Immigration Policies and Farm Labor

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1. Introduction

Immigration has been at the forefront of the public debate for many decades, particularly during election years. Strong public opinion in opposition and support of immigrants persists, which ranges from building walls to pathway to citizenship. According to the Pew Research Center, 11.3 million unauthorized workers resided in the United States in 2014 (?Krogstad et al., 2016). Undocumented workers are an important part of the labor force in agriculture, particularly for labor-intensive fruit and vegetable productions.[1] Over the last decade, because of acute shortages of farm workers, about 20% of fruits and vegetables went unharvested annually in several parts of the country (WSJ, 2007).[2] Moreover, as observed by Charlton and Taylor (2016), agricultural labor supply from rural Mexico, which is the primary source of hired workers for U.S. farms, has undergone a significant negative trend. Because of this dwindling labor force and dearth of native workers

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[1] For example, Wishon et al. (2015) note that vegetable crops can require more than 100 labor hours/acre but non-vegetable crops need only about 29 hours/acre. Guan et al. (2015) report that labor costs are more than 40% of total production costs for certain vegetables and fruits.

[2] Here, we summarize acute labor shortage problems in many states which grow fruits and vegetables. Farms in California and Arizona report constant labor shortages for vegetable harvest and warn that farm jobs could move to Mexico without a well-functioning guest-worker program as many corporate farms buy land in Mexico for cultivation (Rural Migration News, 2007). Due to consistent labor shortage, as many 75% of farm laborers employed in Washington States are unauthorized to work (Turnbull, 2011). Buccola et al. (2012) find that the Oregon nursery industry regularly endures inadequate labor supply. California alone experiences a 15 to 20% farm labor shortfall on an annual basis (Salman, 2014). In Florida, tomato, strawberry, and orange growers face persistent labor shortages (Salman, 2014; Phillips, 2015). Florida strawberry growers experience a 20% yield loss due to labor scarcity, with some growers leaving up to 60% of their fields unharvested (Guan et al., 2015). From 2002 to 2014, the number of field workers has dwindled by more than 20%, which caused an estimated production loss of more than $3.1 billion (Bronars, 2015). Washington State, a major producer of apples, pears, and cherries, endures 8% to 15% labor scarcity (Courtney, 2015).

to perform hard physical work, growers constantly experience labor shortage; however, politicians have been calling for curbing unauthorized entry of immigrants. Several proposals have been introduced in the U.S. Congress and by the Presidents to address the illegal immigration problem. These proposals include tighter border surveillance, stricter domestic enforcement, deportation of unlawful immigrants, pathway to citizenship, and simplifying the H-2A guest-worker program.[3]

H-2A guest-worker program has been in existence for many years, yet this group of workers do not form the adequate farm labor force for several reasons: 1) farmers have to endure the bureaucratic hurdle and cumbersome process to procure guest workers, 2) guest workers are more expensive than undocumented workers,[4] and 3) timing issue, i.e., farmers desire to hire undocumented workers cheaply and wait until the last minute to search for guest workers. Furthermore, as persuasively putforth by Wishon et al. (2015) the H-2A program is highly onerous process because the burden of proof of work eligibility is on the growers and also growers need to prove the shortage of domestic workers for their operations, which forces the growers to make employment decisions months in advance before knowing the exact need for workers, causing unnecessary uncertainty in their production process. Thus, to alleviate labor scarcity, U.S. agricultural producers have expressed a keen desire for overhauling and streamlining the guest-worker program (Guan et al., 2015), and migrant workers also prefer the opportunity to work legally and to obtain long-term work visas than receiving social benefits (Melo et al., 2014).

The goal of our study is to analyze the short- and long-run impacts of stricter domestic and border controls and streamlining of the H-2A guest worker program on U.S. labor-intensive agriculture and Mexican agriculture and labor markets in both countries.

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[3]Some of the prominent legislative proposals introduced in the Senate include the Border Security, Economic Opportunity, and Immigration Modernization Act of 2013 (S.744, 2013) and House of Representatives include the Agricultural Guest-worker Act (H.R. 1773), the Border Security Results Act (H.R. 1417), the Legal Workforce Act (H.R. 1772), and the Strengthen and Fortify Enforcement Act (H.R. 2278). Fan et al. (2015) summarize various national legislations and USCIS (2016) provide a detailed account of plethora of state legislations aimed at curtailing immigrant flows.

[4]The H-2A program is very expensive as it requires producers to incur administrative costs related to visa permits, recruitment activities, housing accommodation, and transportation (round-trip tickets from Mexico and local rides to work sites, grocery shopping, and religious locations). In addition, for equity purpose, employers have to also provide similar accommodations to domestic workers.

This study is very timely because of the contentious and continued debate on illegal immigration.

A vast literature surrounding illegal migration, immigration control, and implications for native workers exists both in general and agricultural economics. While it is impossible to do justice to review all the studies, we present selected studies that are highly relevant to our work. In general economics, Ethier (1986) and Bond and Chen (1987) are the first to theoretically analyze the effects of border controls and domestic enforcement on illegal migration and show that these policies increase the wage rates and negatively impact production and national income in the host country. Djajić (1997) theoretically illustrate that additional flow of unauthorized immigrant workers lower the wage rates of existing undocumented and native unskilled workers, and furthermore, stricter domestic enforcement widens the gap between legal and undocumented workers. Bandyopadhyay and Bandyopadhyay (1998) model the labor markets and the cross-border wage linkage between the source and host countries and demonstrate the border control restricts the flow of unauthorized entries. Gaytan-Fregoso and Lahiri (2000) incorporate both border surveillance and domestic enforcement and find that these policies lower (augment) the host (source) country's welfare.[5]

In agricultural economics, Isé and Perloff (1995) provide evidence that undocumented workers earn less than legal workers and this wage gap can be reduced by improving immigrants' skills such as language ability. Devadoss and Luckstead (2008) find that in California vegetable production one new immigrant displaces only 0.0123 domestic workers and has inconsequential impact on native wage, but augments vegetable production by $23,457 and the productivity of skilled workers, material inputs, and capital by $11,729. Devadoss and Luckstead (2011) theoretically show that since U.S. agriculture heavily relies on undocumented workers, domestic and border enforcement controls not only increase the illegal farm wage rate and decrease the number of unauthorized workers, but also lowers U.S. agricultural exports. Their empirical results quantify that domestic

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[5]Another strand of studies examines the displacement effect of immigrants on natives. Grossman (1982) estimates the substitutability between immigrant and native skilled workers to be minimal. In contrast, the econometric results by Chiswick et al. (1985) show that skilled immigrant workers have high substitutability, though not perfect substitution, to native workers.

surveillance program curb the number of undocumented workers by 8,947 and U.S. exports to Mexico by \$180 million, and border apprehension reduce undocumented workers by 8,147 and exports by \$181 million. Taylor et al. (2012) conclude that because U.S. domestic workers are unwilling to do hard farm work and the dwindling labor supply, the agricultural sector needs to focus on developing labor saving technology. Luckstead et al. (2012) develop an integrated trade-migration model and their theoretical results reveal that NAFTA and U.S. farm subsidies attract illegal labor flow and enhance U.S. exports to Mexico. Their empirical findings indicate that NAFTA augments the number of unauthorized migrants seeking farm work by 1,573 and exports \$6.82 billion, and U.S. farm supports only marginally impacts unauthorized border crossings and expands U.S. exports by \$3.2 billion. Kostandini et al. (2014) find evidence that local immigration enforcement efforts have reduced the number of migrants in counties that have implemented stricter immigration laws, which caused farmers to face higher wage and modified output choices as a results of labor shortages.

Though the literature on immigration is vast, only a few studies employed dynamic models. The earliest work by Djajić (1987) show that because labor markets in the source and host county are interlinked, exogenous shock in one country's labor market reverberates into the other country both in the short- and long-run. This finding is also embedded in our theoretical model, and in addition, we quantify the effects of policy shocks in one country on both countries' labor markets. Palivos's (2009) dynamic analysis of illegal immigration revealed that the host country welfare improved because immigrant workers are paid less than their marginal value product, which is also captured in our model where the wage rate of undocumented workers is less than that of legal workers though both are employed in similar work. Using a dynamic model, Liu (2010) found that though illegal immigration adversely affects the native workers' employment, it enhances the long-run welfare of domestic workers. Our model also incorporates this substitutability between undocumented and native workers.[6] These earlier dynamic immigration models mainly focused on general economy, whereas, in a series of studies, Zahniser et al. (2012a; 2012b)

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[6]Other studies that used dynamic model to examine immigration issues are Hazari and Sgro (2003) and Moy and Yip (2006).

and Zahniser et al. (2012) modeled the impacts of an increase in temporary nonimmigrant workers and a reduction in the number of undocumented workers on U.S. agriculture using a dynamic CGE (computable general equilibrium) model. The dynamic component in Zahniser et al. is driven by capital accumulation, whereas in our model the dynamics enters through adjustments in the labor stock. Since our study focuses on labor-intensive agriculture, our model is a partial equilibrium dynamic model rather than a dynamic CGE model.

In this study, we develop a dynamic model that captures the addition of new arrivals to and deportation of unauthorized migrants from the current stock of existing undocumented workers in the United States and endogenizes the labor-leisure decisions of farm workers in Mexico to study the effects of immigration policies on legal and illegal labor force and wage rates, U.S. labor-intensive agricultural production, Mexican farm workers, and Mexican agricultural production. Analyzing this farm labor market is a compelling study because, as expounded by Devadoss and Luckstead (2008), Devadoss and Luckstead (2011), and Guan et al. (2015), the U.S. labor-intensive agriculture heavily depends on this labor force (74% of farm workers are born in Mexico and 53% are not legally authorized). Thus, any changes in the Mexican farm work force reverberate into the U.S. farm sector because of strong interconnections between the two farm labor markets. Our study contributes to the literature by being the first to 1) explicitly model the dynamic mechanism flow and stock components of the undocumented labor force in the United States and 2) incorporate the endogenous labor decisions of Mexican laborers to work in Mexico, seek employment in the United States through unauthorized entry or guest-worker program, and also allocate time for leisure. Since we model leisure, we generate results which are counterintuitive. For instance, heightened immigration control should generally increase the farm labor availability in Mexico; however, our results show this labor available sharply declines in the early periods as workers in Mexico divert more time to leisure in anticipation of lower wage rates in Mexico and future increase in U.S. wage rates.

2. Model

We develop a dynamic model to theoretically analyze Mexican farm workers' utility maximization, their labor allocation, U.S. and Mexican farmers' production decisions, and labor market equilibrium.

2.1. Mexican Workers

Mexican farm workers maximize their net-present value of utility, with time discount factor β, of consumption (C_t) and leisure $\left(L_t^L\right)$

$$(1) \qquad \max_{C_t, L_t^L} \sum_{t=0}^{\infty} \beta^t \left[\gamma_C \log\left(C_t\right) + \gamma_L \log\left(L_t^L\right) \right],$$

subject to their budget constraint, time allocation, guest-worker program restriction, and the law of motion of labor. The budget constraint is

$$(2) \qquad p_t^C C_t + \tau_t \;=\; w_t^M L_t^S + w_t^U L_t^G + w_t^I L_t^{UI} - \kappa_t L_t^I, \;\; \forall t$$

where p_t^C is the price of the consumption good, τ_t is non-distortionary taxes, w_t^M is the farm wage rate in Mexico, L_t^S is number of workers supplied to Mexican agriculture, w_t^U is the U.S. legal farm wage rate, L_t^G is the number of guest workers, w_t^I is the U.S. wage rate for undocumented workers, L_t^{UI} is the stock of undocumented workers in the United States, κ_t is the cost of illegally migrating (payments to coyotes and foregone wages) from Mexico to the United States, and L_t^I is the flow of unlawful entries in the United States in year t. Thus, spending on consumption, taxes, and cost of migration are met by earnings from Mexico, guest worker program, and unauthorized workers in the United States.

Mexican workers allocate their total time $\left(\bar{L}_t^M\right)$ according to

$$(3) \qquad \bar{L}_t^M = L_t^L + L_t^S + L_t^G + L_t^I + L_t^{UI},$$

where total time is allocated to leisure, work in Mexico, guest work through H-2A, unlawful entry, and unauthorized work in the United States.

Though the H-2A program does not legislate a fixed the number of guest workers, the practical issues surrounding the procurement of these workers (limited number of permits applied by the U.S. growers, cumbersome paper work, bureaucratic delay, Mexican's desire to reside in the United States) have posed an upper bound on the number of permits $\bar{L}_t^G$ available for Mexican workers. Therefore, we include the following constraint

in the analysis:

$$(4) \qquad L_t^G \leq \bar{L}_t^G.$$

The law of motion of labor is

$$(5) \qquad L_{t+1}^{UI} = (1 - d_t) L_t^{UI} + (1 - b_t) L_t^I,$$

where d_t is the deportation rate and b_t is the border apprehension rate. Thus, the law of motion entails the stock of unauthorized workers in the United States is equal to the number of workers that evaded deportation plus new unauthorized entry. We solve for the unauthorized labor flow L_t^I from equation (3) and substitute in the budget constraint (2) and law of motion (5) for the maximization problem, resulting in the Lagrangian:

(6)

$$
\begin{aligned}
\mathcal{L} = &\sum_{t=0}^{\infty} \beta^t \left[\gamma_C \log\left(C_t\right) + \gamma_L \log\left(L_t^L\right) \right] \\
&+ \lambda_t \left(w_t^M L_t^S + w_t^U L_t^G + w_t^I L_t^{UI} - \kappa_t \left(\overline{L}^M - L_t^L - L_t^G - L_t^S - L_t^{UI} \right) - p_t^C C_t - \tau_t \right) \\
&+ \eta_t \left((1 - d_t) L_t^{UI} + (1 - b_t) \left(\overline{L}^M - L_t^L - L_t^G - L_t^S - L_t^{UI} \right) - L_{t+1}^{UI} \right) \\
&+ \mu_t \left(\bar{L}_t^G - L_t^G \right),
\end{aligned}
$$

where λ_t, η_t, and μ_t are the Lagrangian multipliers.

2.2. Labor-Intensive Agricultural Production

Here, we present production technology and profits for U.S. labor-intensive agriculture and the Mexican agricultural sector.

2.2.1. U.S. Production

A representative U.S. farm produces the labor-intensive agricultural commodity Q_t^U using composite low-skilled labor L_t^U according to the production function

$$(7) \qquad Q_t^U = \theta_t^U \left(L_t^U \right)^{\alpha^U},$$

where θ_t^U is the sectoral productivity parameter and α^Us are share parameters.[7] Profits are

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[7]Since our major focus is on the labor market dynamics, we subsume the contribution of all other inputs into the productivity parameter θ_t^U.

$$\Pi_t^U = p_t^U Q_t^U - w_t^I L_t^{DI} - w_t^U \left(L_t^{US} + L_t^G \right) - d_t c_t L_t^{DI},$$

where L_t^{DI} is the number of undocumented workers employed in production, L_t^{US} is the number of U.S. low-skilled workers employed in production, c_t is the penalty levied on producers for illegally employing unauthorized workers, and the U.S. legal wage rate is equal to the illegal wage rate plus the deportation rate times the penalty (see Bond and Chen, 1987; Devadoss and Luckstead, 2011):

$$(8) \qquad\qquad w_t^U = w_t^I + d_t c_t.$$

U.S. producers are able to discern between legal and illegal workers and pay lower wage rate for the later group because they may have to incur the penalty. Substituting this wage linkage into the above profit function and simplifying yields

$$(9) \qquad \Pi_t^U = p_t^U Q_t^U - w_t^U \left(L_t^{DI} + L_t^{US} + L_t^G \right) = p_t^U Q_t^U - w_t^U L_t^U,$$

where $L_t^{DI} + L_t^{US} + L_t^G = L_t^U$, i.e., the total farm labor L_t^U comprises of undocumented workers, legal workers, and guest workers.

2.2.2. Mexican Production

A representative Mexican agricultural farm produces the agricultural commodity Q_t^M using low-skilled labor L_t^{DM} according to

$$(10) \qquad\qquad Q_t^M = \theta_t^M \left(L_t^{DM} \right)^{\alpha^M},$$

where θ_t^M is the sectoral productivity parameter and α^M are share parameters. Profits are

$$(11) \qquad\qquad \Pi_t^M = p_t^M Q_t^M - w_t^M L_t^{DM}.$$

2.3. Labor Market Clearing

We define market clearing conditions for both the U.S. and Mexican labor markets. Because the wage linkage equation 8 connects the legal U.S. wage rate and undocumented wage rate, only one labor clearing conditions exists for the United States. Thus, for the undocumented U.S. labor clearing condition, the demand for undocumented workers

$L_t^{DI} = L_t^U - L_t^{US} - L_t^G$ equals the stock of undocumented workers in the United States

$$(12) \qquad\qquad L_t^{DI} = L_t^{UI},$$

and the U.S. unskilled labor supply is $L_t^{US} = L_t^{US}(w_t^U)$. For the Mexican labor clearing condition, the total labor demand equals the total labor supply:

$$(13) \qquad\qquad L_t^{DM} = L_t^S.$$

These equilibrium conditions clearly underpin the interconnection between the labor markets in the two countries.

2.4. Equilibrium Definition and Discussion

A competitive partial equilibrium is a sequence of quantities $\{C_t, L_t^L, L_t^S, L_t^G, L_t^I, L_{t+1}^{UI}, L_t^U,$ $L_t^{DM}\}_{t=0}^{\infty}$ and wage rates $\{w_t^I, w_t^U, \text{ and } w_t^M\}_{t=0}^{\infty}$, given the initial stock of undocumented workers $\bar{L}_0^{UI}$, that satisfy:

1. Given $\{w_t^I, w_t^U, \text{ and } w_t^M\}_{t=0}^{\infty}$, the representative consumer chooses $\{C_t, L_t^L, L_t^S, L_t^G,$ $L_t^I, \text{ and } L_{t+1}^{UI}\}_{t=0}^{\infty}$ to maximize (1) subject to the budget constraint, the total time allocation constraint (3), the law of motion of labor (5), the guest worker constraint (4), the initial condition on the stock of undocumented workers $L_0^{UI} = \bar{L}_0^{UI}$, and the non-negativity constraints $C_t, L_t^L, L_t^S, L_t^G, L_t^I, L_t^{UI} \geq 0$.

2. Given w_t^U, the labor-intensive U.S. agricultural producer chooses $\{L_t^U\}_{t=0}^{\infty}$ to maximize profits (9) subject to the technology constraint (7) and the non-negativity constraint $L_t^U \geq 0$.

3. Given w_t^M, the Mexican agricultural producer chooses $\{L_t^{DM}\}_{t=0}^{\infty}$ to maximize profits (11) subject to the technology constraint (10) and the non-negativity constraint $L_t^{DM} \geq 0$.

4. The wage linkage equation (8) and the non-negativity condition $w^U \geq 0$ hold.

5. The market clearing conditions (12) and (13) and the non-negativity conditions w^I, $w^M \geq 0$ hold.

We present all the first-order conditions of the Mexican workers' problem (6) and producers problem and provide economic interpretation. The equations for the full dynamic and steady state analysis are provided in the supplemental Appendix (A). The first-order conditions for consumption

$$(14) \qquad \beta^t \frac{\gamma_C}{C_t} = \lambda_t p_t^C,$$

implies the discounted marginal utility is equal to price of the consumption good weighted the Lagrangian multiplier (λ_t), i.e., marginal utility of earnings. As explained above, Mexican workers have five labor options: leisure, work in Mexico, U.S. guest work, illegally crossing to the United States, and unauthorized work in the United States. As a result of the substitution for L_t^I, the intratemporal labor allocations weigh the benefits of leisure, work in Mexico, or guest work against the net earnings of illegal migrating to the United States:

$$(15) \qquad \beta^t \frac{\gamma_L}{L_t^L} = \eta_t (1 - b_t) - \lambda_t \kappa_t,$$

$$(16) \qquad \lambda_t w_t^M = \eta_t (1 - b_t) - \lambda_t \kappa_t$$

$$(17) \qquad \lambda_t w_t^U - \mu_t = \eta_t (1 - b_t) - \lambda_t \kappa_t.$$

The right-hand side of the above three equations captures the potential net benefit of illegal flow in crossing the border, i.e., potential income from unauthorized work (the shadow value (η_t) of the migration constraint times successful entry) minus the cost of migration. The left-hand side of (15) is the discounted marginal utility of leisure, (16) is benefit from domestic farm work in Mexico, and (17) is benefit from U.S. guest work minus the utility cost of the H-2A program constraint (μ_t).

As a result of the stock of undocumented workers in the United States and potential apprehension and deportation, the Mexican worker choose the stock of unauthorized work in the United States in $t+1$ which yields the following intertemporal labor choice

$$(18) \qquad \lambda_{t+1} \left(w_{t+1}^I + \kappa_{t+1} \right) + \eta_{t+1} (1 - d_{t+1}) - \eta_{t+1} (1 - b_{t+1}) = \eta_t.$$

The above intertemporal equation shows that, at the margin, how the benefits of a worker in the current undocumented stock balances against the benefits of a worker, who attempts to cross in t and becomes part of the undocumented stock in $t+1$. Substitute the

equations 14 and 16 into 18 to eliminate λ and η to obtain the Euler equation

(19)
$$\frac{C_{t+1}}{\beta C_t} = (1 - b_t) \left[\frac{\tilde{w}_{t+1}^I - \tilde{w}_{t+1}^M}{\tilde{w}_t^M + \tilde{\kappa}_t} + \left(\frac{1 - d_{t+1}}{1 - b_{t+1}} \right) \left(\frac{\tilde{w}_{t+1}^M + \tilde{\kappa}_{t+1}}{\tilde{w}_t^M + \tilde{\kappa}_t} \right) \right],$$

where $\tilde{w} \equiv \frac{w}{p^C}$ and $\tilde{\kappa} \equiv \frac{\kappa}{p^C}$. The left-hand side is the intertemporal marginal rate of substitution. The first term within the bracket on the right-hand side is the ratio between differential in illegal wage and Mexican wage (benefit of migrating versus working in Mexico) to the Mexican wage plus the cost saving from not migrating. The first ratio in the second term in this bracket is a proxy for successfully working in the United States (the ratio of successfully escaping domestic surveillance to crossing the border), and the second ratio is the sum of the Mexican wage and cost saving in $t+1$ relative to this sum in t. Thus the second term is the opportunity cost staying and working in the United States. Thus, the intertemporal marginal rate of substitution is equal to the weighted average of benefits of illegally working in the United States rather than in Mexico and opportunity cost of lost earning in Mexico because of successful work in the United States.

The final three first-order conditions arise from differentiating the Lagrangian with respect to λ_t, η_t, and μ_t, which respectively yield, the budget constraint (2), law of motion of labor (5), and guest worker program 4.

To derive the relationship between the U.S. illegal wage and the Mexican wage rate, including the migration cost, we utilize the steady state solution to utility maximization also generate the following cross-border wage linkage

(20)
$$w^I = w^M \left(1 + \frac{d}{(1 - b)} \right) + \frac{d}{(1 - b)} \kappa.$$

For a Mexican worker to illegally migrate to the United States, given the risk involved in crossing the border and deportation, the illegal wage rate has to equal to a weighted average of the Mexican wage rate and the migration cost. Suppose, the migration cost is zero, then illegal wage rate is a certain percentage higher than the Mexican wage rate. This percentage is determined by the ratio of the probability of deportation to the probability of successful border crossing. This ratio increase with the rise of deportation and apprehension rates; thus this ratio serves as a measure of deterrent to migration or a measure of the intensity of anti-immigration policies. The larger the apprehension probability and deportation rate, the higher the illegal wage rate. Similarly, the effect of

migration cost on the illegal wage rate is accentuated by the apprehension and deportation probabilities.

The optimal choice of labor use from profit maximization in each country implies the marginal value product equal to the wage rate

$$(21) \qquad p_t^U \alpha^U \theta_t^U \left(L_t^U\right)^{\alpha^U - 1} = w_t^U$$

$$(22) \qquad \theta_t^M \alpha^M \left(L_t^{DM}\right)^{\alpha^M - 1} = w_t^M.$$

3. Numerical Analysis

We solve the system of first-order conditions, wage linkage, and labor-clearing conditions for endogenous variables for both the steady-state long-run and dynamic short-run solutions. This section describes the data, parameter, calibration procedure, and the results. We set all the endogenous variables equal across time to obtain the steady-state equations which are given in Appendix A2.. We numerically solve these equations for steady-state long-run values in the baseline with current policies and in the alternate scenario with new policies. Then we solve for the short-run transition path using the dynamic equations, given in Appendix A1., for the endogenous variables between steady states as follows: In period $t = 0$, the economy is in the initial steady state with baseline policies in place. In period $t = 1$, the government simultaneously announces and implements a change in policy. All economic agents (Mexican workers and U.S. and Mexican agricultural producers) respond optimally to the changes in policy and the endogenous variables converge to its new steady state.

3.1. Data, Parameters, and Calibration

To numerically solve for the long- and short-run values of the endogenous variables, we first calibrate the model to the 2014/2015 production season. The model defined in section 2. contains seven exogenous/policy variables and 12 parameters (Table 1), of which five exogenous variables ($\bar{L}^M$, $\bar{L}^G$, p^C, p^M, and p^U) and seven parameters (β, γ_C, γ_L, α^M, α^U, b, and ω) come from the data and literature and the remaining two policy variables (c and d) and five parameters (θ^U, θ^M, a, κ, and τ) are calibrated. To compute these

Table 1. Values of Exogenous Variables and Parameters

Variables	Values
Data	
$\bar{L}_t^M$	18,104,830
$\bar{L}_t^G$	89,274
Literature	
β	0.96
γ_C	0.67
γ_L	0.33
b	0.50
ω	0.50
p_t^C	1
p_t^M	1
p_t^U	1
Calibrated	
c	17.38
d	0.08
θ^U	45.71
α^U	0.35
θ^M	14.20
α^M	0.44
a	0.21
κ (\$/hr)	50.21
τ (\$/year)	-48.84

variables and calibrate these parameters, we need the baseline values of the endogenous variables for the steady state version of the model.

The value of U.S. labor-intensive agricultural[8] products is $V^U = \$57.571$ billion **?**. This nominal values is converted into quantity $\left(Q^U\right)$ by dividing the value by the price of labor-intensive agricultural goods $\left(p^U\right)$. We normalize this price to one, and thus $Q^U = \frac{V^U}{p^U} = 57.571$. For Mexico, we use *total* agricultural production since Mexican agriculture is relatively labor intensive. The value of this production $\left(V^M\right)$ is $60.256 billion SIAP (2016), which is converted into quantity by dividing by the normalized price $\left(p^M = 1\right)$: $Q^M = \frac{V^M}{p^M} = 60.256$.

In the United States, the total number of farm workers are $1,063,000$, of which labor-intensive agriculture employs about 50% of the workers (ERS, 2016). Thus, the number of workers $\left(L^U\right)$ in this subsector is $531,500$. The U.S. domestic workers $\left(L^{US}\right)$

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[8]For labor-intensive agriculture, we include berries, cut Christmas trees & short term woody crops, fruits, tree nuts, horticultural products, and vegetables.

employed in labor-intensive agriculture is $181,791$. According to ERS (2016), 49% of the farm workforce is unauthorized, and therefore the number of undocumented workers in the labor-intensive agriculture $\left(L^{UI}\right)$ is $260,435$ $(=531,500 \times 0.49)$. The unauthorized flow of migrants is computed using the data from the U.S. Department of Homeland Security DHS (2015) which reports $337,117$ migrants were apprehended. Using the catch rate b of 50% reported in Roberts et al. (2013), the number of entrants without detection is $674,234$ $(=337,117/0.5)$ per year.[9] Therefore, the total number of migrants attempting to cross the border is $674,234 + 337,117 = 1,011,351$, and of which only about 4% (**?**) seek employment in labor-intensive agriculture. Thus, the total number of unauthorized migrants workers $\left(L^I\right)$ seeking farm work is $40,454$ $(=1,011,351 \times 0.04)$. The upper limit for guest workers $\bar{L}^G = 89,274$ is obtained from the number of work permits issued in 2014 (USDS, 2015). The total number of Mexican farm workers $\left(L^S\right)$ is $7,153,516$ The World Bank (2016). Assuming 8 hours of work and 16 hours of leisure in a day, the total time allocated for leisure measured in number of workers is $L^L = \frac{16}{8}\left(L^I + L^G + L^S + L^{UI}\right) = 15,087,358$. In sum, the number of Mexican farm labor endowment is $\bar{L}^M = L^L + L^I + L^G + L^S + L^{UI} = 22,631,037$.

The U.S. legal $\left(w^U\right)$ and undocumented labor-intensive agricultural $\left(w^I\right)$ wage rates are 10.33 and 8.98, respectively, (US Department of Labor, 2016).[10] On average, Mexicans earn about 136 pesos for an 8 hour work day or 17 pesos per hour Marosi (2016), and with an exchange rate of 13.3 USD/peso IMF (2016), the Mexican wage rate $\left(w^M\right)$ in U.S. dollars is 1.28 per hour.

The production parameters α^U and α^M are the share of labor cost in the total value of production: $\alpha^U = \frac{w^U L^U}{p^U Q^U}$ and $\alpha^M = \frac{w^M L^{DM}}{p^M Q^M}$. Using the data above, the computed values of these parameters are 0.15 and 0.09, respectively. The value of the time preference parameter $\beta = 0.96$, which is commonly used value in the macroeconomics literature.

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[9]Gathmann (2008) also found that border surveillance does not have a high degree of apprehension.

[10]The National Agricultural Workers Survey (NAWS) collected extensive data on employment, wage rates, demographics, etc., for crop farm workers over the period 1989-2012. This NAWS survey classifies the workers as undocumented or legal based on the information self-reported by these employees. From this survey, we collected the wage rates for two groups of workers and compute the sampling-weighted mean of the real wage rates for the years 2007-2012. The real wage rate is calculated as nominal wage rate divided by the CPI (BLS, 2016).

For the parameter γ_C in the utility function, we use the share of final consumption expenditure to national income, which is 0.67 for Mexico (The World Bank, 2016) and $\gamma_L = 1 - \gamma_C = 0.33$. Following Devadoss and Luckstead (2008), we consider U.S. labor supply elasticity $\omega = 0.5$.

Given the data and parameters from the literature, we reduce the 13 steady-state equations to 7 independent equations (Appendix A3.) to calibrate the seven remaining parameters: c, d, θ^U, θ^M, a, κ, and τ.

3.2. Steady State and Dynamic Analysis

The national debate on immigration largely focuses on domestic and border enforcement and the agricultural guest-worker program. To quantify the long-run and transitory impacts of potential policy reforms on key endogenous variables, we consider two policy scenarios: 1) a simultaneous tightening of domestic enforcement and border surveillance and 2) streamlining of the H-2A program to increase the availability of guest workers.

3.2.1. Border and Domestic Enforcements

Removals[11] of undocumented immigrants from stricter border and domestic enforcement policies have steadily increased from 189,026 in 2001 to 414,481 in 2014 (**?**). Furthermore, contentious and continuous political debate calls for curtailing the immigrant flows. Consequently, it is worth analyzing the effect of tightening border surveillance and domestic removals. Since border control has more apprehensions than removals from domestic enforcement, we consider a 10% increases b_t and a 5% increase in d_t for $t = 1, ..., T$, where $T = 50$ in our analysis.[12] Table 2 reports the steady state (long-run) results from this change in policy.

Heightened border enforcement increases the probability of deterring illegal entry from Mexico to the United States. Because of this tighter border control, workers from Mexico are discouraged from attempting to illegally cross the border as the potential for higher earnings in the United States relative to the earnings in Mexico declines, and the

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[11]Removals are the mandatory and confirmed return of an inadmissible or deportable immigrants out of the United States resulting from a government order (**?**).

[12]Though domestic removals are difficult to enforce, Kostandini et al. (2014) find evidence that local immigration enforcement efforts do reduce the number of undocumented workers, which forces farmers to pay higher wages.

Table 2. Steady State Results for Border and Domestic Enforcement

Variable	Baseline	Alternate	Percent Change
Thousands			
L^I	40.454	28.111	-30.511
L^{UI}	260.435	155.120	-40.438
L^U	531.500	438.017	-17.588
L^S	7,153.516	7,210.539	0.797
million \$			
V^U	57,571.398	53,822.411	-6.512
V^M	60,256.569	60,468.929	0.352
\$ per hour			
w^I	8.980	10.301	14.709
w^U	10.330	11.718	13.441
w^M	1.023	1.018	-0.441

probability of incurring the migration cost κ for unsuccessful entry rises.[13] If unauthorized migrants are apprehended, they can choose to remain in Mexico or if they choose to reenter they have to re-incur the migration cost κ. Therefore, apprehension not only reduces the chances of successfully crossing, but also the flow of workers attempting to cross, both of which negatively impact the stock of undocumented workers in the United States. In addition, tighter domestic surveillance d also reduces the stock of undocumented workers because of the greater chance of getting caught and returned to Mexico. These greater deportation rates also reduce the benefits of successful entry, and thus indirectly deter the flow of the unauthorized workers L^I. Consequently, the stock of undocumented workers L^{UI} fall by 40.438% from 260.435 thousand to 155.120 thousand due to a reduction in the number of successful border crossings, an increase in the number of deportations, and a reduction in the attempted flow of unauthorized migrants L^I. The decline in the unauthorized flow by 30.511% from 40.454 thousand to 28.111 thousand are, as discussed above, the indirect effects of higher b and d. These findings confirm the results of Pena (2009), Devadoss and Luckstead (2011), and Luckstead et al. (2012) who found that border and domestic enforcements are negatively associated with agricultural worker migration.

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[13]These effects can be seen in the first-order conditions (15) - (18).

These policies reduce the number of undocumented workers available for U.S. labor-intensive agricultural production. With the number of guest workers held constant exogenously, this decline in labor supply is not offset by the increase in the number of domestic U.S. workers because of unwillingness of the U.S. workers to do the hard labor. Consequently, this labor shortfall drives the U.S. wage rate w^U up by 13.441% from 10.330 to 11.718. As the U.S. wage rate increases, the demand for farm workers declines (equation (21)). As a result, total labor L^U used in U.S. labor-intensive agriculture declines by 17.588% from 531.500 thousand to 438.017 thousand workers. The decline in the stock of undocumented workers raises the illegal wage rate w^I by 14.709% from 8.980 to 10.301.[14] The increase in w^U can also be seen from the wage linkage equation 8, as w^I and d rises. The fall in total labor employed in U.S. labor-intensive agriculture production leads to a decline the value of production by 6.512% from \$57,571 million to \$53,822 million. Thus, stricter border and domestic enforcements negatively impact the labor-intensive agricultural sector. Zahniser et al. (2012b) implement an exogenous reduction in the number of undocumented workers by *40%* and show that the agricultural output falls by 2-5% and increase the wage rate of legal workers by 3-7%.

As entering and residing in the United States become more difficult, the Mexican labor employment L^S in agricultural production expands from 7,153.516 thousand to 7,210.539 thousand,[15] which causes the Mexican wage rate to fall by 0.441%. It is worth noting, of the returned workers, part of them engage in leisure, which increases by 60.634 thousand (not reported in Table (2)), because the opportunity cost of leisure falls, i.e., the wage rate for the worker in Mexico declines. As the labor use in Mexico expands, the value of Mexican production increases by \$212.360 million. Thus, tighter U.S. border and domestic enforcements hurt Mexican laborers through lower wages but help Mexican agricultural producers through an increase in production.

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[14]Fan et al. (2016) found that wage rates of legal workers increased more that the wage rates of undocumented workers during recessions.

[15]This quantitative result is consistent with the qualitative observation by Charlton and Taylor (2016) who conclude that tighter immigration policies increase the likelihood that Mexican farm workers find employment in the Mexican agricultural sector.

The dynamic impacts of heightened border and domestic surveillance are depicted in Figures 1 - 3. As discussed at the beginning of this section, the U.S. government announces and implements the tighter border and domestic surveillance in the first period, which implies that Mexican workers and U.S. and Mexican producers respond once these policy changes are implemented.[16] Interestingly, because Mexican workers anticipate the decline in the Mexican wage rate and increase in the U.S. illegal wage rate in the future periods, they forgo the opportunity to illegally migrate to the United States in the early periods to take advantage of the higher Mexican wage rate while it last and then attempt to illegally migrate to the United States after the U.S. illegal wage rate has increased. In addition, at the time U.S. government announces and implements stricter immigration policies, the baseline stock of undocumented workers is 105.315 thousand more than the stock in the alternate level, and the model starts transitioning to the new equilibrium. For this transition to occur, Mexican workers choose to engage in leisure to reduce the supply of unauthorized entry to the United States, which, based on the law of motion of labor, is the most direct way to reduce the stock in the United States. Therefore, the flow of unauthorized immigrants initially drops by 424% from 40.454 thousand in the baseline to 6.483 thousand in the first period of the transition dynamics, and then steadily *increases* to the alternate steady state (long-run) level of 28.111 thousand (see Figure (1).A).
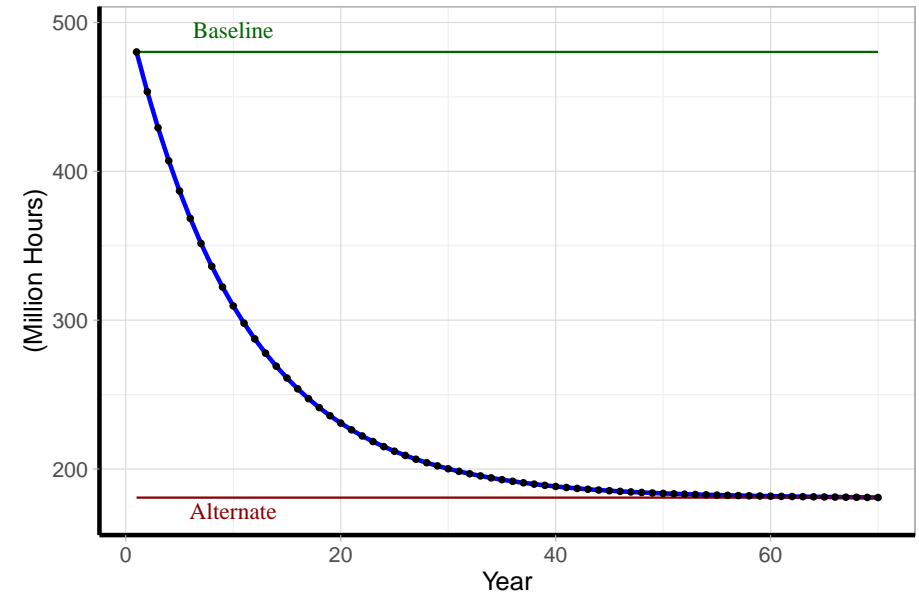
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[16]We can also conduct the dynamic analysis with the policy announcement in the first period and implementation a few periods later, which can impact the transitory paths as agents have time to respond.

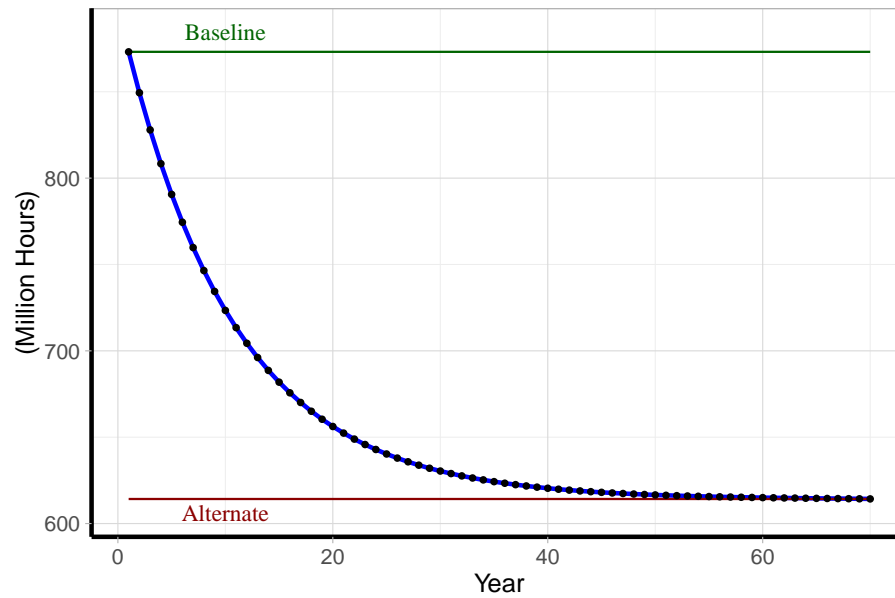Figure 1. Labor Dynamics of Border and Domestic Enforcements

A. Flow of Illegal Immigrants
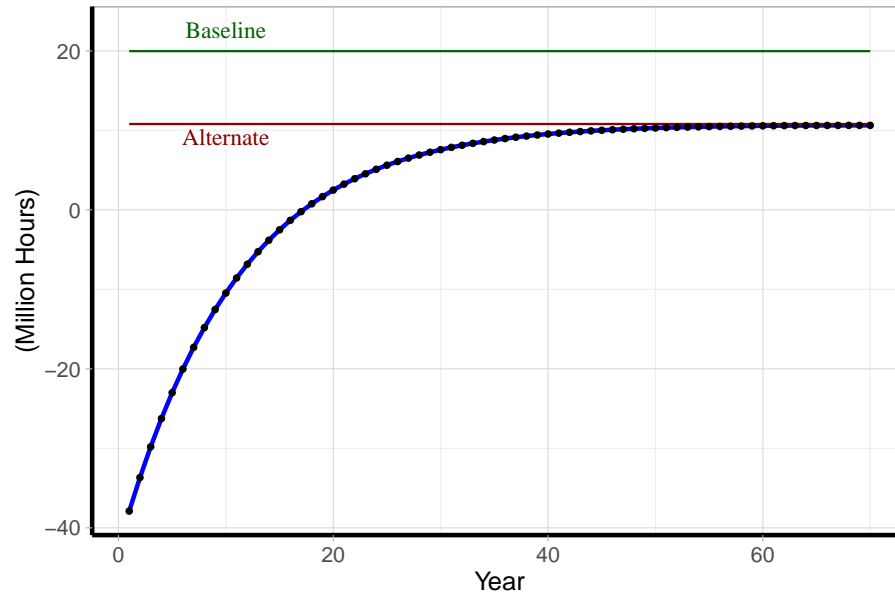
B. Stock of Undocumented Workers

C. Total Workers in U.S. Labor-Intenstive Agriculture
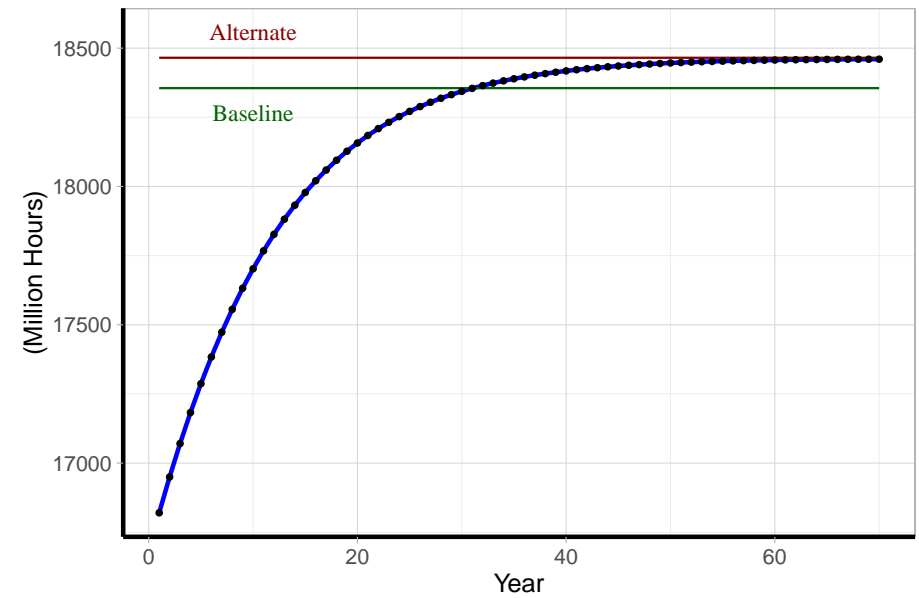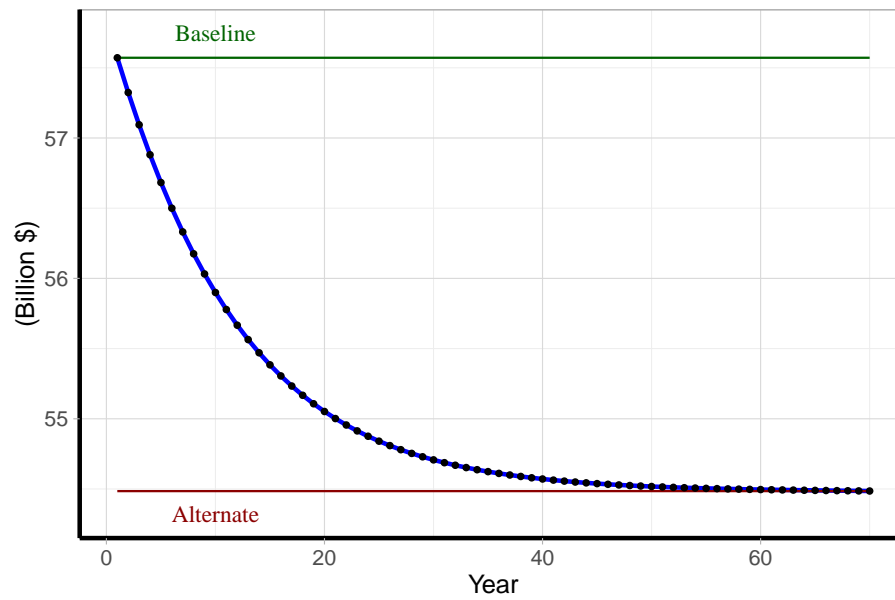
D. Total Workers in Mexican Agriculture

Figure 2. Dynamic Results for Production of Border and Domestic Enforcement

A. U.S. Labor Intenstive Production
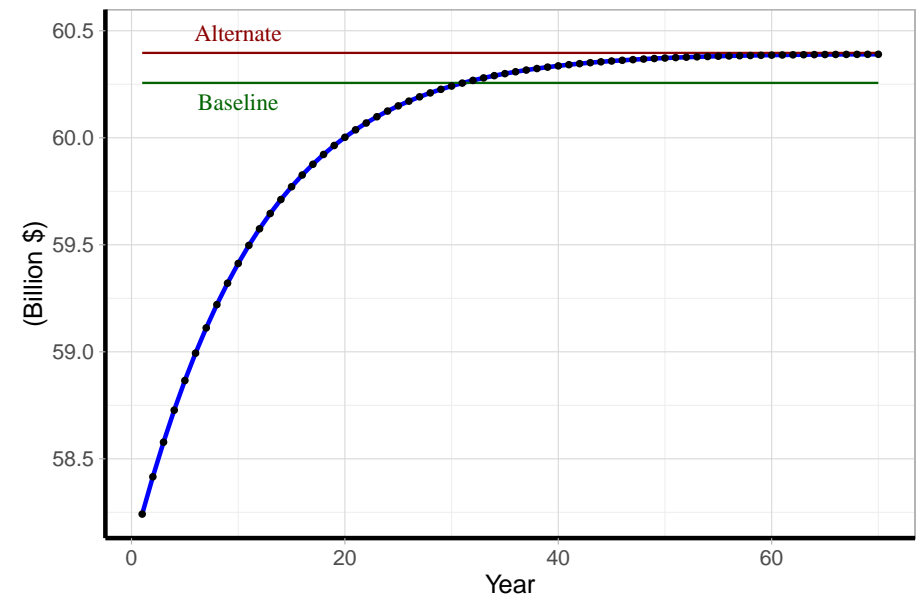
B. Mexican Production

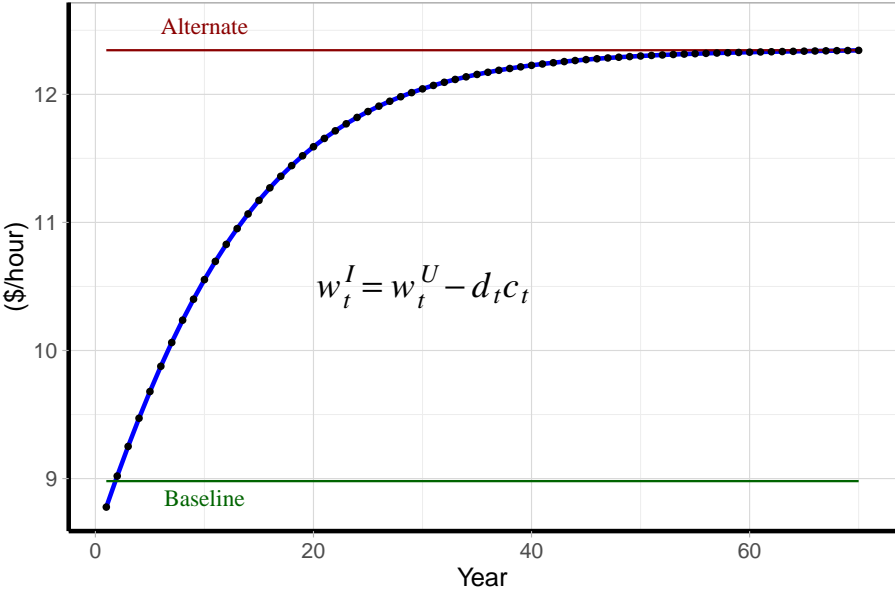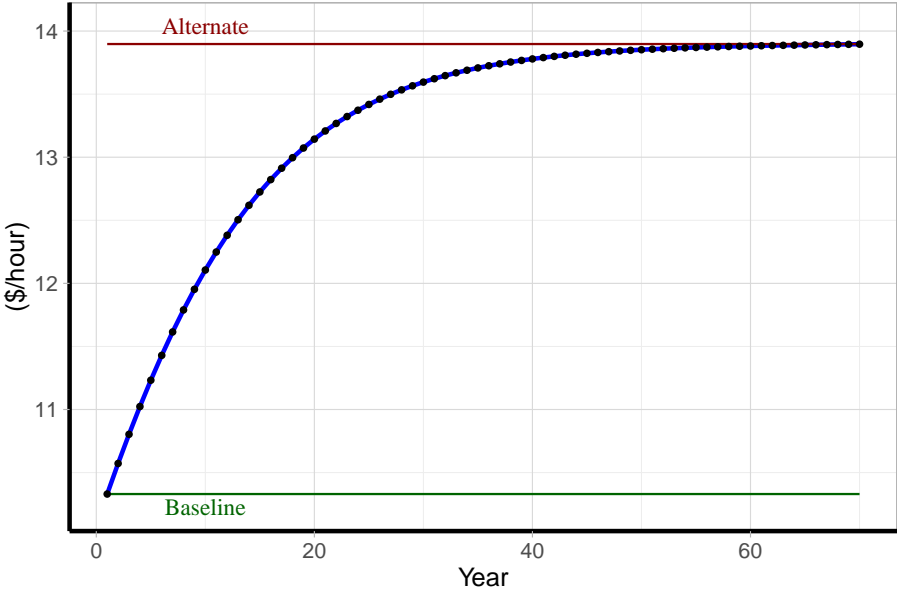## Figure 3. Dynamic Results for Wage Rates of Border and Domestic Enforcement
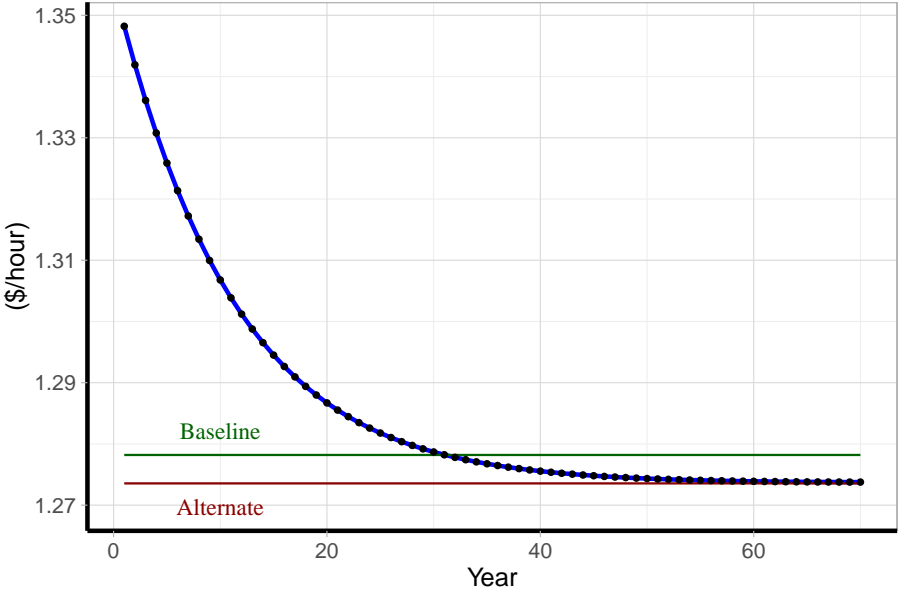
A. U.S. Illegal Wage Rate

B. U.S. Legal Wage Rate

C. Mexican Wage Rate

While the flow of unauthorized migrants falls sharply in the first period and then increases swiftly to the alternate level, the stock of undocumented workers declines steadily from the baseline level to the alternate level as more undocumented workers are deported and fewer migrants are able to cross the border illegally (see Figure (1).B). As the stock of undocumented workers is the major share of total farm workers in the U.S. labor-intensive agriculture, and given that the number of guest workers is held constant and domestic workers respond minimally to this policy change, the transition dynamics for total workers follow a very similar pattern to that undocumented workers (see Figure (1).C).

Because Mexican workers choose to initially partake in leisure as they have more time available from the tighter immigration policies and anticipate a fall in the Mexican wage rate and a rise in the U.S. illegal and legal wage rate, total Mexican farm workers decline by 5.16% below the baseline level to 6784.44 thousand, then increase back to the baseline level of 7153.52 by year 12, and finally converge to the alternate scenario level of 7210.54. These transition dynamics for total Mexican agricultural workers is similar to that of the flow of illegal migrants as seen in Figure (1).D.

Figure (2) illustrates that the dynamic path of U.S. labor-intensive (Mexican) agricultural production mimic that of the total workers in U.S. labor−intensive (Mexican) agricultural sector L_t^U (L_t^S).

As labor availability and wage rates have an inverse relationship, the U.S. legal and illegal wage rates move in the opposite directions of the transition path of legal (domestic and guest) workers and undocumented workers, respectively (Figure (3).A). Similarly, the Mexican wage rate and the total available farm workers in Mexico have an inverse relationship. As the stricter immigration controls reduce the total legal and unauthorized farm workers for labor intensive agriculture, the U.S. legal and illegal wage rates steadily increase from the baseline to the alternate levels (Figure (3).B). It is worth noting that at the beginning the illegal wage rate is slightly below the baseline level because of the increase in domestic enforcement d, which can be seen from the wage linkage equation: $w_t^I = w_t^U - d_t c_t$. The Mexican wage rate initially spikes by 2.99% above the baseline level

Table 3. Steady State Results for Guest Workers

Variable	Baseline	Alternate	Percent Change
	Thousands		
L^I	40.454	33.404	-17.428
L^{UI}	260.435	215.046	-17.428
L^U	531.500	530.824	-0.127
L^S	7,153.516	7,061.212	-1.290
	Millions $		
V^U	57,571.398	57,545.895	-0.044
V^M	60,256.569	59,910.813	-0.574
	$ per hour		
w^I	8.980	8.989	0.095
w^U	10.330	10.339	0.083
w^M	1.023	1.030	0.726

to 1.05 $/hr, then rapidly declines, falling below the baseline level after period 12, and approaches the alternate level (Figure (3).C).

For all the endogenous variables, the transition dynamics adjust rapidly in the early periods (about half way to the alternate level by the fourth year) and slowly in the later periods (requiring an additional 19 years to converge to the alternate level). Consequently, *ceteris paribus*, the economy takes about 23 years to fully adjust to changes in the immigration policies.

3.2.2. Guest worker program

Many farmers find acquiring H-2A visa permits to hire guest workers to be cumbersome, expensive, and a time-consuming process. If a new policy that would reduce the bureaucracy and cost of hiring temporary guest workers, it could lead to a substantial increase in the number of guest workers. It is therefore worth analyzing an expansion in the number of visas available for guest workers $\bar{L}_t^G$ by 50%, i.e., from the baseline value of 89,274 (see Table 1) to 133,911 for $t = 1, ..., T$. Table 3 reports the steady state results for the baseline and alternate scenarios of this change in policy.

In response to the expansion of the H-2A permits, farmers employ more guest workers which reduces the demand for undocumented workers. Because farmers are able to verify the legal status of immigrant workers, they would not hire undocumented workers when there is an adequate number of guest workers to complete the farm operations.

Therefore, we would expect a one-to-one reduction in undocumented workers for every additional guest worker employed. However, the expansion of guest worker visas by 50% (or 44.637 thousand visas) leads to a slightly more than one-to-one decline in the stock of undocumented workers by 45.389 thousand workers (or a 17.428% reduction). The reason of this larger decline is as follows. Because of this reduction in demand, fewer Mexican workers attempt to illegally cross the border (a decline of 7,050). In addition, Mexican farm workers prefer to work as guest workers instead of entering the United States illegally for they can earn higher wages under the H-2A program.[17] As a result of the expansion of the guest worker program, Mexican workers in totality are made better off as income per working hour increases. Consequently, not only fewer Mexican workers illegally migrate to maintain the lower stock of undocumented workers, but, with better employment opportunities and higher income, less incentive exists for migrants to pay to the migration cost κ, putting additional downward pressure of crossing the border. Therefore, the new additions to the undocumented workers falls short of the new guest workers, resulting in the decline stock of undocumented workers being slightly more than the addition of new guest workers. As a result, total supply of labor-intensive agricultural workers in the United States declines slightly (-0.127%),[18] which leads to a small reduction in production (0.044%) and increase in both the legal (0.083%) and illegal (0.095%) wage rate. Our findings on minimal impacts on wage rates are similar to the results of Pena (2010) who found seasonal guest workers program has a negligible effects on wage rates.

Because the sum of the increase in the undocumented workers returning to Mexico and potential unauthorized migrants remaining in Mexico fall short of the increase in leisure due to higher income and the increase in the number of guest workers, total supply of workers in Mexico declines by 1.29%. This leads to a small increase in the Mexican wage (0.726%) and decline in Mexican agricultural production (0.574%).

Next, we discuss the transition adjustments in the key variables in response to the streamlining of the guest worker program (see Figures 4 - 6). Once the migrants realize

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[17]Melo et al. (2014) also observed that immigrants from Mexico highly value the legal work with long-term visas in the United States.

[18]Zahniser et al. (2012b) demonstrated as a *quadruple* increase in temporary workers reduces the number of legal workers by 5 to 6 %.

the opportunity to work under the H-2A program and not to have to incur the migration cost κ, some of them opt out of illegally crossing the border. Furthermore, at the time the U.S. government announces and implements the policy change, the baseline stock of undocumented workers is 45.389 thousand more than the stock in the alternate level. Once the policy is implemented, the system of equations equilibrates and generate the transitions paths from the baseline to alternate level. During this adjustment process, Mexican workers augment their leisure to reduce the supply of unauthorized workers attempting the enter the United States, which, based on the law of motion of labor, is the most direct way to reduce the stock in the United States. Because of these switch to guest workers and rise in leisure, a pronounced decline in the unauthorized flow of migrants occurs in the first period (see Figure (4).A). As the system adjusts, i.e., changes in the supply and demand of labor and wage rates in both countries, the unauthorized entry precipitously reaches the alternate level.

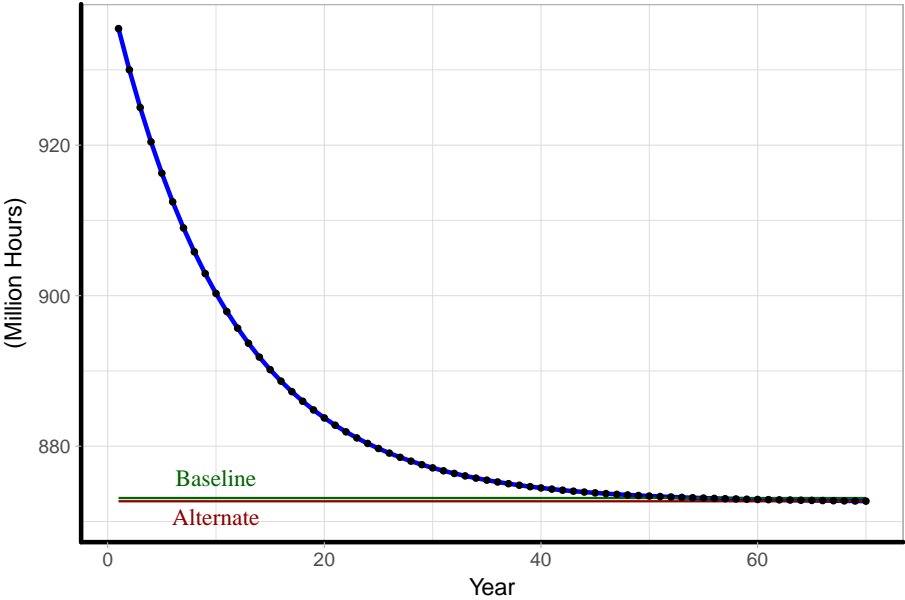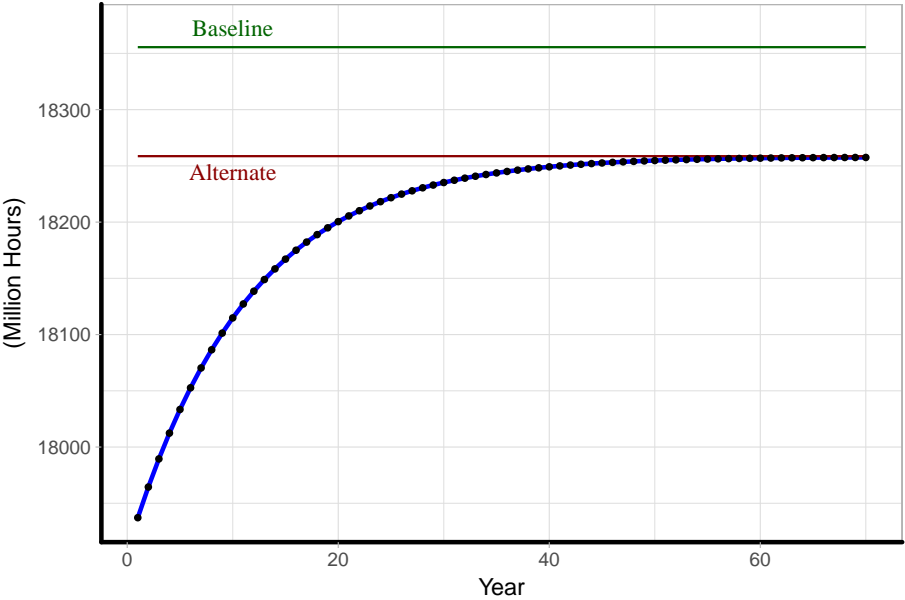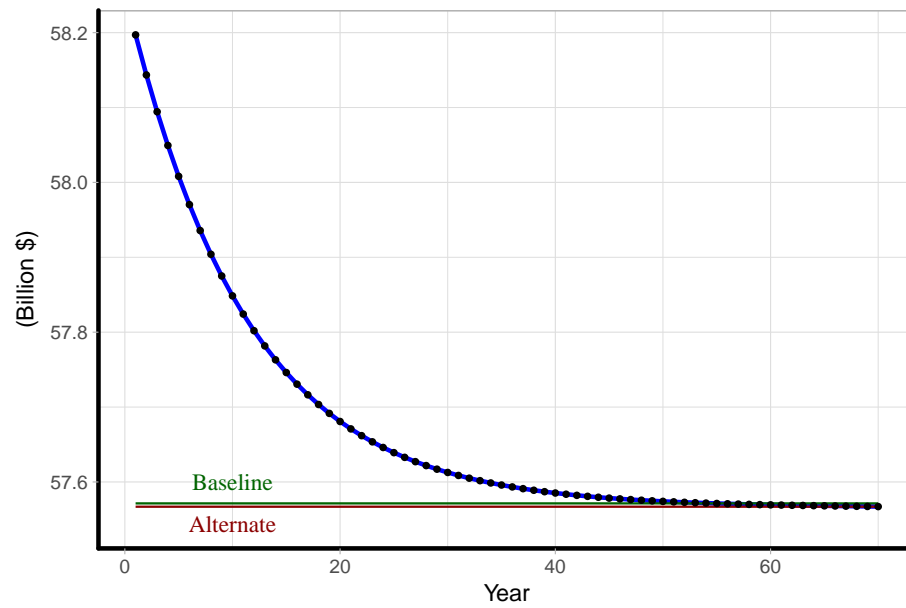Figure 4. Dynamic Results for Labor from the Expansion of Guest Worker Program
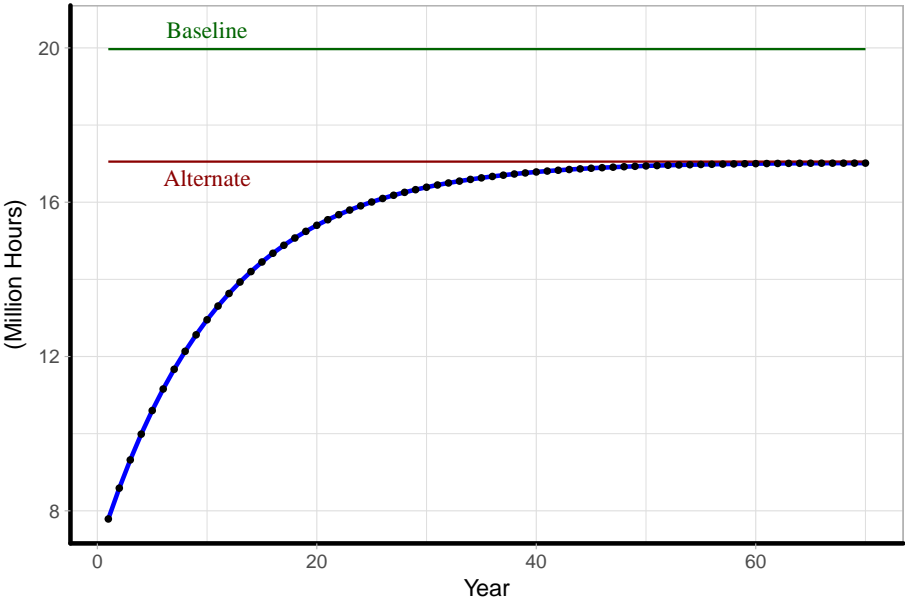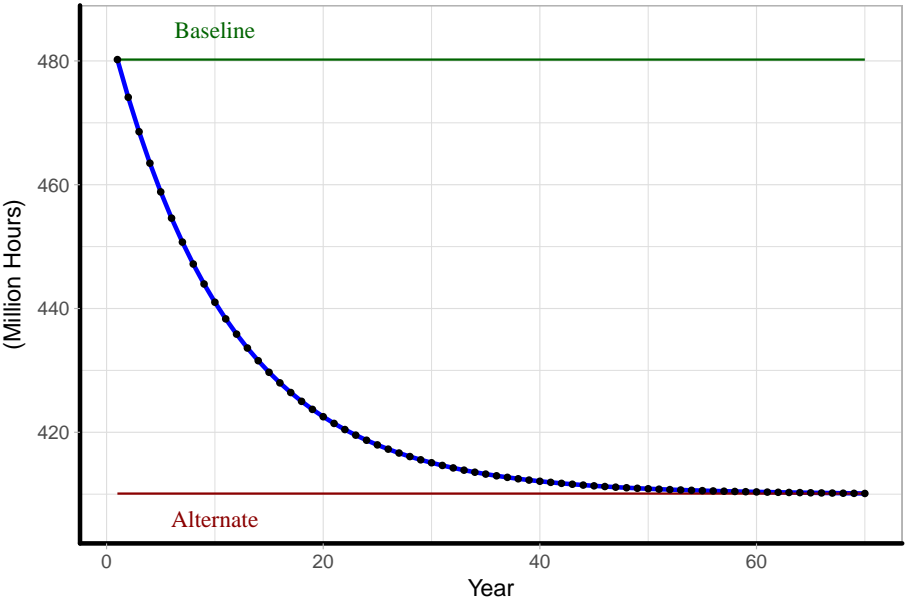
Figure 5. Dynamic Results for Production from the Expansion of Guest Worker Program

A. U.S. Labor-Intensive Production
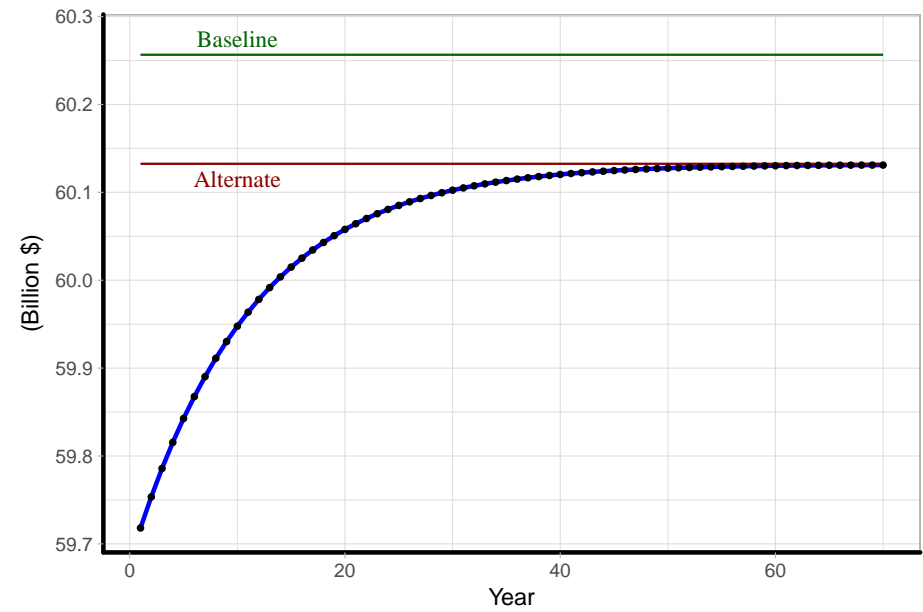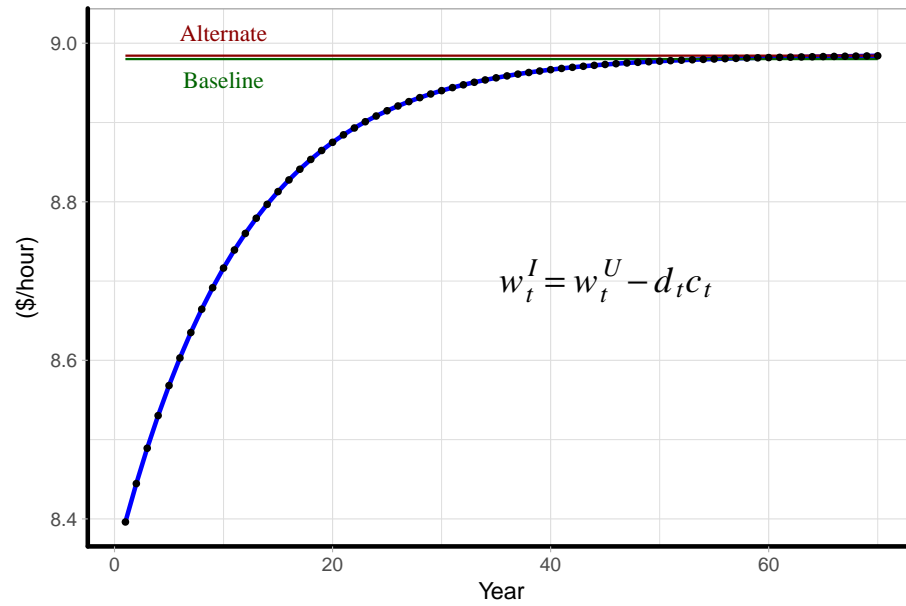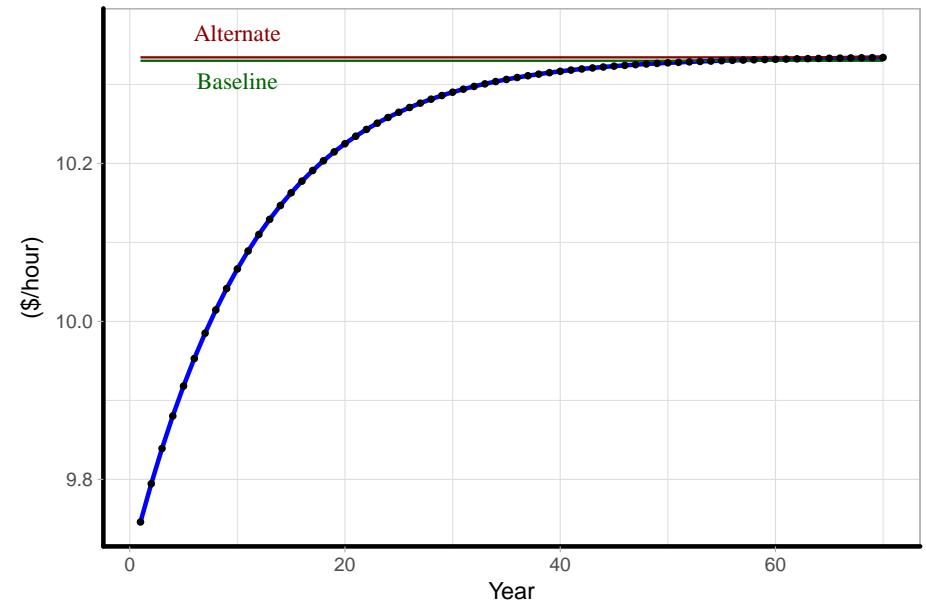
B. Mexican Production

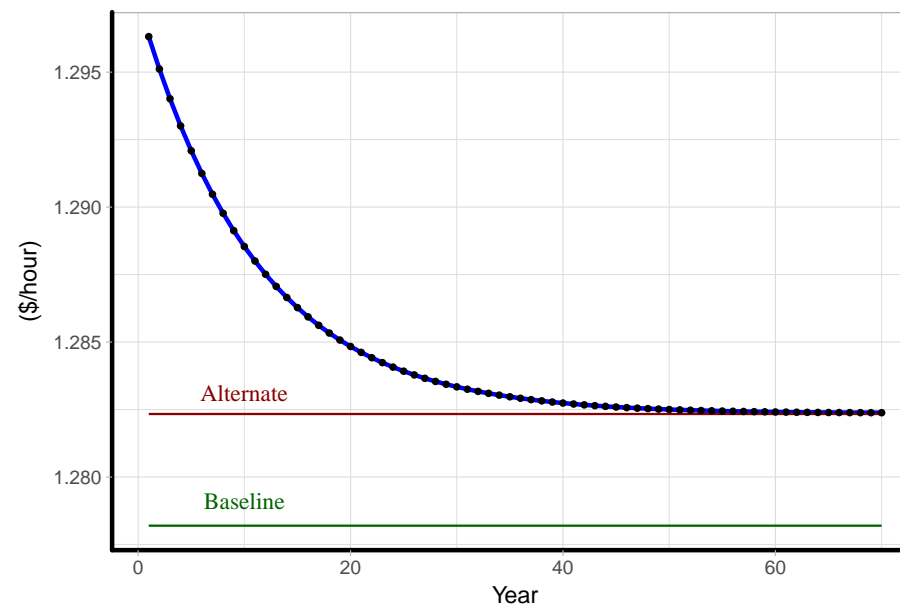Figure 6. Dynamic Results for Wage Rates from the Expansion of Guest Worker Program

A. U.S. Illegal Wage Rate

$$w_t^I = w_t^U - d_t c_t$$

B. U.S. Legal Wage Rate

C. Mexican Wage Rates

With new guest workers displacing undocumented workers and fewer unauthorized entries, the stock of undocumented workers declines from the baseline and approaches the alternate level by $t = 25$ (see Figure (4).B). With the sudden increase in the number of guest workers in period 1 and the stock of undocumented workers is just beginning to exhibit its downward adjustment, the number of total workers in the first few years is significantly above the baseline. With a steady decline in the stock undocumented workers, coupled with the path of unauthorized entry below the alternate level, the dynamic path of total workers approaches its alternate level again around period 25 (see Figure (4).C).

With the sudden increase in the number of guest workers, and higher leisure from the increase in income through U.S. legal wage rate and less spending on unauthorized migration, the number of workers in Mexican agriculture exhibit a deep decline from the baseline level in the first period (see Figure (4).D). Mexican workers in agriculture precipitously rise toward the the alternate steady state level because, even though unauthorized flow rise, the stock of undocumented workers decline and more workers come out of leisure to work.

With very little changes between the baseline and alternate production levels, much of the dynamics in U.S. labor intensive agricultural production is in the early periods and mimics the path of total workers in U.S. labor intensive agriculture (see Figure (5).A). Mexican agricultural production also exhibits a sharp fall in the first year, similar to the workers in this sector, then steadily increases toward the alternate level (see Figure (5).B).

As discussed above in the steady state analysis, the new H-2A program does not have a significant effect on both U.S. illegal and legal wage rates. Consequently, the transition paths of these wage rates follow the opposite direction of total workers in U.S. labor-intensive agriculture (see Figure (6).A and .B). For Mexican agriculture, the wage rate in the alternate scenario is above that of the baseline and its path follows a mirror image of Mexican workers in agriculture (see Figure (6).C).

These results bring out important policy implications in that the streamlining of the guest workers program impacts very little the total number of workers in U.S.

labor-intensive agriculture, and thus, the production in this sector. This is because the additional number of guest workers curtails the unauthorized entry and displaces the undocumented workers by a little more than one-to-one, resulting in only a small change in the number of total workers. In summary, this program lowers the number of of unauthorized border crossing and total stock of undocumented workers but does not significantly increase the total workers or production.

4.   Conclusion and Discussion

Given the contentious public debate to curb illegal migration and deport the unauthorized immigrants residing in the United States, this study develops a dynamic model of farm labor markets and labor-intensive agricultural production in Mexico and the United States to examine the effects of heightened border and domestic surveillance and employing additional guest workers. Our results show that stricter border and domestic controls harms the labor-intensive agricultural sector because these policies exacerbate the labor shortage problem. As these policies work against the interest of growers of high-valued produce such as vegetables and fruits, they may not support these policies. In contrast, since these policies deport undocumented workers to Mexico and curbs the unauthorized entry, more farm workers are available for Mexican agricultural production, they modestly benefit this sector.

With increasing demand for labor by Mexican farmers and U.S. domestic workers are unwilling to perform drudgery farm work, the shrinking labor supply will continue to increase. Under such circumstances, heightened immigration enforcement, as called for by some politicians, without adequate solution for augmenting farm labor will only intensify acute labor shortage faced by farmers.

Since we model leisure, we generate results which are counterintuitive. For instance, heightened immigration control should generally increase the farm labor availability in Mexico; however, our results show this labor available sharply declines in the early periods as workers in Mexico divert more time to leisure in anticipation of lower wage rates in Mexico and future increase in U.S. wage rates.

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In contrast to conventional wisdom that the guest-worker program will increase the labor force in U.S. agriculture, our findings show that total workers actually decline, albeit by a small percentage, because our model allows for substitution between guest workers and undocumented workers.[19] However, this substitution entails that the expansion of the guest-worker program eases the reliance of U.S. farmers on undocumented workers and thereby addresses the labor shortfall with a steady supply of H-2A workers, which corroborates the conclusion of Charlton and Taylor (2016) who note that streamlining the H-2A program can help farmers deal with labor shortages. The results of the H-2A program expansion shows that it lowers U.S. production very slightly because this program displaces the undocumented workers by a little more than the new guest worker additions. The impact of this program on Mexican agriculture is very minimal. In addition, our findings demonstrate that addition of guest workers does not reduce the wage rate domestic workers, because these workers displace the undocumented workers, which is consistent with the policy prescription of H-2A program that hiring of foreign workers should not adversely affect the legal U.S. workers both in terms of job loss and lower wages.

In comparison of both policies, border and domestic enforcements not only have larger adverse effect on U.S. labor-intensive production, but are also costlier than streamlining the H-2A program. Furthermore, our findings underscore the problem facing labor-intensive agriculture, i.e., U.S. immigration policy does not offer a solution to the labor need, rather it accentuates the acute labor shortage. While the guest-worker program offers a viable solution to employing undocumented workers, it does not increase total labor supply nor lowers U.S. legal wages.

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[19]Our finding is consistent with Charlton and Taylor (2016) who observe that streamlining the guest-workers program will only have small impacts on the labor supply to U.S. agriculture.

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A Model Details

This appendix contains the first-order conditions, the steady state equations, and condensed equations used in the calibration.

A1. Optimization and First-order Conditions

The first-order conditions of Utility Maximization are

$$(23) \qquad \beta^t \frac{\gamma_C}{C_t} - \lambda_t p_t^C = 0$$

$$(24) \qquad \beta^t \frac{\gamma_L}{L_t^L} + \lambda_t \kappa_t - \eta_t (1 - b_t) = 0$$

$$(25) \qquad \lambda_t w_t^M + \lambda_t \kappa_t - \eta_t (1 - b_t) = 0$$

$$(26) \qquad \lambda_t w_t^U + \lambda_t \kappa_t - \eta_t (1 - b_t) - \mu_t = 0$$

$$(27) \qquad \lambda_{t+1} \left(w_{t+1}^I + \kappa_{t+1} \right) + \eta_{t+1} \left[(1 - d_{t+1}) - (1 - b_{t+1}) \right] - \eta_t = 0$$

$$(28) \quad w_t^M L_t^S + w_t^U L_t^G + w_t^I L_t^{UI} - \kappa_t \left(\overline{L}^M - L_t^L - L_t^G - L_t^S - L_t^{UI} \right) - p_t^C C_t - \tau_t = 0$$

$$(29) \qquad (1 - d_t) L_t^{UI} + (1 - b_t) \left(\overline{L}^M - L_t^L - L_t^G - L_t^S - L_t^{UI} \right) - L_{t+1}^{UI} = 0$$

$$(30) \qquad \overline{L}_t^G - L_t^G = 0.$$

To complete the full dynamic model, in addition to the above first-order conditions, we need the first-order conditions for production:

$$(31) \qquad p_t^U \alpha^U \theta_t^U \left(L_t^U \right)^{\alpha^U - 1} = w_t^U$$

$$(32) \qquad \theta_t^M \alpha^M \left(L_t^{DM} \right)^{\alpha^M - 1} = w_t^M,$$

and U.S.-Undocumented wage linkage equation and labor clearing conditions:

$$(33) \qquad L_t^U - a \left(w^U \right)^\omega - L_t^G = L_t^{UI}$$

$$(34) \qquad w_t^U = w_t^I + d_t c_t$$

$$(35) \qquad L_t^{DM} = L_t^S.$$

A2. Steady State Equations

For steady state analysis, all endogenous variable are equal across time periods. Eliminating the time subscripts and simple algebra leads to the steady state system of equations:

$$\beta \frac{\gamma_C}{C} - \lambda p^C = 0$$

$$\beta \frac{\gamma_L}{L^L} + \lambda \kappa - \eta (1 - b) = 0$$

$$\lambda w^M + \lambda \kappa - \eta (1 - b) = 0$$

$$\lambda w^U + \lambda \kappa - \eta (1 - b) - \mu = 0$$

$$-\eta (1 - b + d) + \lambda \left(w^I + \kappa \right) = 0$$

$$w^M L^S + w^U L^G + w^I L^{UI} - \kappa \left(\overline{L}^M - L^L - L^G - L^S - L^{UI} \right) - p^C C = 0$$

$$dL^{UI} - (1 - b) \left(\overline{L}^M - L^L - L^G - L^S - L^{UI} \right) = 0$$

$$\overline{L}^G - L^G = 0$$

$$p^U \alpha^U \theta^U \left(L^U \right)^{\alpha^U - 1} - w^U = 0$$

$$p^M \alpha^M \theta^M \left(L^{DM} \right)^{\alpha^M - 1} - w^M = 0$$

$$L^U - a \left(w^U \right)^\omega - L^G - L^{UI} = 0$$

$$w^U - w^I - dc = 0$$

$$L^{DM} - L^S = 0.$$

A3.   Equations for Calibrated Parameters

The steady state equations are simplified to yield the following seven condensed equation for calibrating the model:

$$
\begin{aligned}
c &= \frac{w^U - w^I}{d} \\[2mm]
d &= \frac{(1-b)\left(\overline{L}^M - L^L - \overline{L}^G - L^{DM} - L^{UI}\right)}{L^{UI}} \\[2mm]
\theta^U &= \frac{w^U}{p^U \alpha^U \left(L^U\right)^{\alpha^U - 1}} \\[2mm]
\theta^M &= \frac{w^M}{p^M \alpha^M \left(L^{DM}\right)^{\alpha^M - 1}} \\[2mm]
\kappa &= \left(\frac{b(B) - 1 - d(D)}{d(D)}\right) w^M + \frac{1 - b(B)}{d(D)} w^I \\[2mm]
a &= \frac{L^U - L^G - L^{UI}}{\left(w^U\right)^\omega} \\[2mm]
\tau &= w^M L^{DM} + w^U \overline{L}^G + w^I L^{UI} - \kappa \left(\overline{L}^M - L^L - \overline{L}^G - L^{DM} - L^{UI}\right) - \frac{w^M L^L \gamma_C}{\gamma_L}.
\end{aligned}
$$