the dynamic migration game are dynamic programming and game theory. We use dynamic programming to structurally model dynamic behavior and to incorporate continuation values that explicitly model how expectations about future affect current decisions. We use game theory to structurally model strategic interactions and how the strategy of

We use the estimated parameters to simulate the effects of counterfactual scenarios regarding wages and migration policy on migration decisions and welfare. We find that increases in the wage in Mexico not only increase migration within Mexico, but also increase migration to the US, likely because higher wages make migration to the US more affordable to poor and credit-constrained households. Our result that increases in wages in Mexico will increase migration to the US contradicts a common belief that improving the income of poor households would reduce migration, and therefore that, in order to keep Mexicans in Mexico, one simply needs to improve economic opportunities for Mexicans in their home country.

In addition, owing in part to strategic interactions and dynamic behavior, we find that policies that restrict migration from rural Mexico to the US decrease migration not only to the US but also within Mexico as well, cause migration to the US to decrease by more than what is required by the policy, and decrease average welfare per household-year. The previous literature has shown that barriers to migration from Mexico to the United States do not have a positive effect on US agricultural wages or employment (Clemens, Lewis and Postel, 2018), and may actually have a negative effect on job creation instead (Chassamboulli and Peri, 2020); our results show that such barriers to migration decrease the average welfare of households in rural Mexico.

In order to disentangle the effects of strategic interactions and dynamic behavior in our model, we also simulate counterfactual scenarios in which remove strategic interactions, and counterfactual scenarios in which we remove dynamic behavior. We find that analyses that ignore the possibility of strategic interactions or dynamic behavior lead to misleading results.

The balance of the paper is as follows. Section 2 reviews the related literature. Section 3 presents our model of the dynamic migration game. Section 4 describes our data and application to rural Mexico. Section 5 describes the econometric estimation. Section 6 presents the results of the structural econometric model. Section 7 presents the results of our counterfactual simulations. Section 8 concludes.

one household may depend on the strategies of neighboring households. Aside from dynamic programming and game theory, we impose minimal additional assumptions on our model. For example, our specification of the per-period payoff function is agnostic about the actual functional form of the utility function, the actual nature of the constraints, the actual economic and non-economic channels through which migration affects household utility, and the actual mechanisms by which state variables such as local wages affect utility, and thus is general enough to capture the reduced-form implications of a number of models of general equilibrium behavior of individuals within the household, households in the village, and the village economy.

2 Literature Review

2.1 Determinants of migration

The first strand of literature upon which our paper builds is the literature on determinants of migration. The new economics of labor migration posits the household as the relevant unit of analysis. Using the household as the relevant unit of analysis addresses several observed features of migration that are ignored by individualistic models, including the enormous flows of remittances and the existence of extended families which extend beyond national borders. Most applications of the new economics of labor migration assume that the preferences of the household can be represented by an aggregate utility function and that income is pooled and specified by the household budget constraint.

For example, Stark and Bloom (1985) assume that individuals with different preferences and income not only seek to maximize their utility but also act collectively to minimize risks and loosen constraints imposed by imperfections in credit, insurance, and labor markets. This kind of model assumes that there is an informal contract among members of a family in which members work as financial intermediaries in the form of migrants. The household acts collectively to pay the cost of migration by some of its members, and in turn migrants provide credit and liquidity (in form of remittances), and insurance (when the income of migrants is not correlated with the income generating activities of the household). In this setting, altruism is not a precondition for remittances and cooperation, but it reinforces the implicit contract among household members (Taylor and Martin, 2001). In their analysis of how migration decisions of Mexican households respond to unemployment shocks in the US, Fajardo, Gutiérrez and Larreguy (2017) emphasize the role played by the household, as opposed to individuals, as the decision-making unit at the origin. Garlick, Leibbrandt and Levinsohn (2016) provide a framework with which to analyze the economic impact of migration when individuals migrate and households pool income.

Changes in labor demand in the United States has modified the role of migrant characteristics in determining who migrates. Migrants from rural Mexico, once mainly poorly educated men, more recently have included female, married, and better educated individuals relative to the average rural Mexican population (Taylor and Martin, 2001). Borjas (2008) finds evidence that Puerto Rico migrants to the United States have lower incomes, which is consistent with Borjas' (1987) prediction that migrants have incomes lower than the mean income in both the source and host economies when the source economy has low mean wages and high inequality. On the other hand, Feliciano (2001), Chiquiar and Hanson (2005), Orrenius and Zavodny (2005), McKenzie and Rapoport (2010), Cuecuecha (2005), and Rubalcaba et al. (2008) find that Mexican migrants come from the middle of the wage or education distribution. McKenzie and Rapoport (2007) show that migrants from regions with communities of moderate size in the United States come from the middle of the wealth distribution, while migrants from regions with bigger communities in the United States come from the bottom of the wealth distribution.

The financial costs of migration can be considerable relative to the income of the poorest households in Mexico.[3] Angelucci (2015) finds that financial constraints to international migration are binding for poor Mexicans, some of whom would like to migrate but cannot afford to. Migration costs reflect in part the efforts of the host country to impede migration (Hanson, 2010). Migration costs for illegal crossing from Mexico to the United States are estimated to be 2,750 to 3,000 dollars (Mexican Migration Program, 2014). Border enforcement grew by a factor of 13 between 1986 and 2002 (Massey, 2007; Lessem 2018). Estimates reported in Hanson (2010) suggest that the cost of the "coyote" increased by 37 percent between 1996-1998 and 2002-2004, mainly due to the increase of border enforcement due to the terrorist attacks of 9/11. On the other hand, Gathmann (2008) estimates that even when the border enforcement expenditure for the Mexico-United States border almost quadrupled between 1986 and 2004, the increase in expenditure produced an increase the cost of the coyote of only 17 percent, with almost zero effect on coyote demand. Nevertheless, Lessem (2018) finds that increases in border enforcement decrease migration from Mexico to the United States. Feigenberg (2020) finds that US-Mexico border fence construction induces migrants to substitute toward alternative crossing locations, disproportionately deters low-skilled migrants, and reduces the number of undocumented Mexicans in the United States.

Migration decisions may also be affected by weather and climate (Feng, Krueger and Oppenheimer, 2010; Maystadt, Mueller and Sebastian, 2016; Mason, 2017; Mahajan and Yang, 2020). Jessoe, Manning and Taylor (2018) evaluate the effects of annual fluctuations in weather on employment in rural Mexico to gain insight into the potential labor market implications of climate change, and find that extreme heat increases migration domestically from rural to urban areas and internationally to the United States.

The previous economics literature on migration externalities for migrants from Mexico focuses primarily on externalities that arise at the destination site, including, for example, migration networks. For example, Munshi (2003) identifies job networks among Mexican immigrants in the United States labor market. An exception is recent work by Rojas Valdés, Lin Lawell and Taylor (2020a), who estimate reduced-form models to analyze strategic inter-

[3]Data from the National Council for the Evaluation of the Social Policy in Mexico (CONEVAL) show that the average income of the poorest 20 percent of rural Mexican households was only 456 dollars a year in 2012.

actions, or 'neighborhood effects', in migration decisions in rural Mexico. Similarly, recent work on India considers migration externalities in source communities in the form of network effects (Munshi and Rosenzweig, 2016) and risk sharing (Morten, 2019). Our research fills a gap in the literature by accounting for migration externalities that occur in the source community in Mexico in the form of strategic interactions, and by incorporating these strategic interactions in a dynamic setting and with a structural model.

We build on the previous literature on the determinants of migration by estimating a structural econometric model that incorporates both dynamic behavior and strategic interactions, and that enables us to calculate welfare and to analyze the effects of counterfactual scenarios on decisions and welfare.

2.2 Structural econometric models

In addition to the literature on migration, our paper also builds on previous literature using structural econometric models.

There is a burgeoning literature using structural models in development economics. Shenoy (2016) estimates the cost of migration and migration-related supply elasticity in Thailand using a structural model of location choice. To explain the large spatial wage disparities and low male migration in India, Munshi and Rosenzweig (2016) develop and estimate a structural econometric model of the trade-off between consumption smoothing provided by caste-based rural insurance networks, and the income gains from migration. We build on the work of Shenoy (2016) and Munshi and Rosenzweig (2016) by explicitly modeling the dynamic and strategic aspects of international migration, by allowing for multiple channels of strategic interactions in addition to networks, and by applying our model to migration from rural Mexico.

The seminal work of Rust (1987), who develops an econometric method for estimating single-agent dynamic discrete choice models, is the cornerstone of dynamic structural econometric models. Structural econometric models of dynamic behavior have been applied to model bus engine replacement (Rust, 1987), nuclear power plant shutdown decisions (Rothwell and Rust, 1997), water management (Timmins, 2002), malaria prevention (Mahajan and Tarozzi, 2011), labor supply in rural India (Duflo, Hanna and Ryan, 2012), air conditioner purchase behavior (Rapson, 2014), copper mining decisions (Aguirregabiria and Luengo, 2016), wind turbine shutdowns and upgrades (Cook and Lin Lawell, 2020), agricultural disease management (Carroll et al., 2020b), vehicle scrappage programs (Li and Wei, 2013), supply chain externalities (Carroll et al., 2020a), agricultural productivity (Carroll et al., 2019), organ transplant decisions (Agarwal et al., forthcoming), pesticide spraying decisions (Yeh, Gómez and Lin Lawell, 2020; Sambucci, Lin Lawell and Lybbert, 2020), technology adoption (Oliva et al., 2020), and decisions regarding labor supply, job search, and occupational choices (Keane, Todd and Wolpin, 2011).

We build on the emerging literature on dynamic structural econometric models of migration. As many migrations are temporary (Dustmann and Gorlach, 2016), Kennan and Walker (2011) estimate a dynamic structural econometric model of optimal sequences of migration decisions in order to analyze the effects of expected income on individual migration decisions within the United States. Lessem (2018) develops and estimates a dynamic discrete choice model to study how relative wages and border enforcement affect immigration from Mexico to the US. Morten (2019) develops and estimates a dynamic structural model of risk sharing with limited commitment frictions and endogenous temporary migration to understand the joint determination of migration and risk sharing in rural India. We build on these papers by jointly modeling the dynamic and strategic aspects of international migration, by allowing for multiple channels of strategic interactions in addition to risk sharing, and by applying our model to migration from rural Mexico.

While most of the dynamic structural econometric models in development economics model single-agent dynamic decision-making (see e.g., Todd and Wolpin, 2010; Duflo, Hanna and Ryan, 2012; Lessem, 2018; Mahajan, Michel and Tarozzi, 2020; Oliva et al., 2020), we model a dynamic game between decision-makers, and thus allow for both dynamic and strategic decision-making. Structural econometric models of dynamic games include a model developed by Pakes, Ostrovsky and Berry (2007), which has been applied to the multi-stage investment timing game in offshore petroleum production (Lin, 2013), to ethanol investment decisions (Thome and Lin Lawell, 2020), and to the decision to wear and use glasses (Ma, Lin Lawell and Rozelle, 2020); a model developed by Aguirregabiria and Mira (2007), which has been applied to entry, exit, and growth in oligopoly retail markets (Aguirregabiria, Mira and Roman, 2007); a model developed by Bajari et al. (2015), which has been applied to ethanol investment (Yi and Lin Lawell 2020a; Yi and Lin Lawell, 2020b); and models by Pesendorfer and Schmidt-Dengler (2008), de Paula (2009), Srisuma and Linton (2012), and Dearing and Blevins (2019). Structural econometric models of dynamic games have also been applied to fisheries (Huang and Smith, 2014), dynamic natural monopoly regulation (Lim and Yurukoglu, 2018), Chinese shipbuilding (Kalouptsidi, 2018), industrial policy (Barwick, Kalouptsidi and Zahur, 2020), the airline industry (Benkard, Bodoh-Creed and Lazarev, 2019), coal procurement (Jha, 2020), and preemption (Fang and Yang, 2020).

The structural econometric model of a dynamic game we use is based on a model developed by Bajari, Benkard and Levin (2007), which has been applied to the cement industry (Ryan, 2012; Fowlie, Reguant and Ryan, 2016), the ethanol industry (Yi, Lin Lawell and

Thome, 2020), the world petroleum industry (Kheiravar, Lin Lawell and Jaffe, 2020), calorie consumption (Uetake and Yang, 2018), climate change policy (Zakerinia and Lin Lawell, 2020), the global market for solar panels (Gerarden, 2019), and to the digitization of consumer goods (Leyden, 2019).

3 Dynamic Migration Game

We model the migration decisions of households in a village as a dynamic game in which each household makes decisions about whether to engage in migration, taking into account dynamic considerations about the future and strategic considerations about what neighbors in the village are doing.

The players $i = 1, ..., N$ in our dynamic migration game are households within a village. Each year $t = 1, ..., \infty$, each household i chooses an action from a discrete finite set $a_{it} \in A_i$, and all households in the village choose their time-t actions a_{it} simultaneously, such that $\mathbf{a}_t = (a_{1t}, ..., a_{Nt}) \in A$ summarizes the actions played at t.

In our model, the actions are whether to engage in migration to the US, and whether to engage in migration within Mexico. A household is engaging in migration to the US or within Mexico in year t if the household has a household member who is a migrant to the US or within Mexico, respectively, in year t. The actions are not mutually exclusive, so it is possible for a household to engage in both migration to the US and migration within Mexico at the same time. Thus, in each year t, each household i decides whether to have individual members migrate (or continue to migrate) to the US and/or to other areas within Mexico, while also keeping some members in the village.

The time-t actions a_{it} of each household i are assumed to be functions of a set of state variables and private information:

$$a_{it} = \sigma_i(\mathbf{s}_t, \varepsilon_{it}), \tag{1}$$

where s_{it} is a vector of publicly observable state variables for household i; $\mathbf{s}_t = (s_{1t}, ..., s_{Nt}) \in S$ is the vector of state variables for all households at time t; and ε_{it} is an idiosyncratic private information shock to household i that is not observed by either other households or the econometrician. State variables include natural factors, economic factors, and government policy. The profile of strategies is denoted by $\sigma = (\sigma_1, ..., \sigma_N)$.

The state variables at the household level in s_{it} include the number of males in the household, the age of the household head; the schooling of the household head; the maximum level of schooling achieved by any of the household members; the average level of schooling, measured as the number of years of education that have been completed, of household members 15 years old and above; a dummy if the household's first born was a male; the slope and quality of land owned by the household that is irrigated for agricultural purposes, interacted with village precipitation; whether the household engaged in migration to the US the previous year; and whether the household engaged in migration within Mexico in the previous year. The slope and quality of household land interacted with contemporaneous precipitation captures shocks to agricultural home production and therefore to household income that vary by household and year and that may affect migration decisions.

The state variables at the municipality level in s_{it} include the number of schools in the basic system, the number of schools in the indigenous system, the number of cars, and the number of buses. The state-level variables in s_{it} include employment by sector. The national variables in s_{it} are aggregate variables that represent the broad state of the institutional and economic environment relevant for migration, including the average hourly wage, and wage by sector. The border crossing variables in s_{it} includes variables that measure crime, deaths, and border enforcement at nearby border crossing points.

Each period t, each household i receives an idiosyncratic private information shock $\varepsilon_{it} \in E_i$ independent of other players' private shock with distribution $G_i(\cdot|\mathbf{s}_t)$ such that the collection of idiosyncratic shocks is $\varepsilon_t = (\varepsilon_{1t}, ..., \varepsilon_{Nt})$. The private information shocks may represent, for example, shocks to household costs, health, and/or income.

The per-period payoff to each household i, which measures the household i's utility in a given period t, depends on the actions a_{it} played by household i, the actions a_{-it} played by other households, the state variables s_{it} for household i, and household i's private shock ε_{it}. The per-period payoff (or utility) to a household includes anything and everything the household may care about, including both economic and non-economic sources of utility. Our model therefore captures both economic and non-economic motives for migration.

Our action variables are whether to engage in migration to the US, and whether to engage in migration within Mexico. For the actions of neighbors, we include the fraction of neighbors with migration to the US and the fraction of neighbors with migration within Mexico.

The state variables we use in the per-period payoff function include the number of household members; the household head age; a dummy whether the first born child of the household was male; household head schooling; household average schooling; household land quality interacted with rain; the number of basic schools; the hourly wage; the distance to the closest border crossing point; and the crime rate at the closest, second closest, and third closest border crossing points.

We assume that the payoff function is indexed by a finite parameter vector θ, so that the payoff function is given by $\pi_i(\mathbf{a}, s_i, \varepsilon_i; \theta)$. The parameters θ to be estimated are the coefficients on the terms in the per-period payoff function, which include terms that are functions of action variables, strategic variables, demographic characteristics of the household, natural factors, economic factors, and government policies. In particular, the terms in the per-period payoff function include terms for each of the state variables; terms for the state variables squared; and terms that interact each state variable, including the strategic variables, with the household's own action variables.

The payoff function is the per-period payoff for each household. While the parameters θ are common to all households, the values of the action variables, state variables, and private information shocks vary by household; as a consequence, the per-period payoff is specific to and varies for each household.[4]

We account for the important factors in a household's utility maximization decision by including in the payoff function state variables that affect income from migrating; state variables that affect alternative sources of income; state variables that affect costs of migration; state variables that affect household utility; state variables that affect non-economic considerations such as the marriage market; state variables that affect liquidity and other constraints; and state variables that affect the outside option to not engaging in migration. The per-period payoff function therefore includes terms that are functions of actions, strategic variables, demographic characteristics of the household, natural factors, economic factors, and government policy. We also include shocks to the payoff function that may reflect, for example, shocks to household costs, health, and/or income.

In order to separately identify the effects of state variables s_{it} and the effects of the actions a_{-it} played by other households on a household's per-period payoff in the econometric estimation, we impose the exclusion restriction that a household's per-period payoff depends on its own vector of state variables s_{it} but not additionally on the state variables s_{-it} of other households (Bajari et al., 2010). We implement this exclusion restriction by including several household-specific state variables in the vector of state variables s_{it}, including the number of household members; the household head age; a dummy whether the first born child of the household was male; household head schooling; household average schooling; and household land quality interacted with rain.

Our specification of the per-period payoff function is agnostic about the actual functional form of the utility function, the actual nature of the constraints, the actual economic and non-economic channels through which migration affects household utility, and the actual

[4]We do not aggregate all households into a single utility function (although we do aggregate all members of a household into the household's utility function), nor is the payoff function for an "average" household only. Instead, the payoff function is the per-period payoff specific to each household, and the per-period payoff to each household depends on the actions played by all households.

mechanisms by which state variables such as local wages affect utility, and thus is general enough to capture the reduced-form implications of a number of models of general equilibrium behavior of individuals within the household, households in the village, and the village economy. The primary sources of economic structure in our structural econometric model of the dynamic migration game are dynamic programming and game theory.

There are several sources of uncertainty in our model of a dynamic game. First, future values of the state variables are stochastic. Second, each household i receives private information shocks ε_{it} which may represent, for example, shocks to household costs, health, and/or income. Third, each household i is uncertain about the migration decisions that other households will make.

At each time t, each household i makes its migration decisions in order to maximize the expected present discounted value of the entire stream its expected per-period payoffs, without knowing what the future realizations of its idiosyncratic shocks and the state vector will be, and without knowing what other households will decide to do at time t. Thus, in each period, households face different tradeoffs between the benefits and costs they can generate by migrating to a given location (US or within Mexico) versus those benefits and costs of migrating to a different location or not migrating at all. The tradeoffs depend on the parameters, the action variables, the state variables, and the private information shocks.

Household i's dynamic optimization problem is given by:

$$\max_{\{a_{it}\}} \quad E\left[\sum_{t=0}^{\infty} \beta^t \pi_i(\mathbf{a}_t, s_{it}, \varepsilon_{it}; \theta) | \mathbf{s}_t\right]. \tag{2}$$

The equilibrium concept we use for our incomplete information dynamic migration game is that of a Markov Perfect Nash Equilibrium. For each realization of the state vector $\mathbf{s}$, the expected present discounted value of the entire stream of per-period payoffs for household i from playing strategy σ_i is given by:

$$V_i(\mathbf{s}; \sigma; \theta) = E_\varepsilon\left[\pi_i(\sigma(\mathbf{s}, \varepsilon), s_i, \varepsilon_i; \theta) + \beta \int V_i(\mathbf{s}'; \sigma; \theta) dP(\mathbf{s}' | \sigma(\mathbf{s}, \varepsilon), \mathbf{s}) | \mathbf{s}\right]. \tag{3}$$

In a Markov Perfect Nash Equilibrium, the expected present discounted value that each household i receives from playing its equilibrium strategy σ_i is at least as high as the expected present discounted value it could receive from playing any other alternative strategy σ_i':

$$V_i(\mathbf{s}; \sigma; \theta) \geq V_i(\mathbf{s}; \sigma_i', \sigma_{-i}; \theta). \tag{4}$$

4 Data and Application to Rural Mexico

The economic importance of migration from Mexico to the US is twofold. Since the mid-1980s, migration to the US has represented an employment opportunity for Mexicans during a period of economic instability and increasing inequality in Mexico. In addition, it has represented an important source of income via remittances, especially for rural households (Esquivel and Huerta-Pineda, 2007).[5] Remittances from the US to Mexico amount to an estimated 22.8 US billion dollars per year (World Bank, 2012). An average of 2,115 US dollars in remittances is sent by each of the nearly 11 million Mexicans living in the US, representing up to 2 percent of the Mexican GDP (D'Vera et al., 2013). An estimated 13 percent of household total income and 16 percent of per capita income in Mexico come from migrant remittances (Taylor et al., 2008).[6] With a border 3200 kilometers long, the largest migration flow between two countries, and a wage differential for low-skilled workers between the US and Mexico of 5 to 1 (Cornelious and Salehya, 2007), the US-Mexico migration relationship also imposes challenges to policy-makers of both countries (Rojas Valdés, Lin Lawell and Taylor, 2020b).

We use data from the National Survey of Rural Households in Mexico (ENHRUM) in its three rounds (2002, 2007, and 2010[7]). The survey is a nationally representative sample of Mexican rural households across 80 villages and includes information on the household characteristics such as productive assets and production decisions. It also includes retrospective employment information: individuals report their job history back to 1980. With this information, we construct an annual household-level panel data set that runs from 1990[8] to 2010, and that includes household composition variables such as household size, household head age, and number of males in the household. For each individual, we have information on whether they are working in the same village, in some other state within Mexico (domestic migration), or in the United States (international migration).

In our sample, 446 households (28%) had at least one member migrate within Mexico during at least one year of our data set, but never had any member migrating to the US during the time period of our data set; 321 households (21%) had at least one member migrate to the US during at least one year of our data set, but never had any member

[5]Esquivel and Huerta-Pineda (2007) find that 3 percent of urban households and up to 10 percent of rural households in Mexico receive remittances.

[6]Castelhano et al. (2020) find that migrant remittances are not associated with increases in rural investment in agricultural production in Mexico, however.

[7]The sample of 2010 is smaller than the sample of the two previous rounds because it was impossible to access some villages during that round due to violence and budget constraints.

[8]Since retrospective data from 1980 to 1989 included only some randomly selected individuals in each village who reported their work history, we begin our panel data set in 1990.

migrating within Mexico during the time period of our data set; and 316 households (20%) had both at least one member migrating within Mexico during at least one year and at least one member migrating to the US during at least one (possibly different) year of our data set. The remaining 533 households (33%) never engaged in either type of migration during the time period of our data set.

The survey also includes information about the plots of land owned by each household, including slope, quality, irrigation status, and land area.[9] We construct variables for land quality (1=good, 2=regular, 3=bad, 4=very bad (no land)) and land slope (1=flat, 2=inclined, 3=very inclined, 4=very bad (no land)) for the complete panel using the date at which each plot was acquired. Since a plot's slope and quality are unlikely to change over time (unless investments were taken to considerably change the characteristics of the plots, which we do not observe very often in the data), we interact the plot variables with a measure of contemporaneous precipitation at the village level (Jessoe, Manning and Taylor, 2018) so that the resulting interaction variables vary across households and over time. Rain data covers the period 1990 to 2007. The slope and quality of household land interacted with contemporaneous precipitation captures shocks to agricultural home production and therefore to household income that vary by household and year and that may affect migration decisions.

We use information from the National Statistics Institute (INEGI) to control for the urbanization and education infrastructure at the municipality level, including the number of basic schools and the number of indigenous schools. We also include the number of registered cars and buses. These data cover the period 1990 to 2010.

We also include aggregate variables that represent the broad state of the institutional and economic environment relevant for migration. We use data from the INEGI on the fraction of the labor force employed in each of the three productive sectors (primary, secondary, and tertiary)[10] at the state level, from 1995 to 2010. We use INEGI's National Survey of Employment and the methodology used in Campos-Vazquez, Hincapie and Rojas-Valdés (2012) to calculate the hourly wage at the national level from 1990 to 2010 in each of the three productive sectors and the average wage across all three sectors.

We use two sets of border crossing variables. On the Mexican side, we use INEGI's data on crime to compute the homicide rate per 10,000 inhabitants at each of the 37 the Mexican

[9] We use information on plots of land which are owned by the household because our data set does not include comparable information on plots of land that are rented or borrowed.

[10] The primary sector includes agriculture, livestock, forestry, hunting, and fisheries. The secondary sector includes the extraction industry and electricity, manufacturing, and construction. The tertiary sector includes commerce, restaurants and hotels, transportation, communication and storage, professional services, financial services, corporate services, social services, and government and international organizations.

border municipalities. On the United States' side, we use data from the Border Patrol that include the number of border patrol agents, apprehensions, and deaths of migrants at each of nine border sectors,[11] and match each border sector to its corresponding Mexican municipality. We interact these border crossing variables (which are time-variant, but the same for all villages at a given point in time) with measures of distance from the villages to the border (which are time-invariant for each village, but vary for each village-border location pair).

To determine the distance from each village to each border municipality, we use a map from the International Boundary and Water Commission (2013) to obtain the location of the 26 crossing-points from Mexico to the United States. Using the Google Distance Matrix API, we obtain the shortest driving route from each of the 80 villages in the sample to each of the 26 crossing-points, and match the corresponding municipality at which these crossing-points are located. This procedure allows us to categorize the border municipalities into those less than 1,000 kilometers from the village; and those between 1,000 and 2,000 kilometers from the village.

By interacting the distances to the border crossing points with the border crossing variables, we obtain the mean of each border crossing variable at each of the three closest crossing points, and the mean of each border crossing variable within the municipalities that are in each of the two distance categories defined above. We also compute the mean of each border crossing variable among all the border municipalities.[12]

Figure A.1 in Appendix A presents a map of the villages in our sample (denoted with a filled black circle) and the US-Mexico border crossing points (denoted with a red X). Table A.1 in Appendix A presents the summary statistics for the variables in our data set. Table A.2 in Appendix A presents the within and between variation for the migration variables. 'Within' variation is the variation in the migration variable across years for a given village. 'Between' variation is the variation in the migration variable across villages for a given year. For more detailed information on our data set, including additional descriptive and reduced-form analyses of our data, see Rojas Valdés, Lin Lawell and Taylor (2020a).

[11] A 'border sector' is the term the Border Patrol uses to delineate regions along the border for their administrative purposes.

[12] As our data does not distinguish between legal and illegal migration to the US, we assume that the these border crossing variables have a similar correlation with migration decisions and payoffs whether the migration to the US is legal or not. For instance, a higher cost to illegal migration to the US would increase the cost of migrating to the US both for those who migrate illegally, as well as for those whose migration costs increase because they are induced by the higher costs of illegal migration to opt to incur the costs to obtain legal migration status and migrate legally instead. In 2004, around 56 percent of the Mexicans who migrated to the US were unauthorized (Hanson, 2006).

5 Econometric Estimation

Finding a single equilibrium is computationally costly even for problems with a simple structure. In more complex problems – as in the case of our dynamic migration game, where many agents and decisions are involved – the computational burden is even more important, particularly if there may be multiple equilibria (de Paula, 2013). Bajari, Benkard and Levin (2007) propose a method for recovering the dynamic parameters of the payoff function without having to compute any single equilibrium. Their estimation builds on the two-stage algorithm of Hotz and Miller (1993) but allows for continuous and discrete choice variables, so their approach is more general and can be implemented in a broader array of research questions. The crucial mathematical assumption to be able to estimate the parameters in the payoff function is that the same equilibrium is played in every game (which in our model is a village), even if multiple equilibria exist.

Our econometric estimation takes place in two stages. In the first stage, we estimate policy functions that characterize a household's equilibrium strategy as a function of the state vector. We do so by estimating the empirical relationship between the actions and state variables in the data via reduced-form regressions correlating actions to states. This step avoids the need for the econometrician to both compute the set of all possible equilibria and specify how households decide on which equilibrium will be played, as the policy functions are estimated from the equilibrium that is actually played in the data (Ryan, 2012). In this stage, we also recover the transition densities for the state variables, which describe how state variables evolve over time.

Following methods in Hotz et al. (1994) and Bajari, Benkard and Levin (2007), we use forward simulation to estimate the value functions. This procedure consists of simulating many paths of play for each individual given distinct draws of the idiosyncratic shocks, and then averaging over the paths of play to get an estimate of the expected value function. Our methodological innovation is that we address the endogeneity of neighbors' decisions by using an exclusion restriction combined with a fixed point algorithm.

The second stage consists of estimating the parameters of the payoff function that are consistent with the observed behavior. This is done by appealing to the Markov Perfect Nash Equilibrium condition (4), so each observed decision is each household's best response to the strategies of its neighbors. Following Bajari, Benkard and Levin (2007), we estimate the parameters by minimizing profitable deviations from the optimal strategy.

We present further details of the estimation procedure below.

5.1 Policy functions

We estimate policy functions representing the equilibrium strategy for each of the action variables, which in our model are the decision to engage in migration to the US and the decision to engage in migration within Mexico. The policy functions specify the probability that household i will engage in migration, conditional on the (publicly observable) state variables s_{it}, under household i's optimal strategy. Since policy functions are based only on information that is observable to all households, household i's policy function also represents the beliefs that household i's neighbors have about the probability that household i will engage in migration.

We estimate the policy functions using reduced-form regressions correlating actions to states. The policy functions we estimate represent the empirical relationship between the actions and states observed in the data, and simply characterize what households do mechanically as a function of the state vector.

To estimate the policy functions, we regress household i's decision a_{ikt} to engage in migration of type $k \in [USA, Mexico]$ on the fraction $f(a_{-i\tilde{k}t})$ of the households in the same village household i, excluding i, that engage in migration of each type $\tilde{k} \in [USA, Mexico]$; the state variables s_{it}, which include state variables at the household, village, municipality, state, and national level as well as border crossing variables; and on a village fixed effect μ_i, using the following linear probability model:

$$a_{ikt} = \beta_0 + \sum_{\tilde{k}} \beta_{a\tilde{k}} f(a_{-i\tilde{k}t}) + s_{it}'\beta_s + \mu_i + \varepsilon_{ikt}. \tag{5}$$

The state variables in s_{it} that we use for the policy functions include the number of members in the household; the age of the household head; whether the first born is male; the schooling of the household head; the average level of schooling, measured as the number of years of education that have been completed, of household members 15 years old and above; whether the household engaged in migration within Mexico the previous year; whether the household engaged in migration to the US the previous year; the area of land owned by the household that is irrigated for agricultural purposes, interacted with village precipitation; the number of basic schools; the distance to the closest border crossing point; the crime rates at the closest, second closest, and third closest border crossing points; the hourly wage in the primary sector; and employment in the secondary sector. We include lagged migration to the US and lagged migration within Mexico in the policy functions to allow for possible persistence in migration decisions, including persistence that may generate, for example, multiple migration trips; repeated or return migration; continued migration; or migration of extended duration lasting more than one year at a time.

We address the endogeneity of neighbors' actions in the structural model by using an exclusion restriction combined with a fixed point algorithm. In order to separately identify the effects of state variables s_{it} and the effects of the actions a_{-it} played by other households on a household's observed choices and per-period payoff, we impose the exclusion restriction that a household's per-period payoff depends on its own vector of state variables s_{it} but not additionally on the state variables s_{-it} of other households (Bajari et al., 2010). We implement this exclusion restriction by including several household-specific state variables in the vector of state variables s_{it} we include in the policy functions and per-period payoff, including the number of household members, the household head age, a dummy whether the first born child of the household was male, household head schooling, household average schooling, and household land quality interacted with rain.

Our policy functions also include a rich set of state variables at the village, municipality, state, and national level; border crossing variables; and village fixed effects. As explained above, the municipality-level state variables include the number of schools in the basic system. The village fixed effects control for unobserved conditions that affect all households in the village in the same fashion. For example, the village fixed effects absorb village characteristics such as the overall educational level of the village, infrastructure, and teaching quality. As a consequence, the household-specific state variables we use to satisfy the exclusion restriction, whose values vary across households within the same village and across years, exploit the variation in the characteristics of neighbors that affect their probability of migration.

The error terms ε_{ikt} in the linear probability regressions we use to estimate the policy functions represent unobservable private information shocks that are observed by household i and therefore affect household i's migration decisions a_{ikt} at time t, but are not observed by the econometrician. We assume that, conditional on the state variables s_{it} that we use for the policy functions and on the village fixed effects, these unobservable private information shocks ε_{ikt} are conditionally independent. Given the rich set of state variables and village fixed effects we include in our controls, the conditional independence assumption is reasonable, at least to a first order.

Moreover, since the policy functions for each player i depend on the policy functions for all other players, we further address the endogeneity of neighbors' actions in the structural model by combining the exclusion restriction with a fixed point algorithm in the forward simulation, as described below.

In Table A.3 in Appendix A, we present the results of the policy functions relating states to actions. Column (1) presents the policy function for migration to the US. Column (2) presents the policy function for migration within Mexico. The policy functions we estimate represent the empirical relationship between the actions and states observed in the data, and simply characterize what households do mechanically as a function of the state vector. As the policy functions are reduced-form regressions correlating actions to states, their results therefore show correlations, not causation. We use the coefficients that are significant at a 10% level in our structural model to predict the actions played given the state variables.

One possible concern is that the conditional independence assumption for the unobservable private information shocks ε_{ikt} is violated because unobservables that affect migration decisions may be correlated across households in a village. We address this concern at least in part by controlling for a rich set of state variables and village fixed effects. The village fixed effects absorb unobservable time invariant village characteristics that are correlated across households in a village, and the rich set of state variables likely control for most if not all of the relevant time-varying factors that may be correlated across households in a village. In Rojas Valdés, Lin Lawell and Taylor (2020a), we provide evidence that unobserved village factors that may affect migration decisions are not correlated with the household-specific state variables we use to satisfy the exclusion restriction, thus further alleviating this concern.

Another possible concern is that the conditional independence assumption for the unobservable private information shocks ε_{ikt} is violated because unobservables that affect migration decisions may be serially correlated over time. For example, if unobservable village-specific skills and other factors that affect wages give rise to village location choices that are correlated across time periods, then the observed wages in a village in a year are not a random sample of the population distribution of wages, and the coefficient on wages in the policy function may be biased (Tunali, 2000; Kennan and Walker, 2011; Bayer and Juessen, 2012). We address this concern by using wages at the national level instead of at the village level in our policy function, and by also controlling for village fixed effects.[13]

A related concern is that, over time, serially correlated unobservables that affect migration decisions may lead to a change in the composition of households remaining in the village who do not engage in migration and therefore cause selection bias. We address this concern by modeling each household i's decision a_{ikt} to engage in migration of type $k \in [USA, Mexico]$ as an annual decision that the household makes each year, whether or not the household engaged in migration in the previous year. A household is engaging in migration to the US or within Mexico in year t if the household has a household member who is a migrant to the US or within Mexico, respectively, in year t. We include lagged

[13]Furthermore, the employment state variable we include in the policy function, which is at an aggregate state level rather than the village level, is not statistically significant at a 10% level, and therefore is not used in our structural model to predict the actions played given the state variables.

migration to the US and lagged migration within Mexico in the policy functions to allow for possible persistence in migration decisions, including persistence that may generate, for example, multiple migration trips; repeated or return migration; continued migration; or migration of extended duration lasting more than one year at a time. Thus, the composition of a household's neighbors is not affected by whether the household or its neighbors previously engaged in migration.

5.2 Transition densities

We estimate the distribution of next period's state variables conditional on this period's state variables and actions using flexible transition densities. In particular, we use linear regressions that relate the current level of the state variables to their lags, the lags of other related state variables, and the lags of the action variables.

The following household-level state variables evolve stochastically: the number of males in the household, the number of males in the family,[14] the household size, a dummy indicator for whether the first born of the household was a male, household head schooling, household average schooling, household maximum schooling, household land slope interacted with rain, household land quality interacted with rain, and household irrigated land area interacted with rain. We model the transition densities of these household-level state variables by regressing these variables on lagged values of state and action variables. Thus, although we do not model schooling and other decisions made by household (other than migration) explicitly, our models allows schooling and other household-level variables to evolve endogenously conditional on state variables and actions via the transition densities. The age of the head of the household evolves deterministically, so next year's age is today's age plus one.

At the village level, we regress the crime rate at the closest, second closest, and third closest border crossing points on their lags and the lag of the primary sector wage. At the municipality level, we regress the number of basic schools, the number of indigenous schools, and the number of students in the basic system on the lags of these same variables, and the lags of the employment levels in the three sectors. At the state level, we regress the employment shares in each sector on the lags of the three shares, and on the lags of average wages. At the national level, we regress average wages in the primary, secondary, and tertiary sectors on the the lags of these three same variables.

In Tables A.4-A.6 in Appendix A, we present the results of the transition densities for the variables at the household, municipality, state, and national levels. These transition densities describe the behavior of state variables over time. We regress the level of each variable on

[14] We define a family as the household head, the household head's spouse, and their children.

the lag of other relevant state variables. We use the coefficients that are significant at a 10% level to predict the value of next period's state variables, which affect the actions taken by each household in next period as well as the payoff functions.

5.3 Estimating the structural parameters

The value function for household i is given by:

$$V_i(\mathbf{s};\sigma;\theta) = E\left[\sum_{t=0}^{\infty} \beta^t \pi_i(\sigma(\mathbf{s}_t,\varepsilon_t), s_{it}, \varepsilon_{it};\theta)|\mathbf{s}_0 = \mathbf{s}\right]. \quad (6)$$

Following Bajari, Benkard and Levin (2007), we use forward simulation to calculate the value function, which is the expected present discounted value of the entire stream of per-period payoffs when the actions are chosen optimally. In particular, we simulate $S = 100$ different paths of play of $T = 30$ periods length each using $D = 3$ different initial observed vectors of state variables, and then average the present discounted value of the entire stream of per-period payoffs over the $S = 100$ different paths of play.

Our methodological innovation is that, when evaluating the policy functions each period using that period's state variables to determine that period's actions for each household, we address the endogeneity of neighbors' decisions using a fixed point calculation. Our fixed point algorithm to address the endogeneity of neighbors' decisions is as follows:

- Step 1: Use the observed fraction of neighbors with migration in the data as the initial guess for the expected fraction of neighbors with migration in the policy function.
- Step 2: Predict the actions for all households using the policy function evaluated at latest guess for the expected fraction of neighbors with migration.
- Step 3: Calculate the fraction of neighbors with migration using the predicted actions, which becomes the new guess.
- Repeat Steps 2 and 3 until the difference between the guess and the predicted fraction of neighbors with migration is below a certain threshold.

In order to estimate the parameters θ, we consider alternative strategies that are deviations from the optimal strategy given by the policy functions we estimate in the first stage. A deviation is profitable if the value of the discounted stream of payoffs under the alternative strategy is greater than under the optimal policy. We find the parameters θ that minimize profitable deviations from the optimal strategy given our estimated policy functions. Bajari, Benkard and Levin (2007) show that this estimator is consistent and asymptotically normal.

6 Results

6.1 Structural parameters

We present the parameter estimates of our structural model in Table 1. The parameters we estimate are the coefficients in the per-period payoff function $\pi_i(\mathbf{a}, s_i, \varepsilon_i; \theta)$.

According to our results, the coefficient in the per-period payoff on household head schooling is significant and positive, which indicates that the higher the household head schooling, the higher the per-period payoff to the household. Thus, a household benefits when the household head is more educated.

The coefficient on household land quality interacted with rain is significant and negative. Since higher values of our index for household land quality denote a lower land quality, the significant negative coefficient on the interaction indicates that the higher quality the household land and the more rain, the higher the per-period payoff to the household. This result suggests that the payoff to home agricultural production is higher when land quality is better and there is more rain.

Since higher values of our index for household land quality denote a lower land quality, the significant negative coefficient on household land quality interacted with rain interacted with migration to the US indicates that the higher quality the household land and the more rain, the higher the per-period payoff to having a household member migrate to the US. This result suggests that home agricultural production and migration to the US are complements. The likely mechanism is as follows. Higher incomes from home agricultural production relax household credit constraints and enable the household to send a member to migrate to the US. Migration to the US, in turn, generates additional income for the household via remittances, which enables the household to further improve their home agricultural production.

In contrast, the significant positive coefficient on household land quality interacted with rain interacted with migration within Mexico, which is larger in magnitude than the coefficients on the other terms involving household land quality interacted with rain, indicates that the higher quality the household land and the more rain, the lower the per-period payoff on net to having a household member migrate within Mexico. This result suggests that home agricultural production and migration within Mexico are substitutes. Unlike migration to the US, which is costly but also generates income for the household via remittances, migration within Mexico is a substitute rather than a complement to home agricultural production, possibly at least in part because it is less costly and also generates little if any income for the household via remittances.

As indicated by the significant positive coefficient on hourly wage, the higher the hourly wage, the higher the per-period payoff to the household. The significant positive coefficient on hourly wage interacted with migration to the US indicates that the higher the hourly wage, the higher the per-period payoff to having a household member migrate to the US. In contrast, the significant negative coefficient on hourly wage interacted with migration within Mexico, which is smaller in magnitude than the significant positive coefficient on hourly wage, indicates that the hourly wage has less of a positive effect on net on the per-period payoff when a household engages in migration within Mexico.

The significant positive coefficients on the variables interacting crime rate with migration to the US indicate that the higher the crime rate in Mexico, the higher the per-period payoff to having a household member migrate to the US. This result suggests that the worse the domestic crime conditions in Mexico, the more a household benefits from having a member migrate internationally to work in the US instead.

6.2 Model validation

To assess the goodness of fit of our structural model, we compare the migration and welfare from the observed data with the migration and welfare predicted by our structural econometric model. Welfare is the present discounted value of the entire stream of per-period payoffs over the period 1997-2007, as calculated using the parameter estimates from the structural model. Average welfare per-household-year is welfare divided by the number of household-years. The welfare from the observed data is calculated using actual values of actions and states in the data. Model predicted welfare is calculated using model predicted actions and states generated from 100 simulations. As seen in Table A.7 in Appendix A, which compares welfare calculated using observed data with the welfare predicted by our structural econometric model, our structural econometric model does a fairly good job of predicting welfare calculated based on observed data. Similarly, when comparing the migration observed in the data with the migration predicted by our structural econometric model in Figure A.2 in Appendix A, our structural econometric model does a fairly good job of predicting the upward trends in migration observed in the data.

Our econometric estimation entails finding the parameters θ that minimize any profitable deviations from the optimal strategy as given by the estimated policy functions. Under our estimated structural parameters, the fraction of deviations from the estimated optimal strategy that increase welfare by more than a quarter of a standard deviation is 0.0081, and the fraction of deviations from the estimated optimal strategy that increase welfare by more than a half of a standard deviation is 0.00004. Moreover, under our estimated structural parameters, there are no deviations from the estimated optimal strategy that increase welfare by more than one standard deviation. There are therefore extremely few deviations that are profitable, and the increase in welfare from any profitable deviations are small. Our structural model of the dynamic migration game therefore does a good job explaining the migration decision-making behavior of the households in our data set.

Our measure of profitable deviations might be a conservative upper bound, since some of the alternative strategies that we find to yield profitable deviations for a household might not actually be feasible for the household, for example owing to health or liquidity constraints that we do not observe, assume, impose, or explicitly model.[15] Thus, our parsimonious model appears to do a fairly remarkable job of modeling the migration decision-making behavior of the households in rural Mexico that are in our data set.

7 Counterfactual Simulations

We use the estimated parameters to simulate the effects of counterfactual scenarios regarding wages and migration policy on the migration decisions and welfare of households in rural Mexico. In order to disentangle the effects of strategic interactions and dynamic behavior in our model, we also simulate counterfactual scenarios in which remove strategic interactions, and counterfactual scenarios in which we remove dynamic behavior.

For each counterfactual scenario, we simulate the effects of a counterfactual change that takes place in the year 1997 on the migration decisions and welfare of households in rural Mexico over the years 1997 to 2007. We then compare the average welfare per household-year and the fraction of households with migration under that counterfactual scenario with those under the base case of no change using two-sample t-tests.

There are several channels through which each counterfactual change may affect household welfare. First, the counterfactual change (e.g., in wages) may affect household welfare directly. Second, the counterfactual change may affect migration decisions which affect household welfare. Third, the counterfactual change may affect other decisions of the household which may affect household welfare. Although we focus on explicitly modeling the migration decisions of the households, our model implicitly captures schooling and other decisions made by household by allowing schooling and other household-level variables to evolve endogenously conditional on state variables and actions via the transition densities. Fourth, changes in actions and/or state variables resulting from the counterfactual change may affect future values of the state variables, which may affect future actions and/or wel-

[15] The alternative strategies σ_i' we simulate are pertubations to the optimal strategy σ_i that shift the estimated policy function for the probability of engaging in migration to the US upwards or downwards by up to 0.20, and that shift the estimated policy function for the probability of engaging in migration within Mexico upwards or downwards by up to 0.20. Not all of these alternative strategies might actually be feasible for a household.

fare. Our estimates of the changes in welfare that arise in each counterfactual simulation capture all channels through which the counterfactual scenario may affect household welfare.

As explained in more detail below, in analyzing the short-run effects of each counterfactual scenario, we assume that the counterfactual change we simulate is one that households neither anticipate nor expect to be permanent; and that the counterfactual scenario does not change which equilibrium is played. Adapting the policy invariance assumption and approach of Benkard, Bodoh-Creed and Lazarev (2019), we therefore assume that the policy functions (as functions of state variables), transition densities of unaffected state variables (as functions of lagged state and action variables), and structural parameters we estimate themselves do not change under the different counterfactual changes that take place in the year 1997.

7.1 Wages

Real wages in Mexico plunged after the 1994 crisis and recovered slowly during the period covered by our data set. We simulate changes in the hourly wage in the primary sector. The primary sector includes agriculture, livestock, forestry, hunting, and fisheries. In our structural econometric model, the hourly wage in the primary sector affects both the policy functions and the transition densities.

In 2010, 1 US dollar bought 12.80 Mexican pesos. Thus, the mean hourly wage in the primary sector in our data set, as reported in the summary statistics in Table A.1 in Appendix A, of 29 pesos per hour in 2010 pesos is roughly equivalent to 2.3 dollars per hour in 2010 US dollars. Our simulated changes in the primary sector wage ranging from a 50% decrease to a 50% increase therefore represent simulated primary sector wages ranging from a mean of 14.5 pesos (approximately 1.15 US dollars) per hour after a 50% decrease, to a mean of 43.5 pesos (approximately 3.45 US dollars) per hour after a 50% increase. Even after a 50% increase in primary sector wage, the largest increase in primary sector wage that we simulate, mean wages are still less than half the 1997 US federal minimum wage of 7.01 dollars in 2010 US dollars.[16]

In simulating the effects of a counterfactual change in primary sector wages in 1997, we assume that the policy functions (as functions of state variables, including wages), transition densities of unaffected state variables (as functions of lagged state and action variables, including wages), and structural parameters we estimate themselves do not change under the counterfactual change in primary sector wages that takes place in the year 1997.

[16]The US federal minimum wage in 1997 was 5.15 dollars in 1997 dollars (US Department of Labor, 2017), which is equivalent to 7.01 dollars in 2010 US dollars.

Figure 1 presents the percentage change from the base case in the fraction of households with migration to the US and within Mexico over the entire simulation period (1997-2007) under each simulated change in primary sector wages in the initial year of the simulation (1997). Error bars indicate the 90% confidence interval from a two-sample t-test comparing the results under the counterfactual simulation with those under the base case of no change. Results show that an increase in primary sector wages leads to a statistically significant increase in migration to the US and within Mexico. Similarly, a decrease in primary sector wages leads to statistically significant decreases in migration to both the US and within Mexico in all but one of the simulated scenarios (that of a 15% decrease). Moreover, the more dramatic the simulated change, the more dramatic the response of the fraction of households with migration. In addition, in all the cases the where changes in migration are statistically significant, the magnitudes of the changes in the fraction of households with migration to the US are much larger than those of the changes in the fraction of households with migration within Mexico.

Figure 2 presents the percentage change from the base case in the average welfare per household-year over the entire simulation period (1997-2007) under each simulated change in primary sector wages in the initial year of the simulation (1997). Error bars indicate the 90% confidence interval from a two-sample t-test. As expected, a decrease in primary sector wages leads to a statistically significant decrease in average welfare per household-year, while an increase in primary sector wages leads to a statistically significant increase in average welfare per household-year.

In addition to the pooled results, we also analyze the results by village. In Figure 3 we show the changes by village in the fraction of households with migration to the US and within Mexico over the entire simulation period (1997-2007) under a 10% decrease and a 10% increase in primary sector wages, respectively, in the initial year of the simulation (1997). The red dots denote villages that experience a statistically significant decrease in the fraction of households with migration; the green dots denote villages that experience a statistically significant increase in the fraction of households with migration; and the black dots denote villages with no statistically significant change. We find that there is some heterogeneity at the village level in the changes in the fraction of households with migration to the US and within Mexico.

To examine how this heterogeneity relates to observable village characteristics, we analyze the determinants of significant changes at the village level in the fraction of households with migration. To do so, we regress the village-level changes in the fraction of households with migration over the entire simulation period (1997-2007) that are significant at a 10% level under a simulated 10% increase and a simulated 10% decrease in primary sector wages in the initial year of the simulation (1997), respectively, on the initial village, municipality, state, and national characteristics from the initial year of the simulation (1997). As seen in Table B.1 in Appendix B, under a 10% decrease in wages in the primary sector, significant changes in migration to the US are negatively correlated with the initial household head schooling. This suggests that when the wage decreases, larger decreases in migration to the US are more likely to occur in villages where the household head is more educated, perhaps because a more educated household head increases the return from having other household members stay at home, therefore reducing migration to the US, especially when the household is more credit-constrained.

In Figure 4, we present the changes in average welfare per household-year at the village level under simulated changes of a 10% decrease and a 10% increase in primary sector wages, respectively. Consistent with the aggregate results, most of the villages experience a decrease in welfare under a 10% decrease in primary sector wages, while all of the villages except for one experience a statistically significant increase in welfare under a 10% increase in primary sector wages.[17]

Thus, our simulations regarding wages paid in the primary sector show that migration to the US and within Mexico increase with primary sector wage in the pooled results, but there is some heterogeneity across villages. Average welfare per household-year is increasing in the primary sector wage for almost all villages.

7.2 Migration policy

Given the significance of migration policy, especially from the US perspective, an important question is: what is the effect of migration policies on migration and welfare? We simulate two types of migration policies: a minimum schooling requirement for migration to the US, and a cap on total migration to the US.

[17] Although there is less heterogeneity among villages in the sign of the welfare effects, especially under a 10% increase in primary sector wages, we examine how the sign and magnitudes of the village-level welfare results relate to observable village characteristics by analyzing the determinants of significant changes at the village level in average welfare per household-year. To do so, we regress the village-level changes in the average welfare per household-year over the entire simulation period (1997-2007) that are significant at a 10% level under a simulated 10% increase and a simulated 10% decrease in primary sector wages in the initial year of the simulation (1997), respectively, on the initial village, municipality, state, and national characteristics from the initial year of the simulation (1997). As seen in Table B.2 in Appendix B, statistically significant changes in welfare under a 10% increase in wages in the primary sector are positively correlated with the initial fraction of households with migration within Mexico and the initial household head age, while statistically significant changes in welfare under a 10% decrease in welfare are positively correlated with the initial number of males in the household and the initial household head age, and negatively correlated with the initial fraction of households with migration to the US and the initial fraction of households with migration within Mexico.

7.2.1 Minimum schooling requirement for migration to the US

The first migration policy we simulate is a minimum schooling requirement that specifies a minimum threshold household average schooling needed in order for a household in rural Mexico to be allowed to engage in migration to the US in 1997, the first year of the simulation. We set the threshold to range from 50% to 150% of the average household schooling observed in the data.

In simulating the effects of a counterfactual minimum schooling requirement for migration to the US in 1997, we assume that the policy functions (as functions of state variables), transition densities of unaffected state variables (as functions of lagged state and action variables), and structural parameters we estimate themselves do not change under the counterfactual minimum schooling requirement for migration to the US in 1997. We therefore interpret this migration policy that takes place only in 1997 as a policy that households neither anticipate nor expect to be permanent.

As seen in Figure 5, a minimum schooling requirement for migration to the US would have direct negative effects on migration to the US. The greater the requirement for minimum schooling for migration to the US, the more dramatic the drop in migration to the US, with all the simulated changes being statistically significant. Moreover, a minimum schooling requirement for migration to the US would lead to changes in migration within Mexico as well: a minimum schooling requirement for migration to the US from a 25% of the average schooling up to a 150% of the average schooling leads to a statistically significant decrease in the fraction of households with migration within Mexico. Figure 6 shows that this policy leads to a statistically significant decrease in average welfare per household-year in every simulated minimum threshold of schooling required for migration.

As seen in Figure B.1 in Appendix B, a minimum schooling requirement for migration to the US would have a negative effect on the fraction of households with migration to the US in almost every village, and a significant negative effect on the fraction of households with migration within Mexico in some villages.[18] As seen in Figure B.2 in Appendix B, most of the villages experience a statistically significant decrease in welfare under the simulated

[18] In Table B.3 in Appendix B we show that, under a simulated threshold of 110% of the average schooling for migration, significant changes in the fraction of households with migration to the US are positively correlated with the initial household head schooling at the village level, and negatively correlated with the initial household size and the initial fraction of households with migration to the US, whereas significant changes in migration within Mexico are positively correlated with initial household land quality. Similarly, under a simulated threshold of 90% of the average schooling, the shares of employment in the primary and secondary sectors are associated with significant decreases in migration both to the US and within Mexico, and the initial fraction of households with migration to the US is correlated with significant decreases migration to the US.

minimum thresholds of schooling for migration to the US.[19]

7.2.2 Cap on total migration to the US

The second migration policy we simulate is a cap on total migration to the US. For this counterfactual policy, we set a cap that denies migration to the US to a certain percentage, ranging from 50% to 90%, of the total number of households in rural Mexico who would have engaged in migration to the US under the base case simulation. That is, of the households in rural Mexico who engage in migration to the US under the base case, we restrict a randomly chosen 50% and 90% of these households from migrating to the US in 1997, the first year of the simulation.

In simulating the effects of a counterfactual cap on total migration to the US in 1997, we assume that the policy functions (as functions of state variables), transition densities of unaffected state variables (as functions of lagged state and action variables), and structural parameters we estimate themselves do not change under the counterfactual cap on total migration to the US in 1997. We therefore interpret this migration policy that takes place only in 1997 as a policy that households neither anticipate nor expect to be permanent.

As seen in Figure 7, the simulated caps have statistically significant negative effects on migration not only to the US but also within Mexico. Moreover, the size of the reduction in the fraction of households with migration to the US is greater than the cap. For example, a cap that denies US migration to 50% of the households that would have engaged in migration to the US in the base case leads to a decrease in the fraction of households with migration to the US of 70% for the period of our simulations, due to the spillover effects of the migration decisions. As seen in Figure 8, all our simulated caps on migration lead to a statistically significant decrease in welfare.

In Figure B.3 in Appendix B, we present the effects of a cap of 90% of base case US migration on migration by village. Consistent with our aggregate results, all villages experience a statistically significant decrease in migration to the US, while some villages experience a statistically significant decrease in migration within Mexico.[20] Figure B.4 in Appendix B

[19] As shown in Table B.4 in Appendix B, significant changes in welfare under a threshold of 110% and 90% of average schooling are positively correlated with the initial household head schooling and the initial fraction of households with migration to the US; in addition, significant changes in welfare under a simulated threshold of 90% of average schooling are also negatively correlated with the initial shares of employment in the primary and secondary sectors.

[20] Table B.5 in Appendix B shows that under a simulated cap denying migration to 90% of the households that would have engaged in migration to the US in the base case, significant changes in the fraction of households with migration to the US are positively correlated with initial household head schooling and the initial fraction of households with migration within Mexico, and negatively correlated with the initial household size and the initial fraction of households with migration to the US. Under this simulation, significant changes in migration within Mexico are negatively correlated with the initial fraction of households

shows that all the villages experience a statistically significant decrease in welfare under the simulated cap of migration.[21]

Strategic interactions explain why policies that decrease migration to the US also decrease migration within Mexico. Owing to the significant positive other-migration strategic interaction in the policy functions in Table A.3 in Appendix A, decreases in migration to the US by neighbors are associated with a decrease in a household's probability of migrating within Mexico. Thus, policies that affect the migration behavior of one household in a village may also indirectly affect the migration behavior of the household's neighbors.

Dynamic behavior explains why a cap on total migration to the US causes migration to the US to decrease by more than what is required by the policy. Owing to the significant positive effect of lagged migration to the US on the probability of migration to the US in the policy functions in Table A.3 in Appendix A, there is persistence in the decision to engage in migration to the US. Thus, policies that restrict migration to the US are amplified over time.

We further analyze the effects of strategic interactions and dynamic behavior in our counterfactual scenarios below that remove strategic interactions and dynamic behavior, respectively.

7.3 Removing strategic interactions

In our structural econometric model, strategic interactions can arise through several channels. First, strategic interactions can arise in the policy functions if neighbors' actions affect a household's strategy. Second, strategic interactions can arise in the transition densities if the actions of households in the village affect future values of the the state variables faced by a household. Third, strategic interactions can affect the per-period payoff of a household.

In order to disentangle the effects of strategic interactions in our model, we simulate counterfactual scenarios in which we remove strategic interactions. For these counterfactual scenarios, we set the coefficients on the fraction of neighbors with migration to the US and within Mexico to be 0 in the policy functions; we set the coefficients on the lagged fraction of households with migration to the US and within Mexico to be 0 in the transition densities; and we set the coefficients on all terms involving the fraction of neighbors with migration to be 0 in the per-period payoff function. All other coefficients and parameter values remain the same. By setting the coefficients on all terms in the policy functions, transition densities, and

with migration within Mexico.

[21] As seen in Table B.6 in Appendix B, significant changes in welfare are positively correlated with the initial household head schooling, and negatively correlated with the initial fraction of households with migration to the US and the initial household land quality.

per-period payoff function that involve neighbors to 0, we remove all channels of strategic interactions and our model of the dynamic migration game reduces to a single-agent dynamic decision-making problem.

In simulating the effects of removing strategic interactions, we assume that the policy functions (as functions of state variables), transition densities of unaffected state variables (as functions of lagged state and action variables), and structural parameters we estimate themselves do not change when we remove the strategic interactions; and therefore that the coefficients on all terms that do not involve the fraction of neighbors with migration remain unchanged. We therefore interpret this removal of strategic interactions as a change that households neither anticipate nor expect to be permanent.

The results from our counterfactual scenario eliminating strategic interactions are presented in Table 2. We find that the fraction of household with migrants to both the US and within Mexico would be considerably higher if there were no strategic interactions. These increases in migration would occur in most of the villages in our sample (Figure B.5 in Appendix B). Moreover, in the absence of strategic interactions, the average welfare per household-year would be lower (Table 2). This decrease in average welfare per household-year would occur in all villages in our sample (Figure B.6 in Appendix B). Thus, strategic interactions are welfare-increasing.

The results from our counterfactual simulations of migration policy above show that a cap on total migration to the US decreases welfare and also decreases migration to both the US and within Mexico. To better understand the role of strategic interactions when there is a cap on total migration to the US, we simulate the same migration cap as before, denying migration to the US to a certain percentage, ranging from 50% to 90%, of the total number of households in rural Mexico who would have engaged in migration to the US under the base case simulation, but this time without allowing for strategic interactions. As seen in Figure 9, when there is a cap on migration with no strategic interactions, migration to the US still decreases considerably and by more than what the cap was intended to reduce over our simulation period. But now, migration within Mexico increases, in contrast to the case in which strategic interactions take place. Figure B.10 in Appendix B shows that, when there is a cap on migration with no strategic interactions, migration to the US decreases in all the villages in our sample, while migration within Mexico increases in most villages. Strategic interactions therefore explain why policies that decrease migration to the US also decrease migration within Mexico.

In Figure B.9 we show that the decrease in welfare resulting from a migration cap is even greater in the absence of strategic interactions. As seen in Figure B.11 in Appendix B, average welfare per household-year would decrease in all villages in our sample. The absence of strategic interactions leads to a more inefficient scenario, with more migration within Mexico, and with a larger loss in welfare resulting from the cap on total migration to the US.

7.4 Removing dynamic behavior

In order to disentangle the effects of dynamic behavior in our model, we simulate counterfactual scenarios in which we remove dynamic behavior. For these counterfactual scenarios, we set the discount factor β to 0, and we set the coefficients on lagged migration to the US and within Mexico to 0 in both the US migration and Mexico migration policy functions. All other coefficients and parameter values remain the same. We therefore interpret this removal of dynamic behavior as a change that households neither anticipate nor expect to be permanent.

The results from our counterfactual scenarios eliminating dynamic behavior are presented in Table 3. When households do not consider the future when making their decisions, both migration to the US and within Mexico decrease, and average welfare per household-year decreases as well. This aggregate result is also reflected in the pattern at the village level, as observed in Figures B.7 and B.8 in Appendix B. As seen in Figure B.8 in Appendix B, average welfare per household-year would decrease in all villages in our sample. Thus, household welfare is higher when households behave dynamically and consider the future when making decisions in the present.

The results from our counterfactual simulations of migration policy above show that a cap on total migration to the US decreases welfare and also decreases migration to both the US and within Mexico. To better understand the role of dynamic behavior when there is a cap on total migration to the US, we simulate the same migration cap as before, denying migration to the US to a certain percentage, ranging from 50% to 90%, of the total number of households in rural Mexico who would have engaged in migration to the US under the base case simulation, but this time without allowing for dynamic behavior. As seen in Figure 10, migration to the US decreases even more under a cap on total migration in the absence of dynamic behavior, while migration within Mexico decreases considerably as well. The decrease in welfare resulting from a migration cap is more than 2 orders of magnitude greater in the absence of dynamic behavior, as shown in Figure B.12. As seen in Figure B.14 in Appendix B, average welfare per household-year would decrease in all villages in our sample. Thus, the absence of dynamic behavior would exacerbate the decrease in migration to the US, the decrease in migration within Mexico, and the decrease in welfare resulting from a migration cap.

8 Discussion and Conclusion

Dynamic behavior and strategic interactions are important features of migration decisions. Analyses that ignore the possibility of strategic interactions or dynamic behavior lead to misleading results. We build on the previous literature on the determinants of migration by estimating a structural econometric model that incorporates dynamic behavior and strategic interactions, and that enables us to calculate welfare and to analyze the effects of counterfactual scenarios on decisions and welfare.

We use the estimated parameters to simulate the effects of counterfactual scenarios regarding wages and migration policy on the migration decisions and welfare of households in rural Mexico. In order to disentangle the effects of strategic interactions and dynamic behavior in our model, we also simulate counterfactual scenarios in which remove strategic interactions, and counterfactual scenarios in which we remove dynamic behavior.

8.1 Wages

Our counterfactual simulations regarding wages paid in the primary sector show that migration to the US and within Mexico increase with primary sector wage in the pooled results, but there is some heterogeneity across villages. Average welfare per household-year is increasing in the primary sector wage for almost all villages. Increases in wages in Mexico may increase migration within Mexico if households send a member to migrate within Mexico to take advantage of the higher wage. Increases in wages and income also enable poor and credit-constrained households to better afford investment in schooling, increasing their future expected wage and making future migration more affordable to poor and credit-constrained households.

We find that increases in the wage in Mexico not only increase migration within Mexico, but also increase migration to the US, likely because higher wages make migration to the US more affordable to poor and credit-constrained households. These results are comparable to those of other studies that find that financial constraints are an important determinant of migration and migration selectivity. For example, Angelucci (2015) finds that Oportunidades, the flagship conditional cash transfer program of Mexico, increases migration from Mexico to the US, which similarly provides evidence that poor households in Mexico face binding financial constraints.

Furthermore, our results show that changes in wages have heterogeneous effects by village. Our results that increases in the wage in Mexico tend to increase migration both within Mexico and to the US, but that there is some heterogeneity across villages, build and expand on the work of Lessem (2018), who finds that, while increases in the wage in Mexico can decrease migration to the US, increases in all wages in Mexico except those in a person's home location increases both migration within the Mexico as well as migration to the US.

Our result that increases in wages in Mexico will increase migration to the US from rural Mexico contradicts a common belief that improving the income of poor households would reduce migration, and therefore that, in order to keep Mexicans in Mexico, one simply needs to improve economic opportunities for Mexicans in their home country. Thus, since it is usually assumed that labor moves to the United States mainly because of a lack of opportunities in Mexico (in other words, implying some substitution across activities), our results finding evidence to the contrary have important implications for the discussion and design of policy.

8.2 Migration policy

In terms of counterfactual government migration policy, we find that a minimum threshold household average schooling needed by households in rural Mexico for migration to the US decreases migration not only to the US but also within Mexico, and also decreases average welfare per household-year. Similarly, a cap on total migration to the US by households in rural Mexico decreases migration not only to the US but also within Mexico as well, causes migration to the US to decrease by more than what is required by the policy, and decreases average welfare per household-year.

The current policy discussion on border enforcement at the US border focuses largely on illegal migration from Mexico. Feigenberg (2020) finds that US-Mexico border fence construction significantly reduces migration from Mexico to the United States, and significantly reduces the number of undocumented Mexicans in the United States. Our results suggest that such a policy aimed at reducing migration to the US would also reduce migration within Mexico.

Previous studies have found that the United States does not necessarily benefit from reducing migration from Mexico. In their analysis of a policy change that excluded almost half a million Mexican bracero seasonal agricultural workers from the US, Clemens, Lewis and Postel (2018) fail to reject the hypothesis that exclusion did not affect US agricultural wages or employment. Similarly, Mayda et al. (2018) find that the reduction that took place in 2004 in the annual quota on new H-1B visas allowing skilled foreign-born individuals to work in the United States did not increase the hiring of US workers. Likewise, Lee, Peri and Yasenov (2019) find that an extensive campaign that repatriated around 400,000 Mexicans from the US in 1929-1934 produced a decline in the incumbent US natives' probability of having a job, a decline in their occupation-based wage, no significant effect on aggregate employment, and a large negative effect on occupational wages in the US.

Results of previous studies similarly suggest that migration from Mexico to the US is not necessarily bad for the United States. In their review of the literature on historical and contemporary immigration to the United States, Abramitzky and Boustan (2017) find that although immigrants appear to reduce the wages of some natives, the evidence does not support the view that, on net, immigrants have negative effects on the US economy. Moreover, immigrants tend to be more educated, less unemployed, and less reliant on the welfare state than natives perceive them to be (Alesina, Miano and Stantcheva, 2019; Alesina and Stantcheva, 2020). In his analysis of the labor market impact of migration from Mexico to the US during the Mexican peso crisis of 1995, Monràs (forthcoming) finds that local immigration shocks are quickly dissipated across locations and affect the national-level market outcomes of only some cohorts of workers. Similarly, in their analysis of migrants from Mexico to the US, Lessem and Nakajimae (2019) find, while the flexibility of immigrant wages may increase the volatility of low-skilled native employment, it may also reduce the volatility of high-skilled native employment over the business cycles.

Indeed, the results of some previous studies suggest that migration from Mexico may instead have beneficial effects on the United States. For example, migration can benefit the host economy by driving productive knowledge diffusion, reducing inequality (Bahar and Rapoport, 2018), increasing innovation (Burchardi et al., 2020), and creating jobs (Azoulay et al., 2020). Chassamboulli and Peri (2020) find that all types of immigrants to the US generate higher surplus for US firms relative to natives; hence, restricting their entry has a depressing effect on job creation and, in turn, on native labor markets.

Thus, the previous literature has shown that barriers to migration from Mexico to the United States do not have a positive effect on US agricultural wages or employment (Clemens, Lewis and Postel, 2018), and may actually have a negative effect on job creation instead (Chassamboulli and Peri, 2020). Our results show that such barriers to migration decrease the average welfare of households in rural Mexico.

In the previous literature, Hanson, Liu and McIntosh (2017) examine how the scale and composition of low-skilled immigration in the United States have evolved over time, and find that, because major source countries for US immigration are now seeing and will continue to see weak growth of the labor supply relative to the United States, future immigration rates of young, low-skilled workers appear unlikely to rebound, whether or not US immigration policies tighten further. Our results show that migration policies that cap total migration from Mexico to the US decrease migration not only to the US but also within Mexico as well, and cause migration to the US to decrease by more than what is required by the policy.

Our result that a cap on total migration from Mexico to the US decreases migration not only to the US but also within Mexico as well, and causes migration to the US to decrease by more than what is required by the policy, arises in part from dynamic behavior and strategic interactions. Strategic interactions explain why policies that decrease migration to the US also decrease migration within Mexico: decreases in migration to the US by neighbors are associated with a decrease in a household's probability of migrating within Mexico. Thus, owing to strategic interactions, policies that affect the migration behavior of one household in a village may also indirectly affect the migration behavior of the household's neighbors.

Dynamic behavior explains why a cap on total migration to the US causes migration to the US to decrease by more than what is required by the policy: there is persistence in the decision to engage in migration to the US. Thus, owing to dynamic behavior, policies that restrict migration to the US are amplified over time.

Dynamic behavior may also explain why policies that decrease migration to the US also decrease migration within Mexico. Migration within Mexico may be a form of transitory migration whereby households may decide to engage in migration to a given location as a means to eventually engage in migration to another location (Artuc and Ozden, 2018). In particular, migration within Mexico may have an option value of facilitating subsequent migration to the US. Thus, policies that decrease migration to the US may also decrease the option value a household may receive from engaging in migration within Mexico, and may therefore decrease migration within Mexico as well.

Shutting down the option to engage in migration to the US therefore radically modifies the nature of the decision-making problem faced by households in rural Mexico, and therefore the decisions they make and the welfare they are able to achieve. One possible mechanism whose implications our general model captures is as follows.[22] By increasing household income via remittances, migration may enable agricultural home production to be run more efficiently and productively than it could be run when there are restrictions to mobility, thereby relaxing the credit constraints that agricultural households face. In addition, with the income generated by migration, households might be able to hire labor to substitute for household labor allocated to the US or other states within Mexico. But when a policy restricts migration to the US, credit constraints bind again and households can no longer afford to hire labor, so household labor allocated somewhere else is called back. Thus, policies that restrict migration to the US decrease migration both to the US and within Mexico, and

[22]As explained in more detail in our model of the dynamic migration game, our specification of the per-period payoff function is agnostic about the actual functional form of the utility function, the actual nature of the constraints, the actual economic and non-economic channels through which migration affects household utility, and the actual mechanisms by which state variables such as local wages affect utility, and thus is general enough to capture the reduced-form implications of a number of models of general equilibrium behavior of individuals within the household, households in the village, and the village economy.

reduce household welfare.

Our result that a cap on total migration to the US decreases migration not only to the US but also within Mexico as well, causes migration to the US to decrease by more than what is required by the policy, and decreases average welfare per household-year is consistent with the results of Makovec et al. (2018), who find that migration restriction policies (in their case, a policy that restricted the migration of Indonesian female domestic workers to Saudi Arabia) can have unintended consequences such as a deterioration in the local labor markets at the origin.

8.3 Dynamic behavior and strategic interactions

Dynamic behavior and strategic interactions are important features of migration decisions. Analyses that ignore the possibility of strategic interactions or dynamic behavior lead to misleading results.

Counterfactual simulations that remove the possibility of strategic interactions show that strategic interactions are welfare-increasing, and their absence would result in inefficient rates of migration. Household welfare increases when households consider what other households are doing when making their own migration decisions.

For example, our results show that removing strategic interactions increases migration to the US. At first glance, this result might appear to be counterintuitive from the point of view of migration externalities. A reduction in the number of neighbors migrating reduces the amount of information and externalities available for other households. Since these externalities operate in a dynamic setting, however, households respond to this absence of information by providing more migration than what is optimal. This can be interpreted in the context of a model of network formation. In the absence of strategic interactions and the possibility of benefiting from the networks of their neighbors, households may contribute more to own network by having their own household members migrate instead.

Counterfactual simulations that remove the possibility of dynamic behavior show that household welfare is higher when households behave dynamically and consider the future when making decisions in the present. The absence of dynamic behavior would exacerbate the decrease in migration to the US, the decrease in migration within Mexico, and the decrease in welfare resulting from a migration cap.

8.4 Potential avenues for future research

Our results point to several potential future avenues of research. First, our model distinguishes between migration within Mexico and to the US, and we include wages and employment of different sectors in Mexico as factors that may affect household decisions and payoffs. In future work we hope to also distinguish between different jobs and different locations within Mexico and within the US.

Second, consistent with early models of household decision-making (e.g., Becker, 1981) and the new economics of labor migration, we model decision-making at the household level. Nevertheless, intra-household dynamics and interactions may affect decisions about migration as well. For example, Lessem (2018) finds in her dynamic programming model that when individuals account for the location of their spouse when making migration decisions, increases in Mexican wages reduce migration rates and durations, and increases in border enforcement reduce migration rates and increase durations of stay in the US. In ongoing work, we are analyzing intra-household decision-making to better understand how decisions are made regarding migration, labor, and schooling within a household.

Third, in future work we hope to develop techniques for analyzing counterfactual scenarios that might change the equilibrium being played, and for improving the ability to use counterfactual scenarios to extrapolate to different regions and time periods, building on the work of Gechter (2016) and Gechter et al. (2019). Fourth, in future work we hope to develop techniques for better capturing unobserved heterogeneity and serially correlated unobservables, building on the work of Aguirregabiria and Mira (2007), Arcidiacono and Miller (2011), and Bayer and Juessen (2012).

Our structural econometric model of the dynamic migration game enables a better understanding of the factors that affect migration decisions, and can be used to design policies that better improve the welfare of households in rural Mexico and other parts of the developing world.

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Table 1: Parameter estimates

	Estimate	Standard error
Coefficients in the per-period payoff function on:		
Migration to US	-0.000380	0.07848
Migration within Mexico	-0.000580	0.09041
Fraction of neighbors with migration to US	0.000510	0.06887
Fraction of neighbors with migration to US, squared	-0.000300	0.10875
Fraction of neighbors with migration within Mexico	0.000880	0.06611
Fraction of neighbors with migration within Mexico, squared	-0.000620	0.10882
Number of household members	-0.001190	0.00068 *
Number of household members, squared	0.028990	0.00010 ***
Household head age	-0.448320	0.00000 ***
Household head age, squared	-0.023520	0.00000 ***
First born was a male (dummy)	0.000000	0.21732
Household head schooling (years)	0.002880	0.00035 ***
Household head schooling (years), squared	0.014020	0.00005 ***
Household average schooling (years)	-0.014330	0.00066 ***
Household average schooling (years), squared	0.040190	0.00011 ***
Household land quality (1=good to 4=very bad) interacted with rain	-0.014520	0.00025 ***
Household land quality (1=good to 4=very bad) interacted with rain, squared	0.000050	0.00001 ***
Number of basic schools	-0.030090	0.00007 ***
Number of basic schools, squared	-0.000110	0.00000 ***
Hourly wage in primary sector (pesos)	0.035280	0.00194 ***
Hourly wage in primary sector (pesos), squared	0.000400	0.00002 ***
Migration to US interacted with:		
Fraction of neighbors with migration to US	-0.000290	0.12603
Fraction of neighbors with migration within Mexico	-0.000470	0.06262
Number of household members	0.001840	0.00482
Household head age	-0.000630	0.00380
First born was a male (dummy)	-0.000010	0.10227
Household head schooling (years)	-0.001160	0.00530
Household average schooling (years)	0.000370	0.00496
Household land quality (1=good to 4=very bad) interacted with rain	-0.009950	0.00016 ***
Number of basic schools	0.062860	0.00022 ***
Hourly wage in primary sector (pesos)	0.004070	0.00066 ***
Distance to closest border crossing point	0.013130	0.00066 ***
Crime rate at closest border crossing point	0.039170	0.00299 ***
Crime rate at second closest border crossing point	0.009600	0.00029 ***
Crime rate at third closest border crossing point	0.013340	0.00134 ***
Migration within Mexico interacted with:		
Fraction of neighbors with migration to US	-0.000430	0.06094
Fraction of neighbors with migration within Mexico	-0.000440	0.12824
Number of household members	0.002850	0.00493
Household head age	-0.001240	0.00359
First born was a male (dummy)	-0.000010	0.10861
Household head schooling (years)	-0.001330	0.00625
Household average schooling (years)	-0.000040	0.00500
Household land quality (1=good to 4=very bad) interacted with rain	0.023690	0.00018 ***
Number of basic schools	0.122170	0.00026 ***
Hourly wage in primary sector (pesos)	-0.015870	0.00080 ***
Distance to closest border crossing point	-0.008240	0.00068 ***
Crime rate at closest border crossing point	0.050480	0.00272 ***
Crime rate at second closest border crossing point	-0.005120	0.00033 ***
Crime rate at third closest border crossing point	0.033550	0.00125 ***

Notes: Standard errors in parentheses. Crime rates are in homicides per 10,000 inhabitants.
Wages are in 2010 Mexican pesos.
Significance codes: * $p<0.10$, ** $p<0.05$, *** $p<0.01$

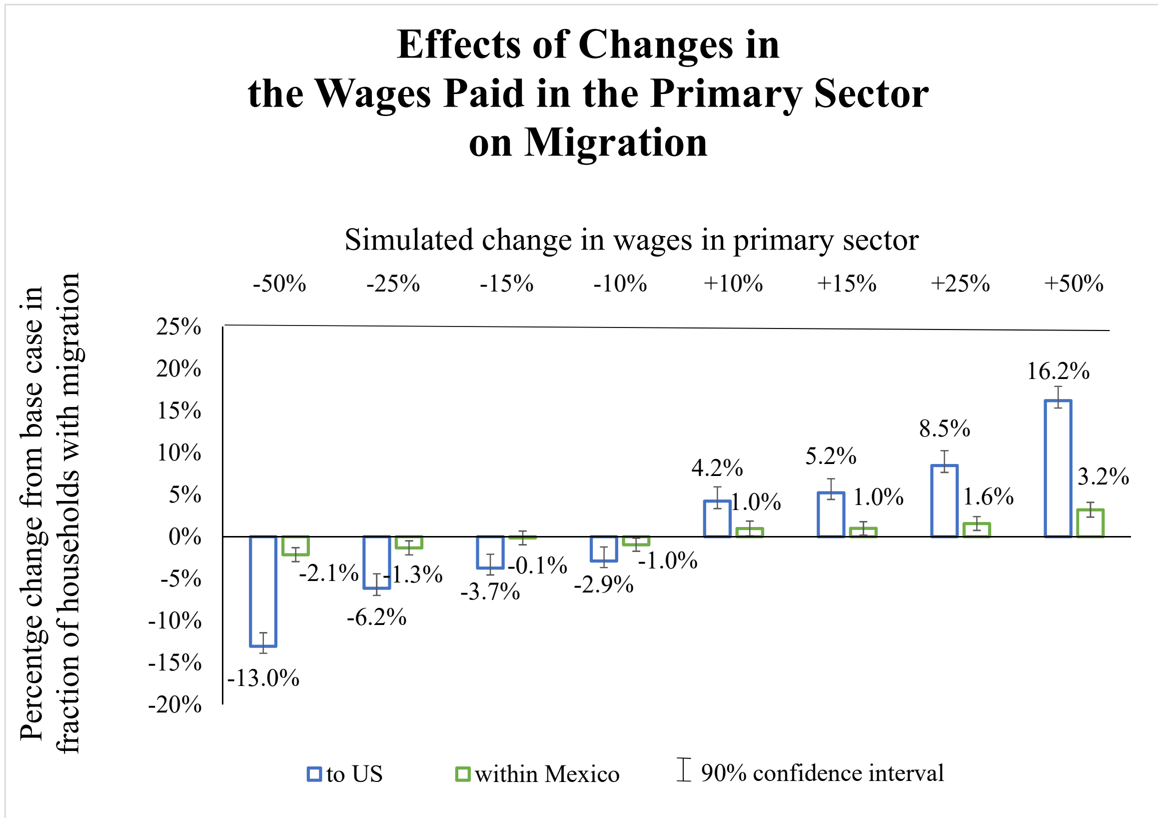


Figure 1: Results of two-sample t-test of the effects of changes in wages in the primary sector on the fraction of households with migration

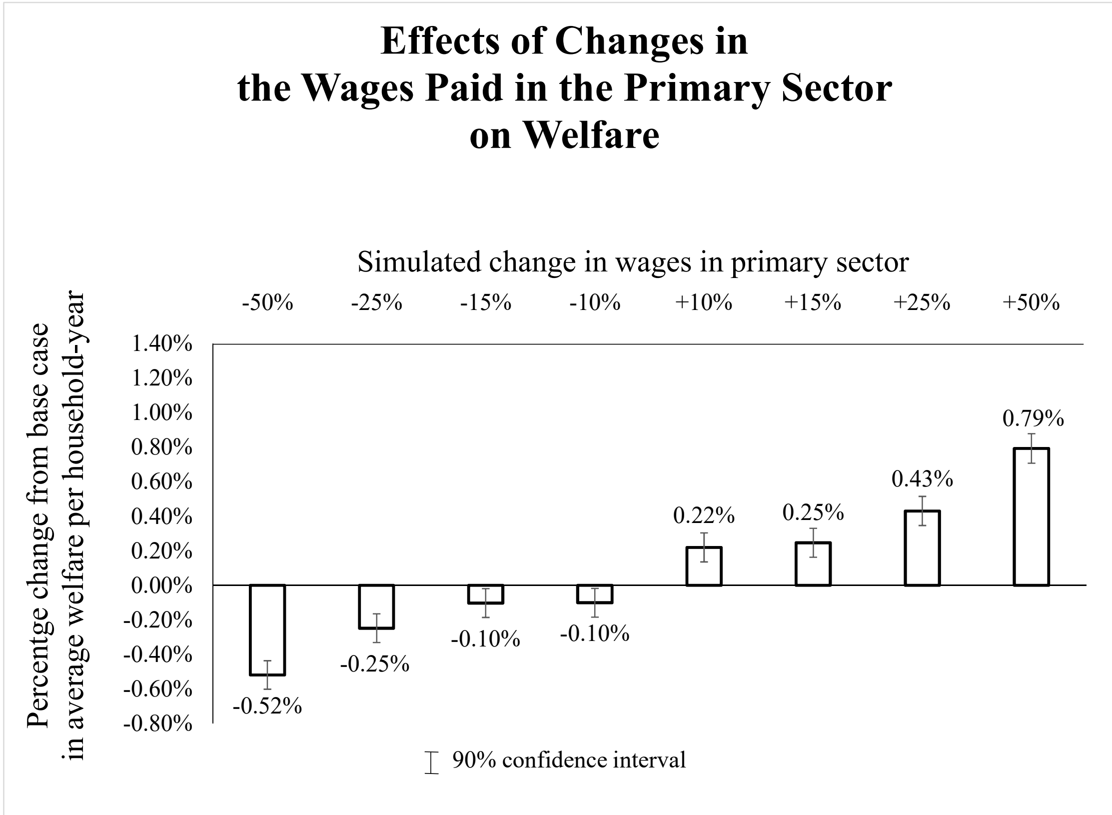


Figure 2: Results of two-sample t-test of the effects of changes in wages in the primary sector on average welfare per household-year

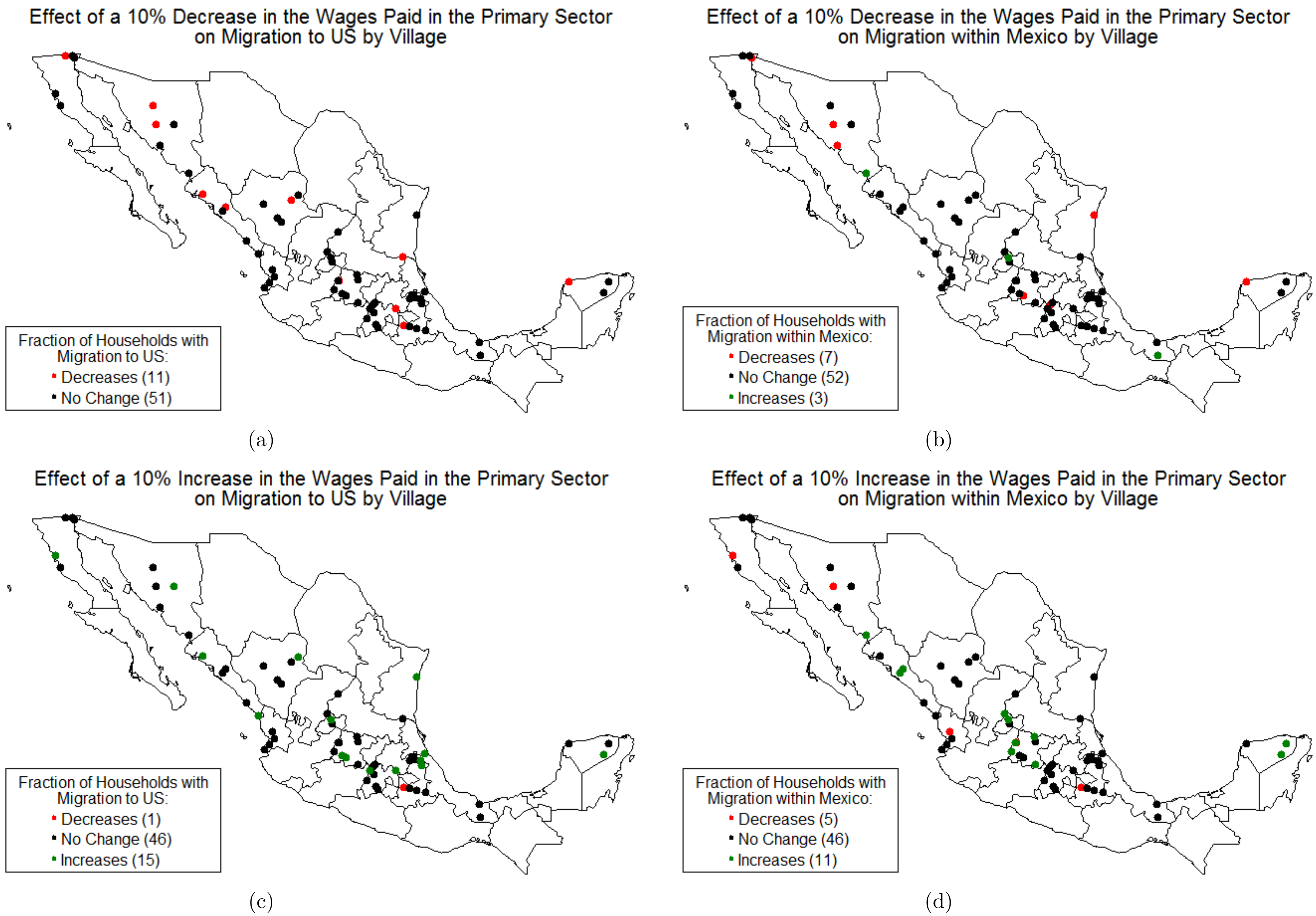
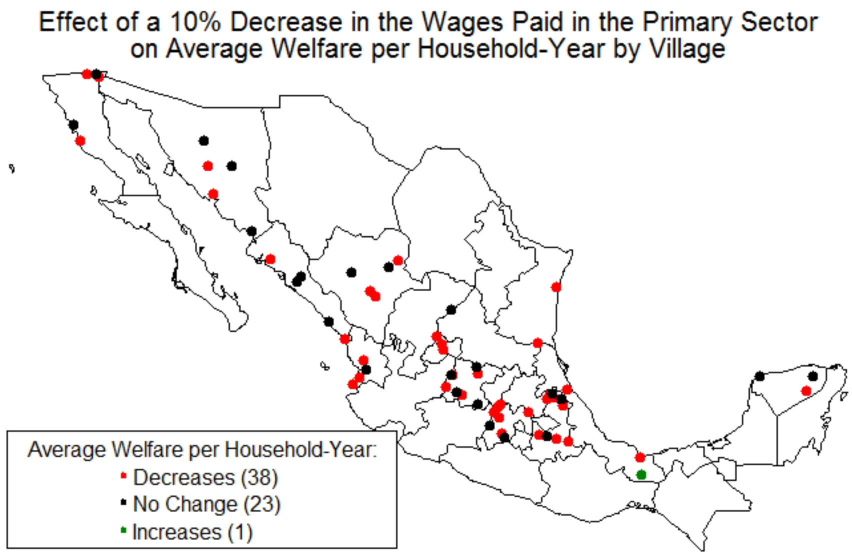
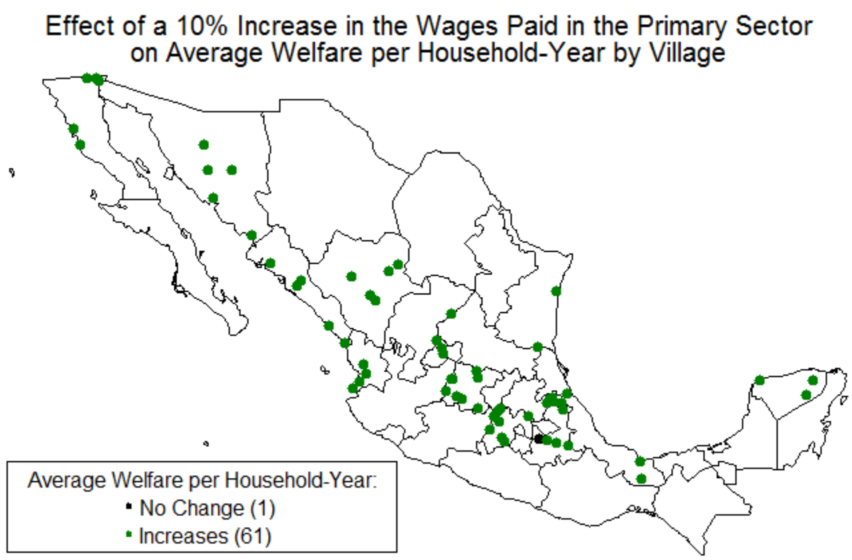


Figure 3: Signs of changes in migration by village that are significant at a 10% level under a 10% change in the wages paid in the primary sector



(a)



(b)

Figure 4: Signs of changes in average welfare per household-year by village that are significant at a 10% level under a 10% change in the wages paid in the primary sector

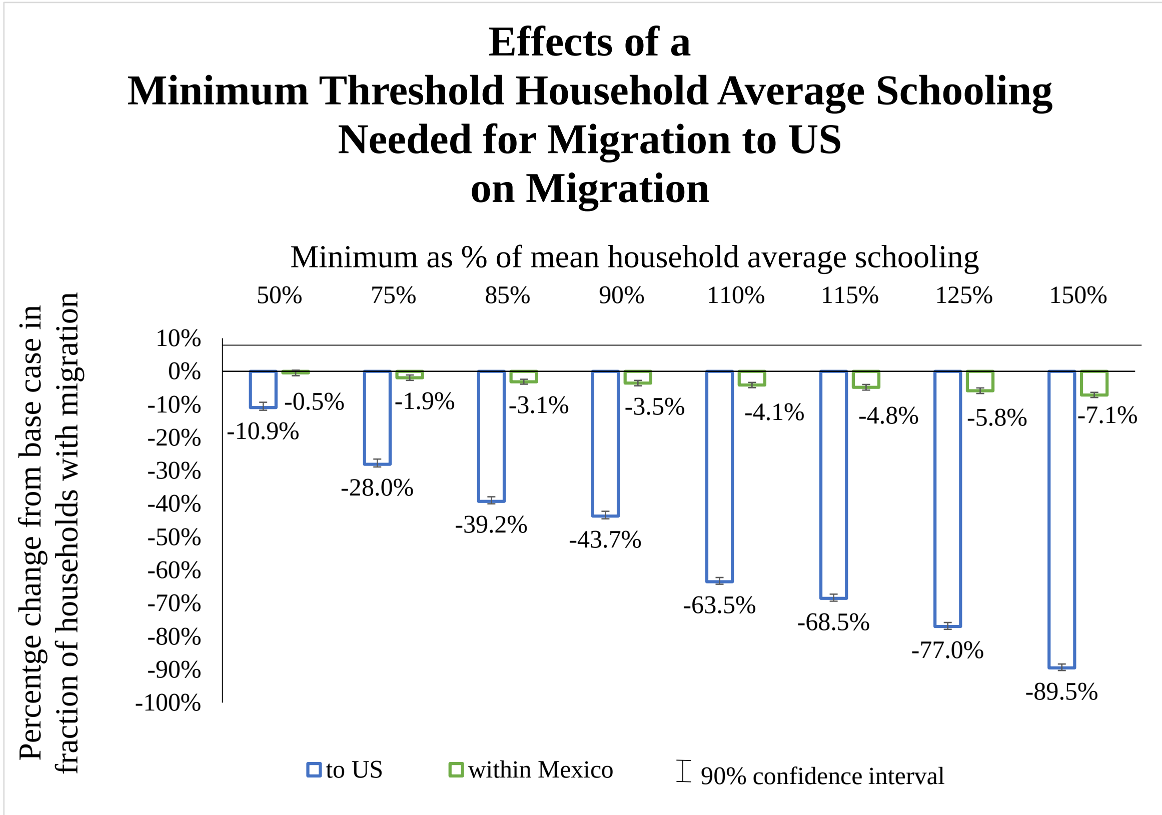


Figure 5: Results of two-sample t-test of the effects of a minimum threshold household average schooling needed for migration to US on the fraction of households with migration

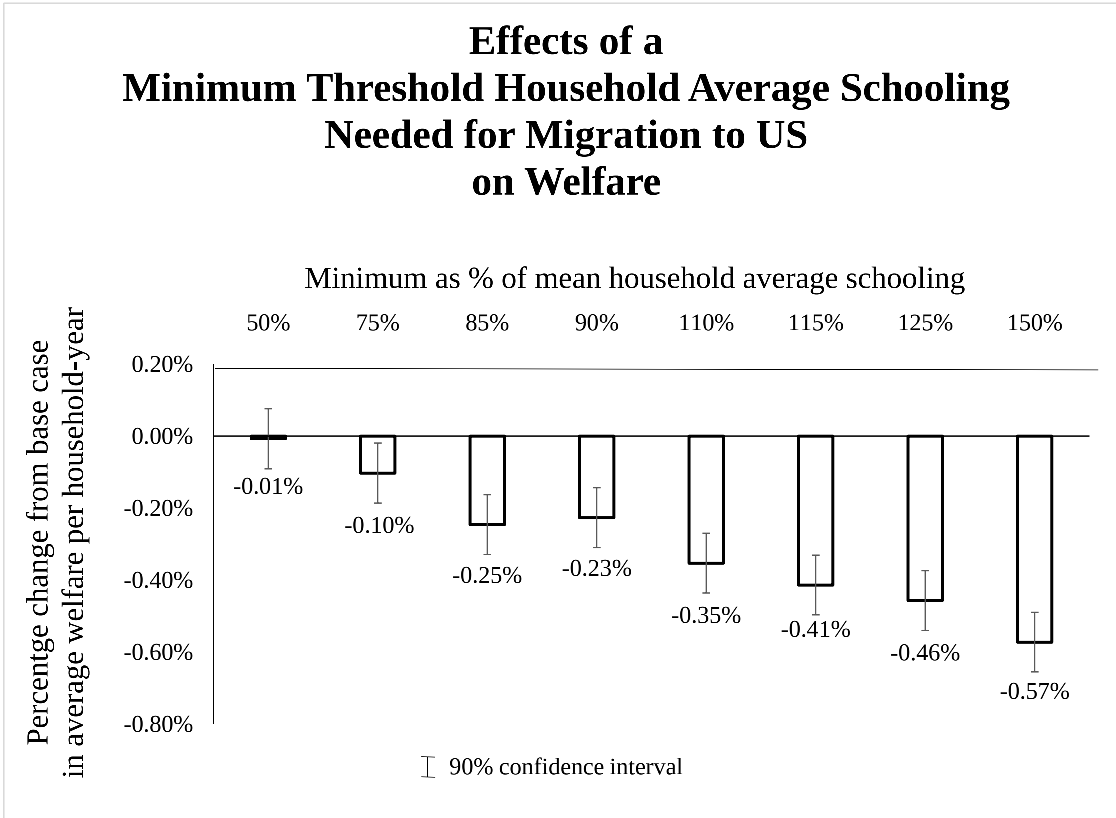


Figure 6: Results of two-sample t-test of the effects of a minimum threshold household average schooling needed for migration to US on average welfare per household-year

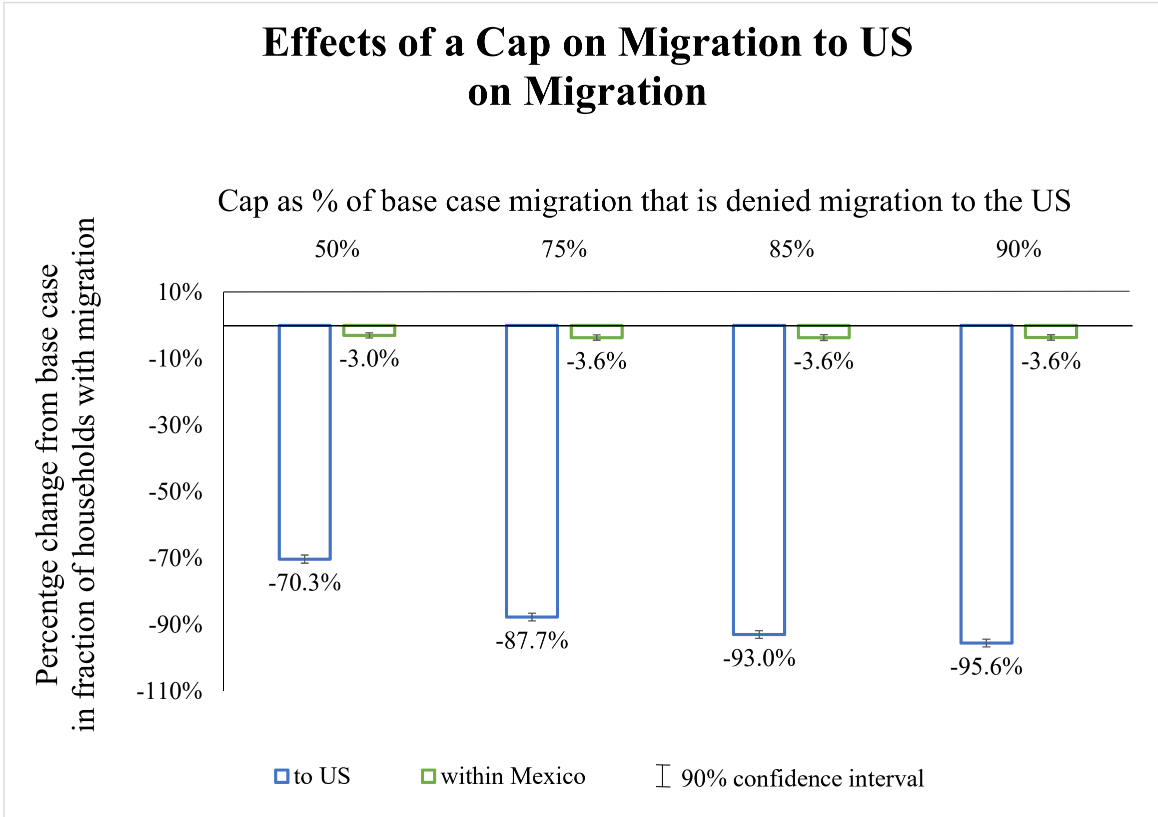


Figure 7: Results of two-sample t-test of the effects of a cap on total migration to US on the fraction of households with migration

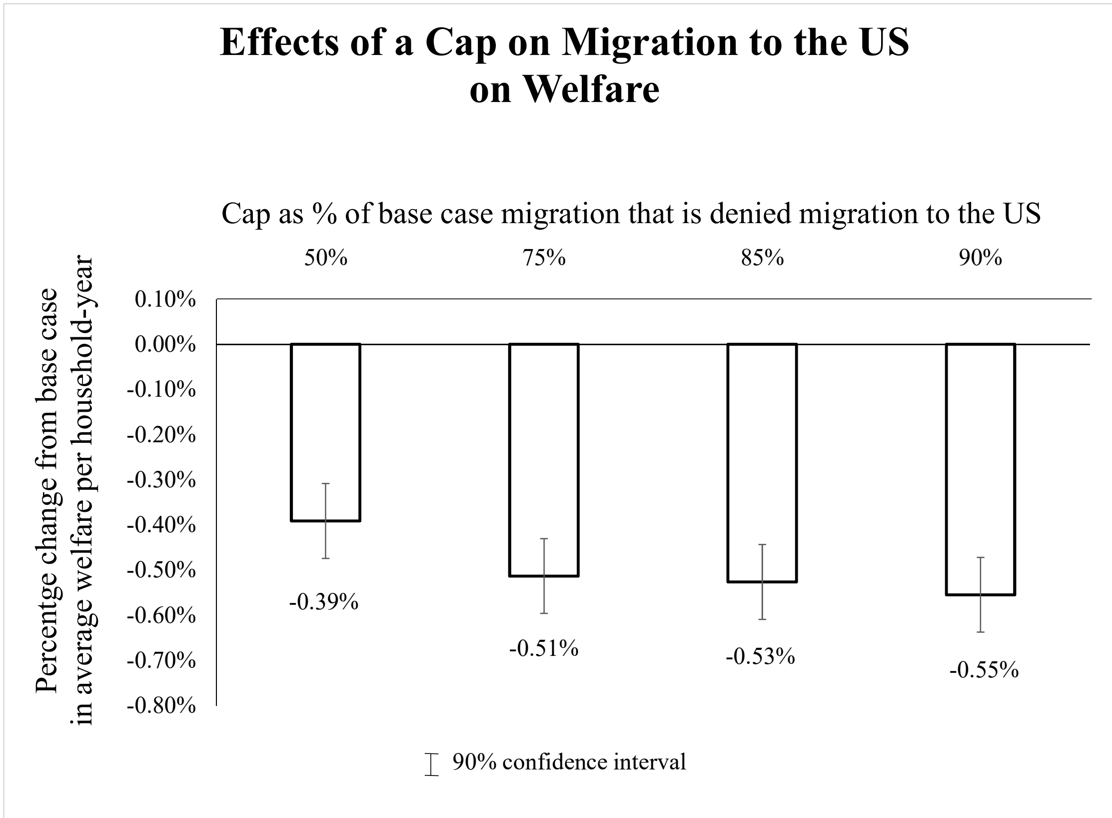


Figure 8: Results of two-sample t-test of the effects of a cap on total migration to US on average welfare per household-year

Effects of No Strategic Interactions

Table 2: Results of two-sample t-test of the effects of no strategic interactions

	Percentage change from base case
Fraction of households with migration to the US	16.6000 ***
Fraction of households with migration within Mexico	23.1464***
Average welfare per household-year	-1.2378***

Significance codes: * p<0.10, ** p<0.05, *** p<0.01

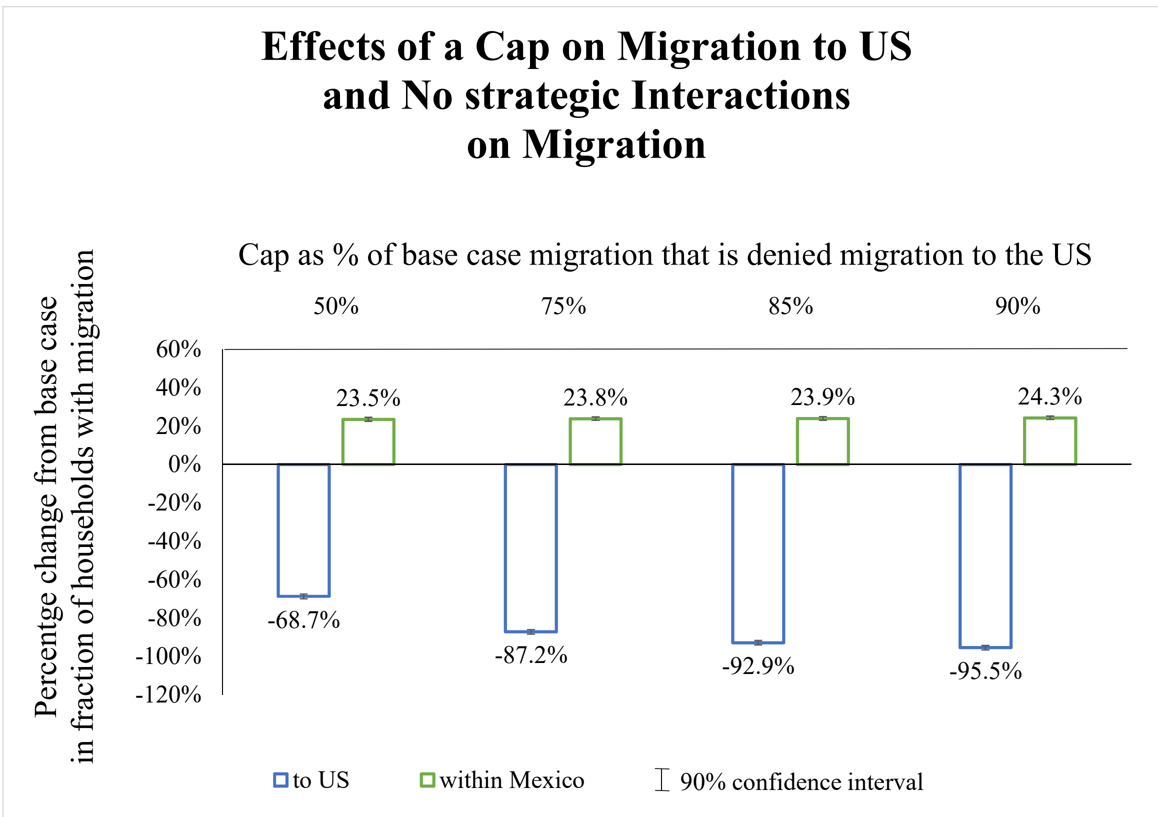


Figure 9: Results of two-sample t-test of the effects of a cap on total migration to US with no strategic interactions on the fraction of households with migration

Effects of No Dynamic Behavior

Table 3: Results of two-sample t-test of the effects of no dynamic behavior

	Percentage change from base case
Fraction of households with migration to the US	-63.3507***
Fraction of households with migration within Mexico	-63.1481***
Average welfare per household-year	-65.3700***

Significance codes: * p<0.10, ** p<0.05, *** p<0.01

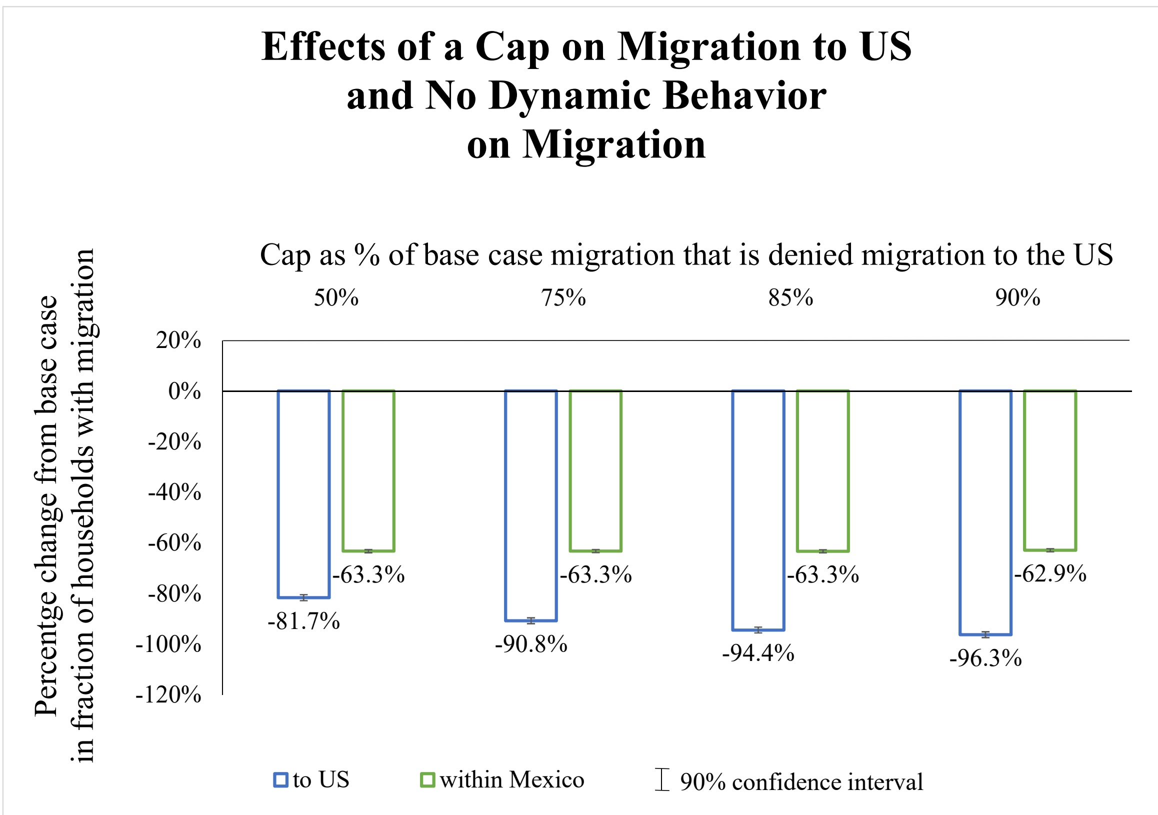


Figure 10: Results of two-sample t-test of the effects of a cap on total migration to US with no dynamic behavior on the fraction of households with migration

Appendix A. Supplementary Tables and Figures

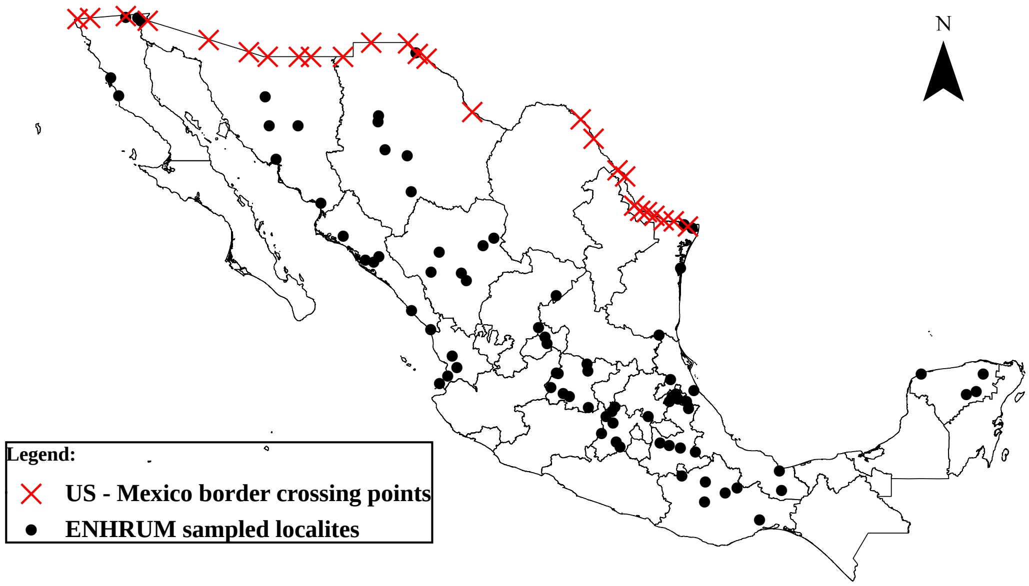


Figure A.1: Location of sampled villages in the ENHRUM survey and the border crossing municipalities

Table A.1: Summary statistics

	Mean	**Std.Dev.**	**Min**	**Max**	**# Obs**
Household migration variables					
Household has a migrant to the US (dummy)	0.17	0.38	0	1	25761
Household has a migrant within Mexico (dummy)	0.2	0.4	0	1	25761
Neighbor migration variables					
Fraction of neighbors with migrants to US	0.17	0.21	0	1	25761
Fraction of neighbors with migrants to Mexico	0.2	0.17	0	0.89	25761
Household characteristics					
Number of household members	5.94	3.15	1	24	25761
Number of family members	5.48	2.83	1	17	25761
Number of children in household	2.17	1.86	0	12	25761
Number of children in family	1.82	1.85	0	11	25761
Number of males in household	2.93	1.84	0	17	25761
Number of males in family	2.74	1.72	0	12	25761
First born is a male (dummy)	0.5	0.5	0	1	25761
Household head age (years)	45.15	16.26	3	100	25725
Household head schooling (years)	4.75	3.84	0	23	25725
Household average schooling (years)	6.21	2.97	0	20.5	25554
Household maximum schooling (years)	8.99	3.84	0	23	25761
Household head is the most educated (dummy)	0.26	0.44	0	1	30313
Irrigated area (hectares)	0.22	3.38	0	426	21257
Household land slope (1=flat to 4=very bad)	3.42	0.81	1	4	23836
Household land quality (1=good to 4=very bad)	3.33	0.92	1	4	23811

Table A.1: (continued)

	Mean	Std.Dev.	Min	Max	# Obs
Municipality characteristics					
Number of basic schools	284.97	332.44	0	1762	22763
Number of indigenous schools	6.08	12.78	0	72	23313
Number of schools	238.87	301.17	0	1603	13107
Number of classrooms	1399.33	2236.64	0	12707	13322
Number of public libraries	20.09	34.74	0	327	11523
Number of labs	47.84	82.72	0	482	12987
Number of workshops	42.78	69.6	0	424	12987
Number of public libraries	4.92	5.69	0	28	19165
Number of students	42284.31	70057.57	0	372625	22763
Number of vehicles	44556.99	88624.85	0	502836	24220
Number of cars	29396.74	64269.9	0	383512	24220
Number of buses	371.1	841.11	0	5355	24220
Number of trucks	14203.43	23759.15	0	113819	24220
Number of motos	585.72	1685.87	0	18650	24220
State-level variables					
Employment in primary sector (% working population)	20.3	10.37	4.3	52	20635
Employment in secondary sector (% working population)	26.58	6.03	15.1	40.7	20635
Employment in tertiaty sector (% working population)	52.78	7.14	31.6	68.1	20635
National variables					
Hourly wage in primary sector (2010 Mexican pesos)	29.48	5.3	21.91	39.45	30313
Hourly wage in secondary sector (2010 Mexican pesos)	31.77	3.4	24.9	35.98	30313
Hourly wage in tertiary sector (2010 Mexican pesos)	37.81	4.21	30.27	43.54	30313
Average hourly wage (2010 Mexican pesos)	35.97	3.34	29.61	41.44	33873
Border crossing variables					
Distance to the closest border crossing point (km)	847.4	474.1	7.0	2178.3	30352

Table A.1: (continued)

	Mean	**Std.Dev.**	**Min**	**Max**	**# Obs**
Number of border crossing points					
... < 1000 km	6.3	5.4	0.0	17.0	30352
... 1000-2000 km	12.4	6.0	0.0	26.0	30352
Average crime rate (murders per 10,000 inhabitants)					
... in crossing municipalities < 1000 km	11.5	8.8	1.9	83.7	12166
... in crossing municipalities 1000-2000 km	12.2	7.4	2.9	52.3	16612
... along border municipalities	14.3	2.5	9.9	18.4	17554
... at the closest crossing point	8.7	6.6	0.0	38.2	17554
... at the second closest crossing point	13.8	26.3	0.0	217.4	17554
... at the third closest crossing point	9.6	19.2	0.0	144.2	17554

Table A.2: Within and between variation of migration decisions

		Mean	**Std. Dev.**	**Min**	**Max**	**# Obs**
Household has a migrant to the US (dummy)						
	Overall	0.1746	0.3796	0.0000	1.0000	25,761
	Within		0.2254	-0.7778	1.1269	
	Between		0.3095	0.0000	1.0000	
Household has a migrant within Mexico (dummy)						
	Overall	0.2000	0.4000	0.0000	1.0000	25,761
	Within		0.2477	-0.7523	1.1524	
	Between		0.3197	0.0000	1.0000	

Notes: "Within" variation is the variation in the migration variable across years for a given village. "Between" variation is the variation in the migration variable across villages for a given year.

Table A.3: Policy functions

	US	*Mexico*
Dependent variable is probability of migration to/within	(1)	(2)
Fraction of neighbors with migration to US	-0.1479***	0.0685**
	(0.0322)	(0.0289)
Fraction of neighbors with migration within Mexico	0.0537*	-0.2136***
	(0.0302)	(0.0369)
Number of household members	0.0052***	0.0052***
	(0.0009)	(0.0009)
Household head age (years)	0.0003	0.0007***
	(0.0002)	(0.0002)
First born is male (dummy)	0.0104**	0.0049
	(0.0042)	(0.0043)
Household head schooling (years)	-0.0016*	-0.0030***
	(0.0009)	(0.0009)
Household average schooling (years)	0.0024**	0.0044***
	(0.0011)	(0.0011)
Lag of migration to US	0.8020***	-0.0048
	(0.0108)	(0.0061)
Lag of migration within Mexico	0.0137**	0.8269***
	(0.0058)	(0.0093)
Household land quality (1=good to 4=very bad) interacted with rain	-0.0000	0.0000
	(0.0000)	(0.0000)
Number of basic schools	0.0001***	-0.0001
	(0.0000)	(0.0001)
Distance to closest border crossing point (km)	0.0001**	-0.0002**
	(0.0000)	(0.0001)
Crime rate at closest border crossing point	-0.0001	0.0005*
	(0.0004)	(0.0003)
Crime rate second closest border crossing point	-0.0001***	-0.0000
	(0.0000)	(0.0001)
Crime rate third closest border crossing point	-0.0000	0.0002*
	(0.0001)	(0.0001)
Hourly wage in primary sector	0.0025***	0.0006
	(0.0005)	(0.0005)
Employment in secondary sector	-0.0013	0.0011
	(0.0012)	(0.0012)
Constant	-0.2782***	0.2369**
	(0.0616)	(0.1031)
Village fixed effects	Y	Y
p-value (Pr>F)	0.000	0.000
adjusted R-squared	0.743	0.773
# observations	9486	9486

Notes: Standard errors in parentheses. Significance codes: * p<0.10, ** p<0.05, *** p<0.01. Crime rates are in homicides per 10,000 inhabitants. Employment is in % working population.

Table A.4: Transition densities coefficients at the household level

	Dependent variables is:									
	Number of males in household	Number of males in family	Household size	First born is male (dummy)	Household head schooling (years)	Household average schooling (years)	Household maximum schooling (years)	Household's land slope interacted with rain	Household's land quality interacted with rain	Household's irrigated area interacted with rain
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Lag of number of males in household	1.0087***	-0.0020	0.0271***	0.0075***	0.0003	-0.0372***	-0.0238**	4.5062	3.1666	-0.8995
	(0.0036)	(0.0032)	(0.0053)	(0.0016)	(0.0033)	(0.0093)	(0.0104)	(19.7362)	(19.7635)	(4.1497)
Lag of number of males in family	-0.0146***	0.9970***	-0.0347***	-0.0039***	-0.0030	0.0334***	0.0219**	-21.0162	-20.2062	0.2350
	(0.0033)	(0.0029)	(0.0049)	(0.0015)	(0.0030)	(0.0086)	(0.0096)	(18.1221)	(18.1472)	(3.8096)
Lag of first born is male (dummy)	0.0143***	0.0140***	0.0119**	0.9790***	-0.0125***	-0.0169*	-0.0076	25.6640	28.5128	-2.2195
	(0.0036)	(0.0032)	(0.0053)	(0.0016)	(0.0032)	(0.0092)	(0.0103)	(19.4757)	(19.5027)	(4.0718)
Lag of household head age (years)	-0.0016***	-0.0016***	-0.0031***	-0.0007***	-0.0006***	-0.0017***	-0.0022***	-0.7295	-0.7458	0.2896*
	(0.0001)	(0.0001)	(0.0002)	(0.0001)	(0.0001)	(0.0003)	(0.0004)	(0.7210)	(0.7220)	(0.1510)
Lag of household size (members)	0.0022**	0.0000	1.0021***	-0.0044***	-0.0017*	0.0064**	0.0084***	3.4226	3.9097	0.4858
	(0.0010)	(0.0009)	(0.0015)	(0.0005)	(0.0010)	(0.0028)	(0.0031)	(5.8200)	(5.8281)	(1.2166)
Lag of household head schooling (years)	-0.0004	0.0000	-0.0017	-0.0007**	0.9995***	0.0067***	0.0020	3.5709	3.3941	1.4838*
	(0.0007)	(0.0006)	(0.0010)	(0.0003)	(0.0006)	(0.0018)	(0.0020)	(3.7224)	(3.7275)	(0.7782)
Lag of household average schooling (years)	-0.0012	-0.0015	-0.0007	0.0002	0.0014	0.9434***	-0.0335***	-9.0181	-8.7666	-0.8912
	(0.0013)	(0.0012)	(0.0020)	(0.0006)	(0.0012)	(0.0035)	(0.0039)	(7.3142)	(7.3243)	(1.5289)
Lag of household maximum schooling (years)	-0.0006	-0.0006	-0.0017	0.0003	0.0007	0.0371***	1.0197***	-0.9318	-0.8082	0.3536
	(0.0009)	(0.0008)	(0.0013)	(0.0004)	(0.0008)	(0.0023)	(0.0026)	(4.7920)	(4.7986)	(1.0018)
Lag of fraction of households with migration to US	0.0001	0.0063	0.0030	-0.0047	-0.0030	0.0091	-0.0509*	148.7091***	141.8349***	15.1994
	(0.0090)	(0.0080)	(0.0133)	(0.0040)	(0.0083)	(0.0236)	(0.0264)	(48.2475)	(48.3143)	(10.0782)
Lag of fraction of households with migration within Mexico	-0.0336***	-0.0217**	-0.0454***	-0.0096**	-0.0178	0.0544*	0.0720**	689.5393***	701.5287***	23.7046*
	(0.0110)	(0.0097)	(0.0162)	(0.0048)	(0.0114)	(0.0326)	(0.0364)	(66.0319)	(66.1234)	(13.7949)
Lag of own household migration to US (dummy)	0.0043	0.0053	0.0009	0.0093***	0.0124***	-0.0310**	-0.0003	6.7006	7.0530	-9.4844
	(0.0052)	(0.0046)	(0.0077)	(0.0023)	(0.0046)	(0.0133)	(0.0148)	(28.1827)	(28.2218)	(5.8896)
Lag of own household migration within Mexico (dummy)	0.0102**	0.0086**	0.0161**	0.0082***	0.0095**	-0.0241**	-0.0418***	20.5595	21.1400	-3.2179
	(0.0046)	(0.0041)	(0.0068)	(0.0020)	(0.0040)	(0.0115)	(0.0128)	(24.4302)	(24.4640)	(5.1016)
Lag of number of basic schools					-0.0000	0.0001**	-0.0000			
					(0.0000)	(0.0000)	(0.0000)			
Lag of number of indigenous schools					0.0001*	0.0003*	0.0010***			
					(0.0001)	(0.0002)	(0.0002)			
Lag of household land slope interacted with rain					0.0000	-0.0000	-0.0000	0.8535***	-0.1555***	-0.0036
					(0.0000)	(0.0000)	(0.0000)	(0.0397)	(0.0397)	(0.0085)
Lag of household land quality interacted with rain					-0.0000	0.0000	0.0000	-0.0270	0.9817***	0.0009
					(0.0000)	(0.0000)	(0.0000)	(0.0395)	(0.0396)	(0.0085)
Lag of household's irrigated area interacted with rain					-0.0000	-0.0000	0.0000	0.0046	0.0042	1.0032***
					(0.0000)	(0.0000)	(0.0000)	(0.0139)	(0.0139)	(0.0037)
Constant	0.1221***	0.1225***	0.2423***	0.0653***	0.0538***	0.1398***	0.2563***	319.0271***	314.7990***	-13.8696
	(0.0080)	(0.0071)	(0.0118)	(0.0035)	(0.0079)	(0.0226)	(0.0252)	(43.9870)	(44.0480)	(9.1763)
adjusted R-squared	0.9882	0.9898	0.9908	0.9705	0.9993	0.9889	0.9905	0.7588	0.7628	0.9163
# observations	14554	14554	14554	14554	6497	6497	6497	7168	7168	7117

Notes: Standard errors in parentheses. Significance codes: * p<0.10, ** p<0.05, *** p<0.01.

Table A.5: Transition densities coefficients at the village and municipality level

	Dependent variable is: Crime at closest crossing border point (11)	Crime at second crossing border point (12)	Crime at third crossing border point (13)	Number of basic schools (14)	Number of indigenous schools (15)	Number of students in basic system (16)
Lag of number of basic schools				0.5484***	0.0003	27.0023***
				(0.0431)	(0.0073)	(3.9734)
Lag of number of indigenous schools				-0.2278	0.4956***	-14.9978
				(0.2207)	(0.0372)	(20.3280)
Lag of number of students in basic system				0.0009*	-0.0001	0.0941**
				(0.0004)	(0.0001)	(0.0413)
Lag of employment in primary sector				1.0530	0.0180	-18.8602
				(1.2750)	(0.2160)	(117.4470)
Lag of employment in secondary sector				1.3148	-0.0555	-51.5847
				(1.2895)	(0.2188)	(118.7885)
Lag of employment in tertiary sector				0.7357	-0.0007	10.5247
				(1.3240)	(0.2243)	(121.9671)
Lag of avg. hourly wage in primary sector (pesos)	-0.5765***	4.2476***	0.4092			
	(0.1314)	(0.8395)	(0.3101)			
Lag of avg. hourly wage in secondary sector (pesos)	-2.0471***	0.3548	0.3891			
	(0.2333)	(1.4910)	(0.5507)			
Lag of avg. hourly wage in tertiary sector (pesos)	1.9010***	-2.6400	-0.9146			
	(0.2633)	(1.6822)	(0.6213)			
Lag of crime at closest border crossing point	0.3543***	0.9985***	0.3662***			
	(0.0285)	(0.1822)	(0.0673)			
Lag of crime at second closest border crossing point	0.0347***	0.2047***	0.0389***			
	(0.0050)	(0.0321)	(0.0118)			
Lag of crime at third closest border crossing point	0.0850***	0.4031***	0.1935***			
	(0.0142)	(0.0909)	(0.0336)			
Constant	17.2215***	-33.4177*	15.3372**	-35.3086	8.6043	19691.8306*
	(3.1505)	(20.1307)	(7.4350)	(126.5089)	(21.4457)	(11653.7577)
adjusted R-squared	0.3736	0.1547	0.1001	0.9814	0.9907	0.7589
# observations	960	960	960	743	735	743

Notes: Standard errors in parentheses. Employment is in % working population. Crime is in homicides per 10,000 inhabitants.
Significance codes: * p<0.10, ** p<0.05, *** p<0.01.

Table A.6: Transition densities coefficients at the state and national level

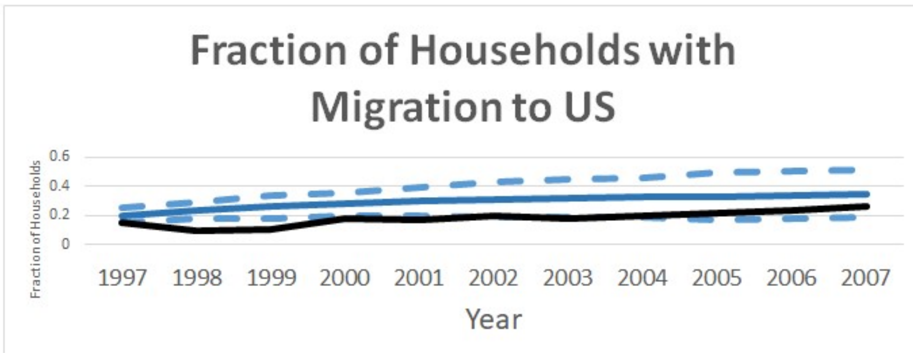
	Employment in: primary sector	secondary sector	tertiary sector	Avg. hourly wage in: primary sector (pesos)	secondary sector (pesos)	tertiary sector (pesos)
	(17)	(18)	(19)	(20)	(21)	(22)
Lag of employment in primary sector	-0.1632	0.2706	0.6664***			
	(0.2584)	(0.2075)	(0.2382)			
Lag of employment in secondary sector	-0.4812**	0.7253***	0.5811***			
	(0.2405)	(0.1932)	(0.2217)			
Lag of employment in tertiary sector	-0.4501**	0.1884	1.0455***			
	(0.2202)	(0.1769)	(0.2030)			
Lag of avg. hourly wage in primary sector (pesos)	-0.4508***	0.2284**	0.3217**	0.9509*	0.8702**	1.0556**
	(0.1342)	(0.1078)	(0.1237)	(0.5007)	(0.2892)	(0.3295)
Lag of avg. hourly wage in secondary sector (pesos)	-0.1500	0.0685	0.1867	-0.0404	0.9658*	0.4484
	(0.1820)	(0.1462)	(0.1678)	(0.8731)	(0.5043)	(0.5745)
Lag of avg. hourly wage in tertiary sector (pesos)	0.2400	-0.3680*	-0.1159	0.1823	-1.0594	-0.6512
	(0.2726)	(0.2189)	(0.2513)	(1.0005)	(0.5779)	(0.6583)
Constant	57.7381**	1.0251	-36.6682*	-2.7204	15.6277**	17.2455**
	(23.1182)	(18.5670)	(21.3111)	(11.1884)	(6.4624)	(7.3613)
adjusted R-squared	0.9547	0.9204	0.9101	0.7020	0.7410	0.7777
# observations	154	154	154	12	12	12

Notes: Standard errors in parentheses. Employment is in % working population. Wages are in 2010 Mexican pesos. Significance codes: * p<0.10, ** p<0.05, *** p<0.01.

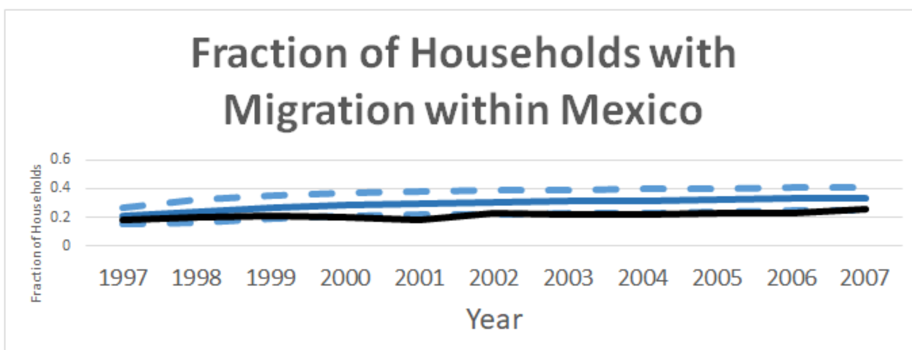
Table A.7: Welfare based on observed and model predicted data

	Estimate
Average welfare per household-year based on:	
Observed data	-0.0177
Model predicted data	-0.0122

Notes: Welfare is the present discounted value of the entire stream of per-period payoffs over the period 1997-2007, as calculated using the parameter estimates from the structural model. Average welfare per-household-year is welfare divided by the number of household-years. Welfare calculated using observed data is calculated using actual values of actions and states in the data. Model predicted welfare is calculated using model predicted actions and states generated from 100 simulations.



(a) Actual vs. model predicted migration to US



(b) Actual vs. model predicted migration within Mexico

Figure A.2: Actual vs. model predicted migration

Notes: The black solid line plots actual fraction of households with migration (a) to US and (b) within Mexico. The blue solid line plots model predicted migration, as averaged over 100 simulations, and the blue dashed line indicates the 99.99% confidence interval.

Appendix B. Supplementary Counterfactual Simulations

Table B.1: Effects of Changes in the Wages Paid in the Primary Sector:
Determinants of significant changes at the village level
in the fraction of households with migration

Dependent variable is the value of significant changes in the fraction of households with migration to/within:	*US*	*Mexico*	*US*	*Mexico*
Simulated change in wages in primary sector:	10% Increase		10% Decrease	
Characteristics from the initial year of the simulation (1997):				
Distance to closest border crossing point (1000 km)	-0.0012	0.0102***	0.0020	0.0016
	(0.0055)	(0.0037)	(0.0037)	(0.0046)
Crime rate at closest border crossing point	-0.0002	-0.0002	0.0003	-0.0001
	(0.0005)	(0.0003)	(0.0003)	(0.0004)
Employment in primary sector	0.0001	0.0000	-0.0000	0.0003
	(0.0004)	(0.0002)	(0.0002)	(0.0003)
Employment in secondary sector	0.0004	-0.0000	-0.0001	-0.0005
	(0.0006)	(0.0004)	(0.0004)	(0.0005)
Number of males in household	0.0012	0.0092*	-0.0010	0.0091
	(0.0080)	(0.0053)	(0.0053)	(0.0066)
Household head age	0.0004	0.0007*	-0.0004	0.0003
	(0.0006)	(0.0004)	(0.0004)	(0.0005)
Household head schooling	0.0033	-0.0018	-0.0049**	0.0003
	(0.0036)	(0.0024)	(0.0024)	(0.0030)
Number of household members	-0.0048	-0.0074**	-0.0016	-0.0033
	(0.0053)	(0.0035)	(0.0035)	(0.0044)
Fraction of households with migration to US	0.0180	0.0102	0.0032	-0.0002
	(0.0151)	(0.0101)	(0.0101)	(0.0125)
Fraction of households with migration within Mexico	0.0448*	-0.0031	0.0184	-0.0225
	(0.0230)	(0.0153)	(0.0154)	(0.0191)
Household average schooling	-0.0017	-0.0006	0.0045*	-0.0026
	(0.0039)	(0.0026)	(0.0026)	(0.0032)
Household land quality (1=good to 4=very bad)	0.0005	0.0038	-0.0013	-0.0043
	(0.0056)	(0.0038)	(0.0038)	(0.0047)
Constant	-0.0105	-0.0173	0.0154	0.0218
	(0.0470)	(0.0313)	(0.0314)	(0.0390)
p-value (Pr>F)	0.8550	0.1480	0.4930	0.2520
# observations	62	62	62	62

Notes: Standard errors in parentheses. To analyze the determinants of significant changes at the village level in the fraction of households with migration, we regress the village-level changes in the fraction of households with migration over the entire simulation period (1997-2007) that are significant at a 10% level under a simulated 10% increase and a simulated 10% decrease in primary sector wages in the initial year of the simulation (1997), respectively, on the initial village, municipality, state, and national characteristics from the initial year of the simulation (1997). Crime rates are in homicides per 10,000 inhabitants.
Significance codes: * p<0.10, ** p<0.05, *** p<0.01.

Table B.2: Effects of Changes in the Wages Paid in the Primary Sector: Determinants of significant changes at the village level in the average welfare per household-year

Dependent variable is the value of significant changes in the average welfare per household-year:

Simulated change in wages in primary sector:	10% Increase	10% Decrease
Characteristics from the initial year of the simulation (1997):		
Distance to closest border crossing point (1000 km)	0.0003	0.0004
	(0.0003)	(0.0003)
Crime rate at closest border crossing point	-0.0184	0.0059
	(0.0250)	(0.0276)
Employment in primary sector	0.0048	0.0282
	(0.0176)	(0.0194)
Employment in secondary sector	0.0084	0.0191
	(0.0291)	(0.0321)
Number of males in household	0.3362	0.7454*
	(0.3906)	(0.4310)
Household head age	0.0472*	0.0892***
	(0.0278)	(0.0307)
Household head schooling	-0.1787	-0.2499
	(0.1760)	(0.1942)
Number of household members	-0.3348	-0.3094
	(0.2575)	(0.2841)
Fraction of households with migration to US	0.4864	-1.5430*
	(0.7390)	(0.8154)
Fraction of households with migration within Mexico	2.1125*	-2.1275*
	(1.1273)	(1.2439)
Household average schooling	0.0739	0.1690
	(0.1885)	(0.2080)
Household land quality (1=good to 4=very bad)	-0.1487	0.4680
	(0.2758)	(0.3044)
Constant	1.9611	-7.5317***
	(2.2989)	(2.5366)
p-value (Pr>F)	0.0350	0.0126
# observations	62	62

Notes: Standard errors in parentheses. To analyze the determinants of significant changes at the village level in the average welfare per household-year, we regress the village-level changes in the average welfare per household-year over the entire simulation period (1997-2007) that are significant at a 10% level under a simulated 10% increase and a simulated 10% decrease in primary sector wages in the initial year of the simulation (1997), respectively, on the initial village, municipality, state, and national characteristics from the initial year of the simulation (1997). Crime rates are in homicides per 10,000 inhabitants.
Significance codes: * $p<0.10$, ** $p<0.05$, *** $p<0.01$.

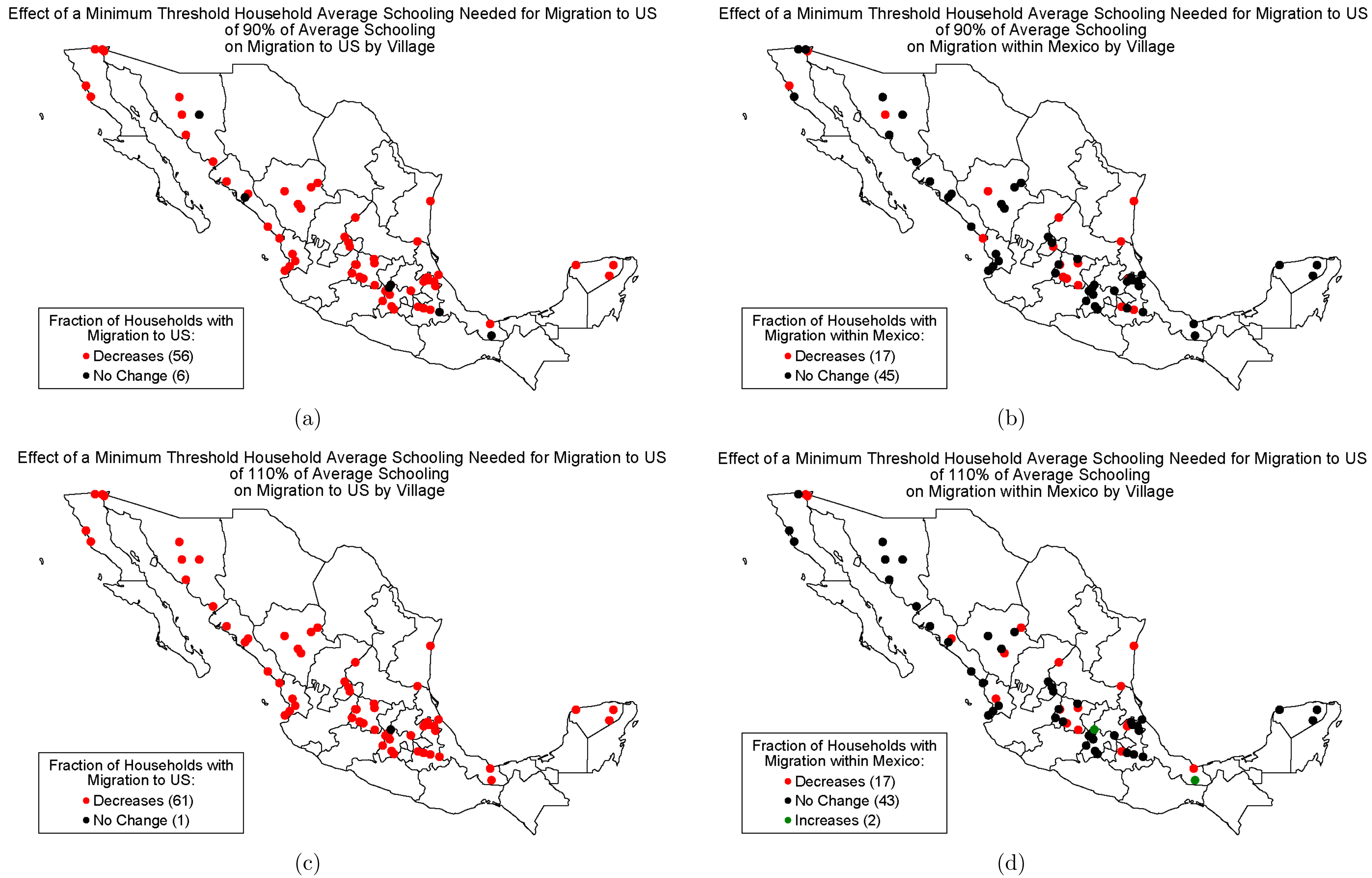
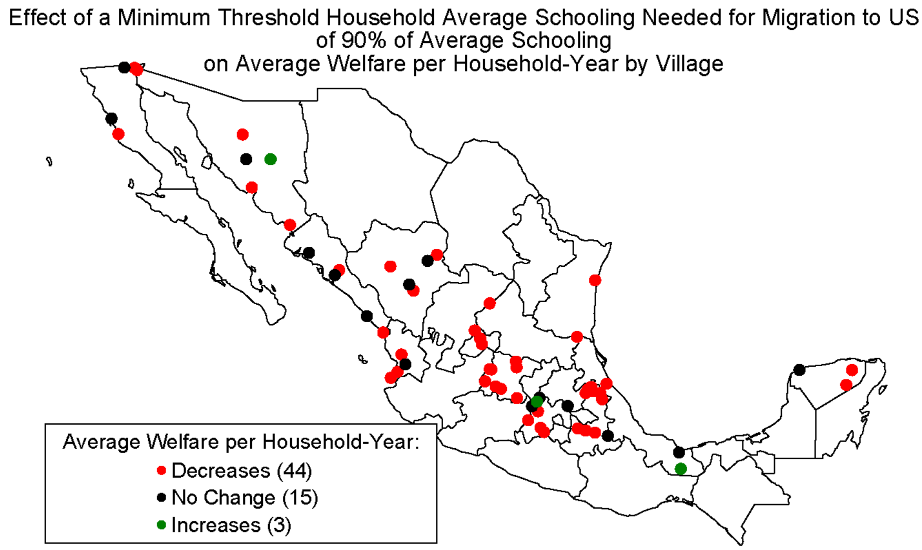


Figure B.1: Signs of changes in migration by village that are significant at a 10% level under a minimum threshold household average schooling needed for migration to US of 10% above and below the average schooling

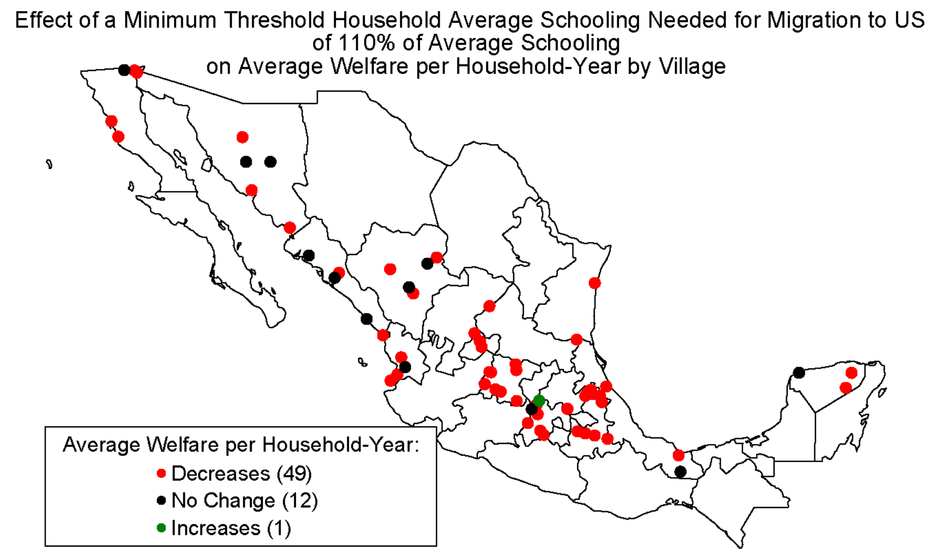
Table B.3: Effects of a Minimum Threshold Household Average Schooling Needed for Migration to US:
Determinants of significant changes at the village level in the fraction of households with migration

Dependent variable is the value of significant changes in the fraction of households with migration to/within:	*US*	*Mexico*	*US*	*Mexico*
Minimum as % of mean household avg. schooling :	110%		90%	
Characteristics from the initial year of the simulation (1997):				
Distance to closest border crossing point (1000 km)	0.0060	0.0095	0.0039	0.0059
	(0.0234)	(0.0064)	(0.0270)	(0.0041)
Crime rate at closest border crossing point	-0.0006	0.0001	0.0011	-0.0002
	(0.0022)	(0.0006)	(0.0025)	(0.0004)
Employment in primary sector	-0.0025	-0.0004	-0.0034*	-0.0005*
	(0.0015)	(0.0004)	(0.0018)	(0.0003)
Employment in secondary sector	-0.0033	-0.0007	-0.0058*	-0.0008*
	(0.0025)	(0.0007)	(0.0029)	(0.0004)
Number of males in household	0.0542	0.0061	0.0303	0.0038
	(0.0340)	(0.0093)	(0.0392)	(0.0060)
Household head age	-0.0007	-0.0008	-0.0031	0.0003
	(0.0024)	(0.0007)	(0.0028)	(0.0004)
Household head schooling	0.0292*	-0.0010	0.0219	0.0004
	(0.0153)	(0.0042)	(0.0177)	(0.0027)
Number of household members	-0.0424*	-0.0031	-0.0229	-0.0051
	(0.0224)	(0.0061)	(0.0258)	(0.0040)
Fraction of households with migration to US	-0.4193***	-0.0230	-0.3037***	-0.0022
	(0.0642)	(0.0175)	(0.0741)	(0.0114)
Fraction of households with migration within Mexico	0.0297	-0.0408	-0.0105	0.0038
	(0.0980)	(0.0268)	(0.1131)	(0.0174)
Household average schooling	0.0009	0.0032	0.0023	-0.0002
	(0.0164)	(0.0045)	(0.0189)	(0.0029)
Household land quality (1=good to 4=very bad)	0.0037	-0.0179***	0.0025	-0.0012
	(0.0240)	(0.0065)	(0.0277)	(0.0043)
Constant	-0.0259	0.1014*	0.1685	0.0327
	(0.1998)	(0.0546)	(0.2306)	(0.0355)
p-value (Pr>F)	0.0000	0.1190	0.0000	0.2170
# observations	62	62	62	62

Notes: Standard errors in parentheses. To analyze the determinants of significant changes at the village level in the fraction of households with migration, we regress the village-level changes in the fraction of households with migration over the entire simulation period (1997-2007) that are significant at a 10% level under a simulated minimum threshold household average schooling needed for migration to US in the initial year of the simulation (1997) of 110% and 90% of the average household schooling observed in the data, respectively, on the initial village, municipality, state, and national characteristics from the initial year of the simulation (1997). Crime rates are in homicides per 10,000 inhabitants.
Significance codes: * p<0.10, ** p<0.05, *** p<0.01.



(a)



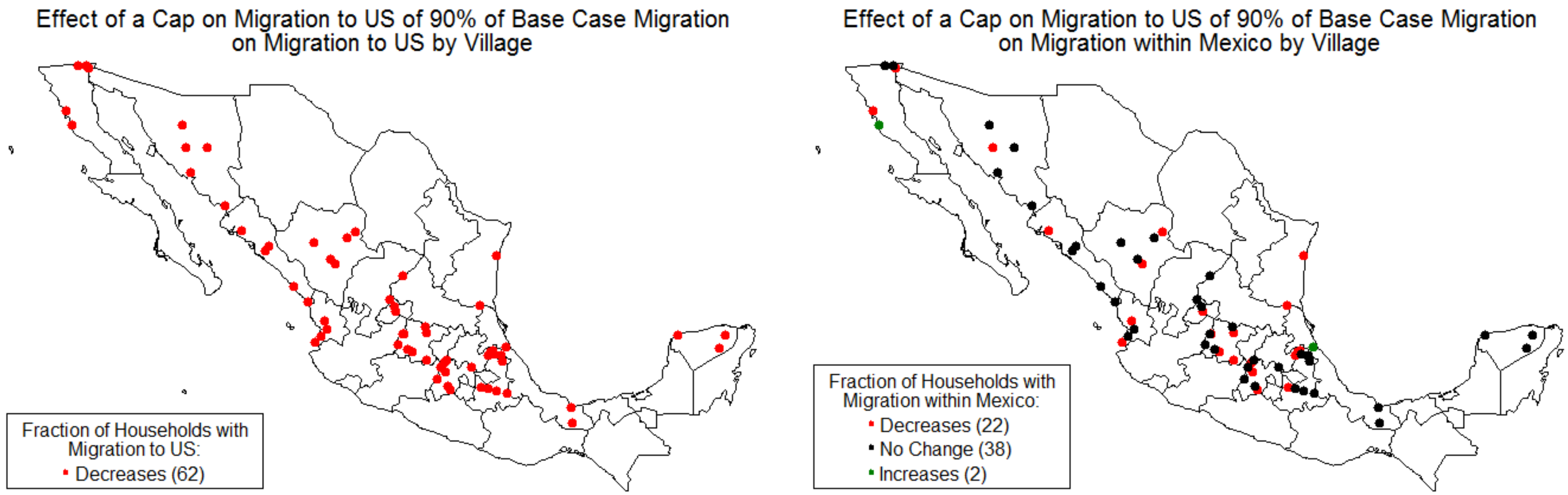
(b)

Figure B.2: Signs of changes in average welfare per household-year by village that are significant at a 10% level under a minimum threshold household average schooling needed for migration to US of 10% above and below the average schooling

Table B.4: Effects of a Minimum Threshold Household Average Schooling Needed for Migration to US:
Determinants of significant changes at the village level in the average welfare per household-year

Dependent variable is the value of significant changes in the average welfare per household-year:		
Minimum as % of mean household avg. schooling :	110%	90%
Characteristics from the initial year of the simulation (1997):		
Distance to closest border crossing point (1000 km)	0.0001	-0.0001
	(0.0009)	(0.0009)
Crime rate at closest border crossing point	-0.0426	0.0199
	(0.0795)	(0.0848)
Employment in primary sector	-0.0733	-0.1102*
	(0.0559)	(0.0597)
Employment in secondary sector	-0.1004	-0.1809*
	(0.0923)	(0.0985)
Number of males in household	1.6459	1.0590
	(1.2400)	(1.3226)
Household head age	-0.0034	-0.0971
	(0.0883)	(0.0942)
Household head schooling	1.1830**	1.0083*
	(0.5588)	(0.5960)
Number of household members	-0.7789	-0.4507
	(0.8174)	(0.8719)
Fraction of households with migration to US	-13.3467***	-8.8057***
	(2.3461)	(2.5024)
Fraction of households with migration within Mexico	-2.0534	-1.3157
	(3.5787)	(3.8171)
Household average schooling	-0.1743	-0.3158
	(0.5984)	(0.6383)
Household land quality (1=good to 4=very bad)	0.1624	0.4884
	(0.8757)	(0.9340)
Constant	-2.1404	4.7190
	(7.2982)	(7.7843)
p-value (Pr>F)	0.0000	0.0000
# observations	62	62

Notes: Standard errors in parentheses. To analyze the determinants of significant changes at the village level in the average welfare per household-year, we regress the village-level changes in the average welfare per household-year over the entire simulation period (1997-2007) that are significant at a 10% level under a simulated minimum threshold household average schooling needed for migration to US in the initial year of the simulation (1997) of 110% and 90% of the average household schooling observed in the data, respectively, on the initial village, municipality, state, and national characteristics from the initial year of the simulation (1997). Crime rates are in homicides per 10,000 inhabitants.
Significance codes: * p<0.10, ** p<0.05, *** p<0.01.



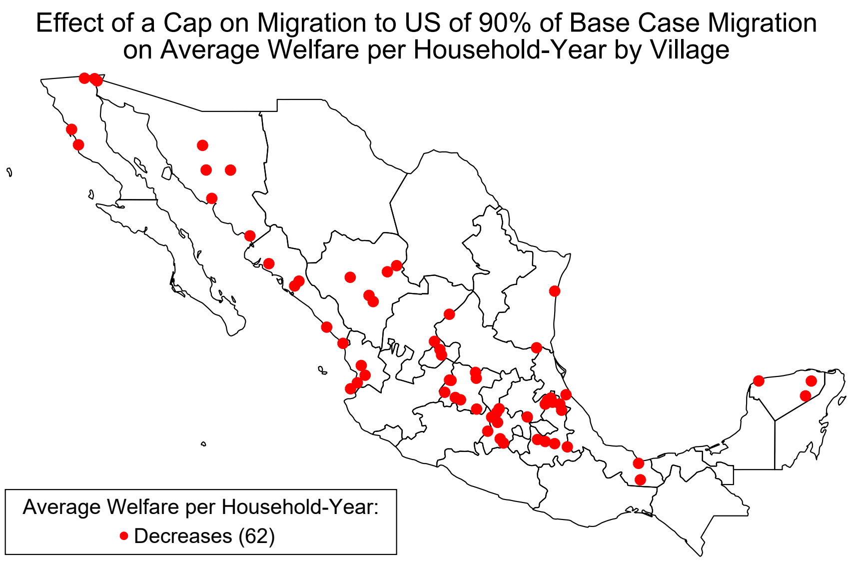
(a) (b)

Figure B.3: Signs of changes in migration by village that are significant at a 10% level under a cap on total migration to US of 90% of base case migration

Table B.5: Effects of a Cap on Total Migration to US:
Determinants of significant changes at the village level
in the fraction of households with migration

Dependent variable is the value of significant changes in the fraction of households with migration to/within:	*US*	*Mexico*
Cap as % of base case migration that is denied migration to US:	90%	
Characteristics from the initial year of the simulation (1997):		
Distance to closest border crossing point (1000 km)	0.0110	0.0055
	(0.0139)	(0.0055)
Crime rate at closest border crossing point	-0.0006	-0.0001
	(0.0013)	(0.0005)
Employment in primary sector	-0.0015	0.0003
	(0.0009)	(0.0004)
Employment in secondary sector	-0.0004	-0.0003
	(0.0015)	(0.0006)
Number of males in household	0.0188	0.0089
	(0.0202)	(0.0080)
Household head age	0.0005	0.0003
	(0.0014)	(0.0006)
Household head schooling	0.0218**	-0.0017
	(0.0091)	(0.0036)
Number of household members	-0.0228*	-0.0059
	(0.0133)	(0.0053)
Fraction of households with migration to US	-0.5293***	-0.0246
	(0.0382)	(0.0151)
Fraction of households with migration within Mexico	0.1350**	-0.0446*
	(0.0583)	(0.0230)
Household average schooling	-0.0159	0.0014
	(0.0098)	(0.0039)
Household land quality (1=good to 4=very bad)	0.0238	-0.0018
	(0.0143)	(0.0056)
Constant	-0.2165*	0.0010
	(0.1189)	(0.0470)
p-value (Pr>F)	0.0000	0.2130
# observations	62	62

Notes: Standard errors in parentheses. To analyze the determinants of significant changes at the village level in the fraction of households with migration, we regress the village-level changes in the fraction of households with migration over the entire simulation period (1997-2007) that are significant at a 10% level under a simulated cap denying migration to 90% of the households that would have engaged in migration to the US in the base case, on the initial village, municipality, state, and national characteristics from the initial year of the simulation (1997). Crime rates are in homicides per 10,000 inhabitants.
Significance codes: * p<0.10, ** p<0.05, *** p<0.01.



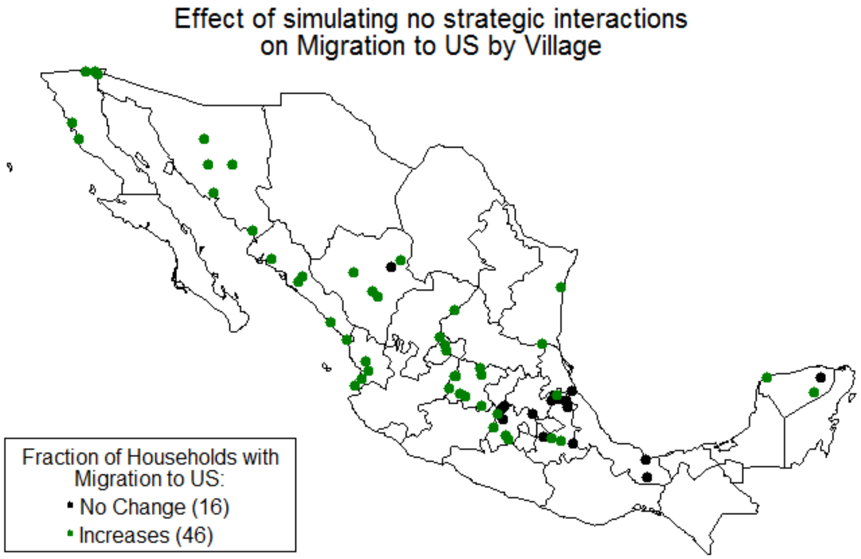
(a)

Figure B.4: Signs of changes in average welfare per household-year by village that are significant at a 10% level under a cap on total migration to US of 90% of base case migration

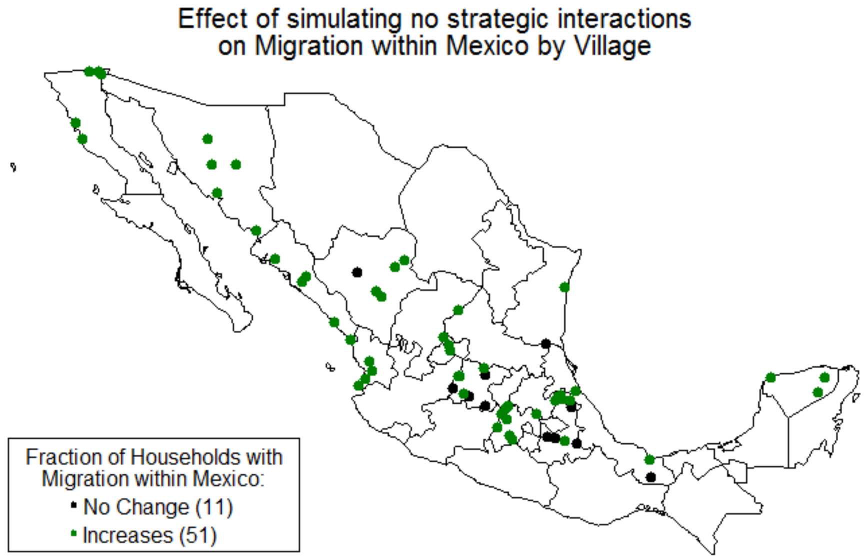
Table B.6: Effects of a Cap on Total Migration to US:
Determinants of significant changes at the village level in
the average welfare per household-year

Dependent variable is the value of significant changes in the average welfare per household-year:	
Cap as % of base case migration that is denied migration to US:	90%
Characteristics from the initial year of the simulation (1997):	
Distance to closest border crossing point (1000 km)	-0.0004
	(0.0007)
Crime rate at closest border crossing point	-0.0891
	(0.0635)
Employment in primary sector	-0.0480
	(0.0447)
Employment in secondary sector	-0.0308
	(0.0738)
Number of males in household	0.3228
	(0.9909)
Household head age	0.0276
	(0.0706)
Household head schooling	0.8344*
	(0.4465)
Number of household members	0.0176
	(0.6532)
Fraction of households with migration to US	-16.5421***
	(1.8749)
Fraction of households with migration within Mexico	0.8716
	(2.8599)
Household average schooling	-0.4593
	(0.4782)
Household land quality (1=good to 4=very bad)	1.5704**
	(0.6998)
Constant	-9.5214
	(5.8322)
p-value (Pr>F)	0.0000
# observations	62

Notes: Standard errors in parentheses. To analyze the determinants of significant changes at the village level in the average welfare per household-year, we regress the village-level changes in the average welfare per household-year over the entire simulation period (1997-2007) that are significant at a 10% level under a simulated cap denying migration to 90% of the households that would have engaged in migration to the US in the base case, on the initial village, municipality, state, and national characteristics from the initial year of the simulation (1997). Crime rates are in homicides per 10,000 inhabitants.
Significance codes: * p<0.10, ** p<0.05, *** p<0.01.

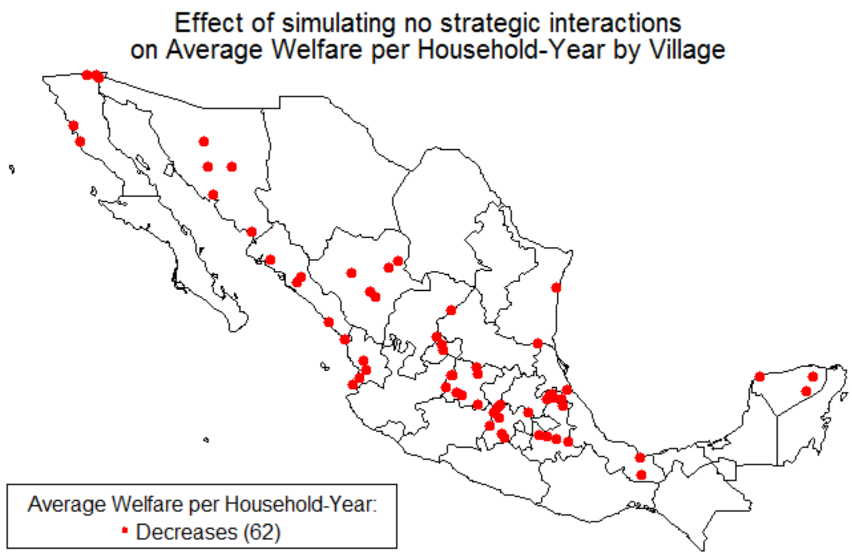


(a)



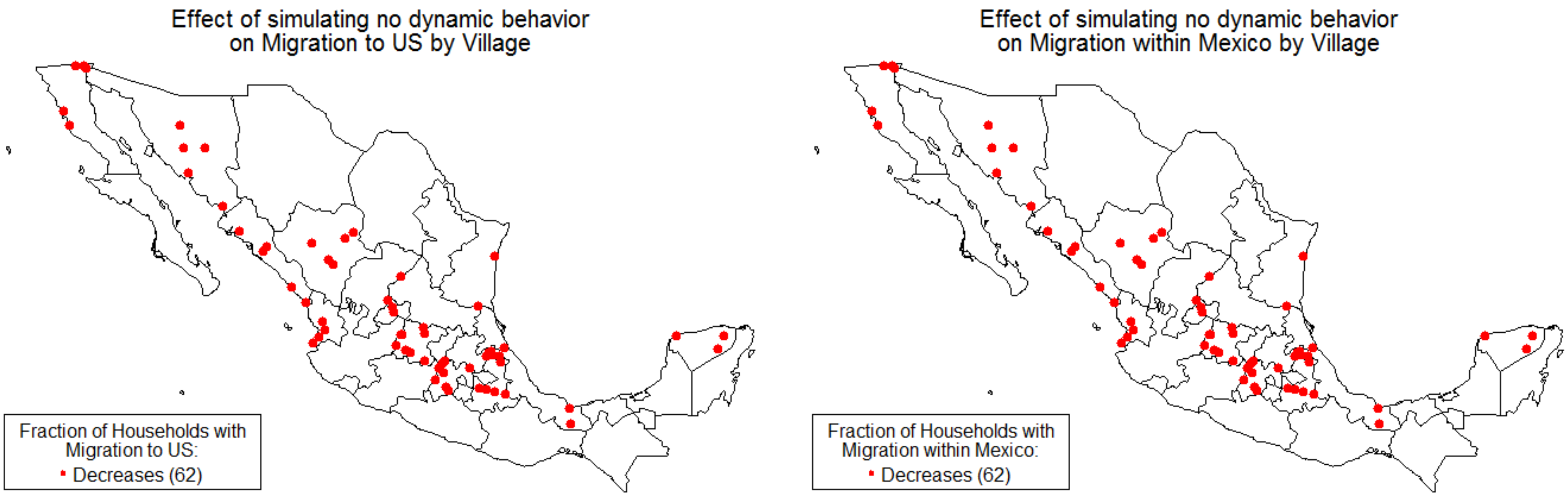
(b)

Figure B.5: Signs of changes in migration by village that are significant at a 10% level when simulating no strategic interactions



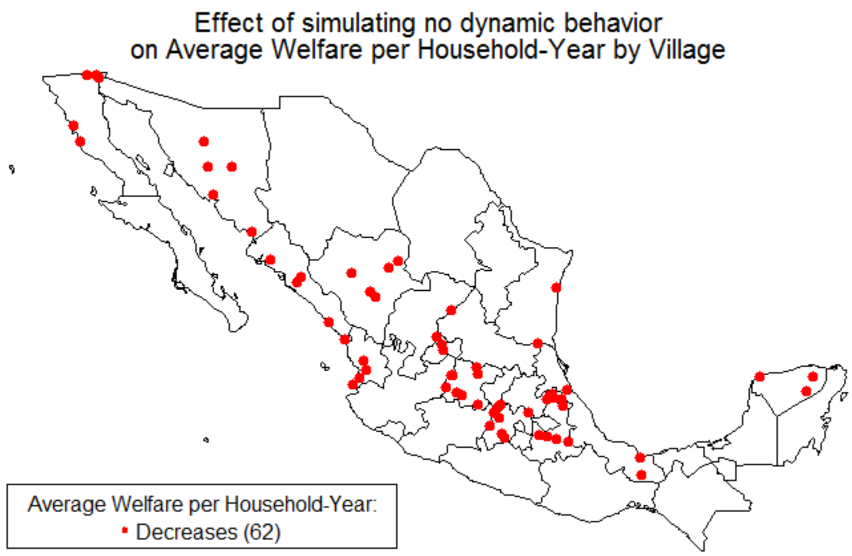
(a)

Figure B.6: Signs of changes in average welfare per household-year by village that are significant at a 10% level when simulating no strategic interactions



(a) (b)

Figure B.7: Signs of changes in migration by village that are significant at a 10% level when simulating no dynamic behavior



(a)

Figure B.8: Signs of changes in average welfare per household-year by village that are significant at a 10% level when simulating no dynamic behavior

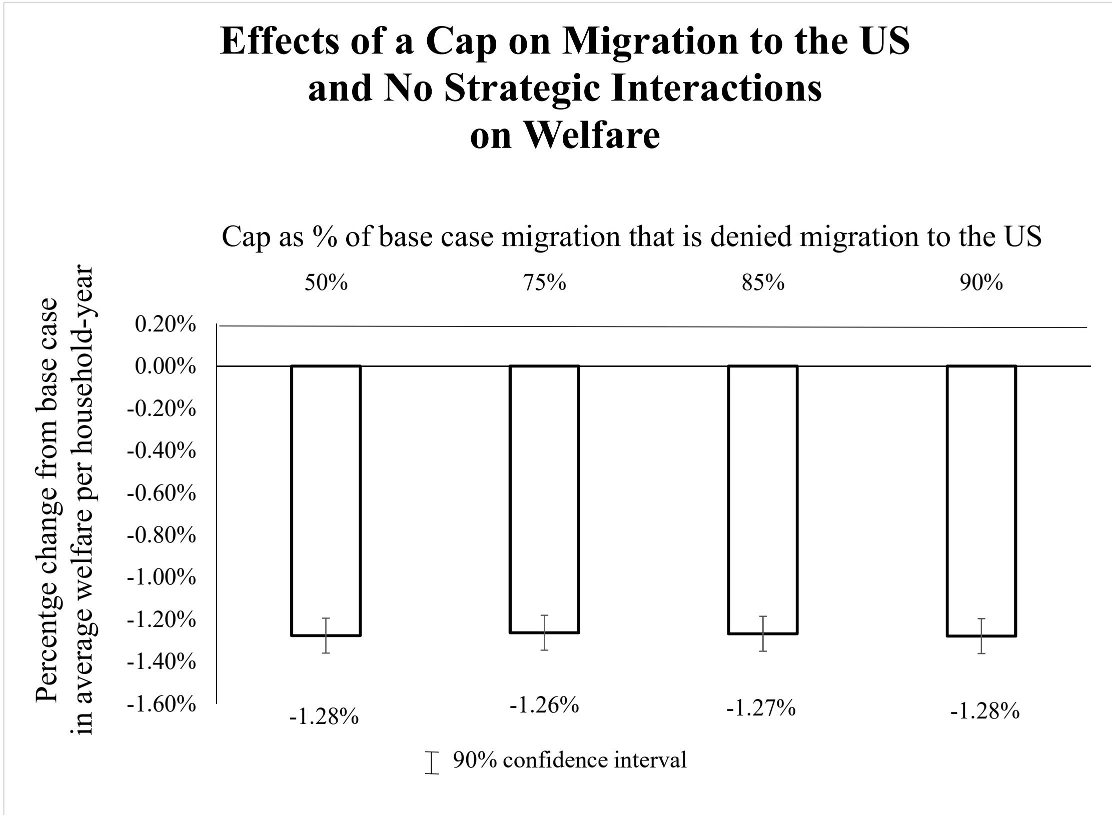
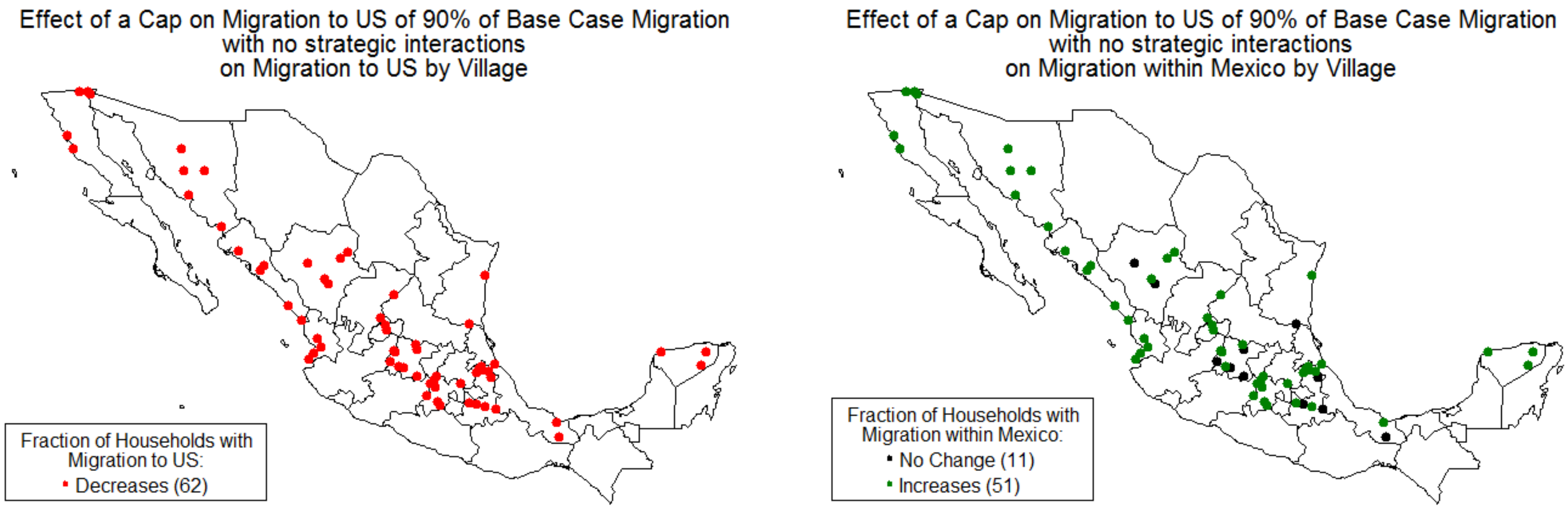
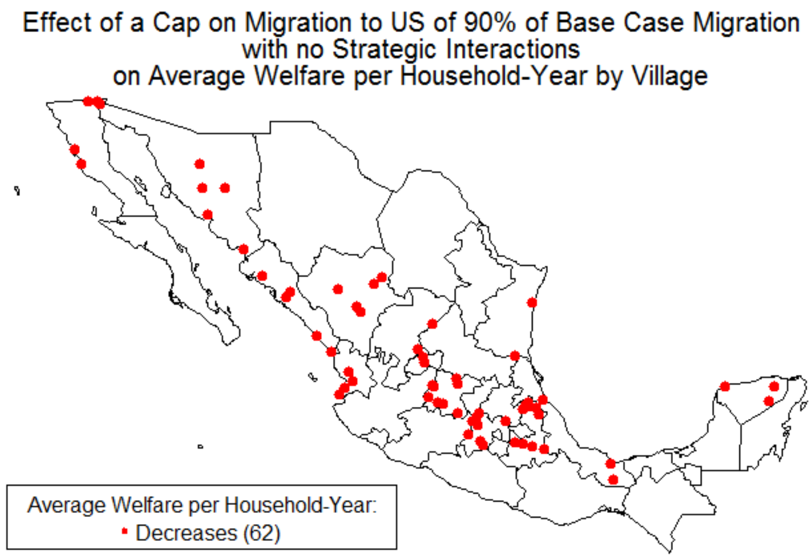


Figure B.9: Results of two-sample t-test of the effects of a cap on total migration to US with no strategic interactions on average welfare per household-year



(a) (b)

Figure B.10: Signs of changes in migration by village that are significant at a 10% level under a cap of 90% of base case migration and no strategic interactions



(a)

Figure B.11: Signs of changes in average welfare per household-year by village that are significant at a 10% level under a cap of 90% of base case migration and no strategic interactions

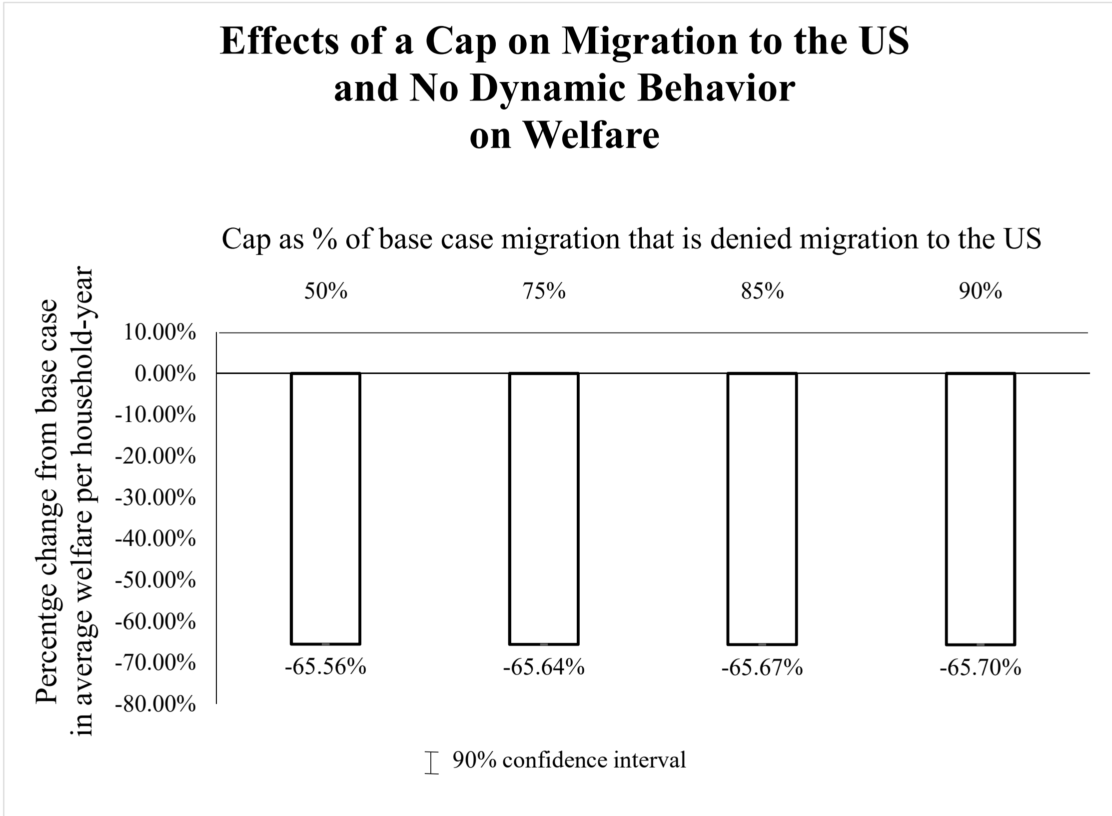
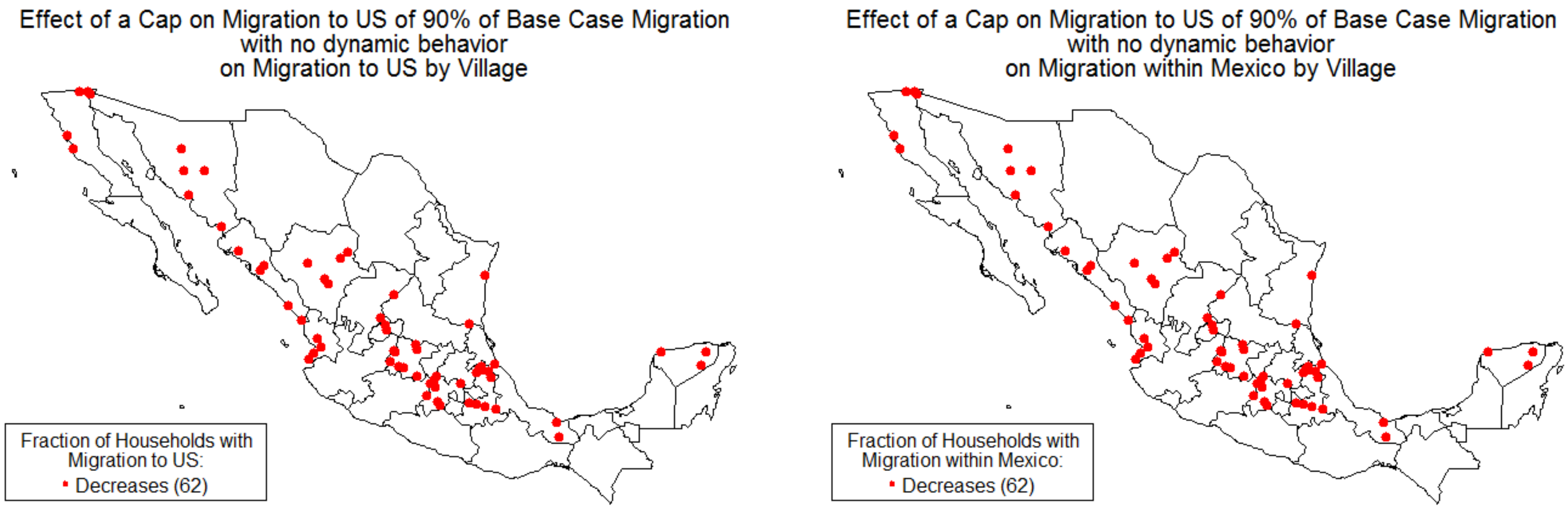
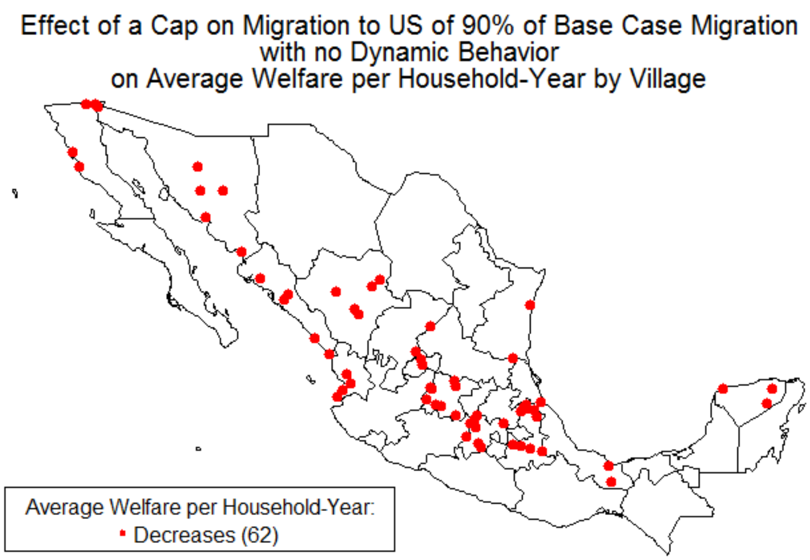


Figure B.12: Results of two-sample t-test of the effects of a cap on total migration to US with no dynamic behavior on average welfare per household-year



(a) (b)

Figure B.13: Signs of changes in migration by village that are significant at a 10% level under a cap of 90% of base case migration and no dynamic behavior



(a)

Figure B.14: Signs of changes in average welfare per household-year by village that are significant at a 10% level under a cap of 90% of base case migration and no dynamic behavior