Immigration, Labor Shortages, and Labor Market Dynamics

Federico Mandelman
Federal Reserve Bank of Atlanta

Yang Yu
Shanghai Jiao Tong University

Francesco Zanetti*
University of Oxford

March 2026

Abstract

Immigration has become a central driver of U.S. labor force growth. We document new empirical findings that shed light on the relationships between immigration, labor shortages, wage growth, and job openings during the high-immigration period of 2021-2024. The textbook search-and-matching model implies highly counterfactual labor market dynamics: it predicts that a surge in immigration lowers hiring costs and stimulates vacancy posting, leaving labor market tightness and wages largely unchanged. This prediction contradicts the data, which shows a negative correlation between immigration and vacancy growth. To reconcile the evidence, we extend the framework to incorporate complementarities between native and immigrant workers together with a Leontief-type production technology that generates labor shortages similar to those observed in the post-pandemic period. In this environment, immigration alleviates these shortages by helping fill vacancies and dampening wage growth, consistent with the data.

Keywords: Immigration, labor shortages, search-and-matching models.

JEL classification: E24, E32, J63, J64, F22.

*We thank Andres Blanco, David Wiczer, Andrei Zlate, and conference participants at Clemson University, SED 2025, University of Oxford, and WESEAMS 2025 for helpful comments. Nick Croteau provided excellent research assistance. The views expressed in this paper are solely the responsibility of the authors and should not be interpreted as reflecting the views of the Federal Reserve Bank of Atlanta or the Federal Reserve System. The usual disclaimer applies.

1 Introduction

During 2019-2024, all employment growth in the U.S. stemmed from increased employment of foreign-born workers, while employment among native-born individuals remained at pre-pandemic levels. During this period, employment of foreign-born individuals increased by 12 percent, accounting for the entire 3 percent total employment growth in the United States.[1]

Immigration has shown significant volatility as well, primarily linked to large fluctuations in unregulated inflows, particularly among low-skilled workers entering through the U.S.-Mexico border.[2] Figure 1 illustrates the evolution of unregulated immigration to the United States.[3] After expanding rapidly from the 1980s onward, the population of undocumented workers leveled off during the 2008 Great Recession. The ensuing plateau through 2022 (orange line) contributed to a gradual buildup of labor shortages in low-skill occupations, as output recovered from the recession, the stock of undocumented immigrants remained persistently below its previous trend.[4] As discussed below, these labor shortages turned into severe bottlenecks following the COVID-19 pandemic. The sharp rebound in undocumented immigration between 2021 and 2024 (purple line) helped substantially alleviate these shortages.[5]

In light of these labor market developments, we address the following questions. How do large changes in immigration affect labor market dynamics? To what extent are they associated with labor shortages, vacancy posting, and wage pressures? And can the textbook search-and-matching model of the labor market account for these patterns? These questions are important because the large literature on cyclical labor market dynamics has largely overlooked fluctuations in labor supply. Traditionally, changes in labor supply are linked to slow-moving demographic forces—factors typically viewed as secondary to the business-cycle fluctuations that are the primary focus of our analysis.

We document three new empirical facts that reveal the cyclical interplay between immigration, labor shortages, wage growth, and vacancy postings during the high-immigration period of

[1]The data source is the Current Population Survey (CPS). See Data Appendix G for details.

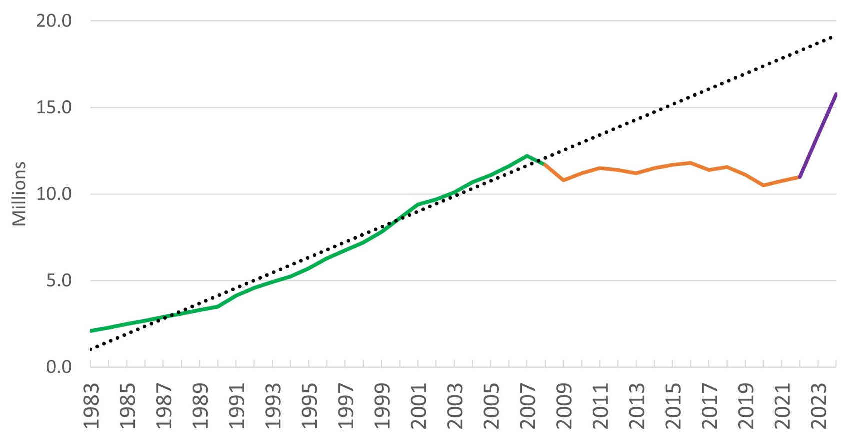
[2]See Data Appendix G for details. Unregulated immigration includes undocumented (unauthorized) workers, refugees, and individuals granted Temporary Protected Status (TPS).

[3]Data from the Pew Research Center, the U.S. Department of Homeland Security (DHS), U.S. Citizenship and Immigration Services (USCIS), and the Congressional Budget Office (CBO) was used to construct these series. See data appendix for details.

[4]See Cohen and dup Shampine (2022) and Mandelman et al. (2024) for a description of the evidence.

[5]According to the CBO, the cumulative net inflow reached approximately 4.9 million individuals—an increase of 45 percent from 2019 levels (Congressional Budget Office, 2024).

Figure 1: Stock of Undocumented Immigrants in the United States



Notes: The figure shows estimates of the stock of undocumented immigrants in the United States (in millions, at an annual frequency), obtained from PEW Research (1983-2008, in green); the U.S. Department of Homeland Security and U.S. Citizenship and Immigration Services (2009-2022, in orange); and the Congressional Budget Office (2023-2024, in purple), along with the linear pre-2007 trend (dotted black line). See the Appendix for more details.

2021-2024, using data from the Bureau of Labor Statistics. We define a sectoral labor shortage as a cyclical decline in a sector's employment share accompanied by strong vacancy posting—a sign of bottlenecks arising from low employment alongside elevated job vacancies in the effort to hire workers. With this measurement, we establish three new facts. Fact 1 shows that sectoral labor shortages predict vacancy growth. We interpret this as elevated labor demand in industries with unusually low employment shares relative to long-term trends. Fact 2 consistently shows that labor shortages also predict wage growth in the affected industries. Most importantly, Fact 3 reveals a negative correlation between immigration inflows and subsequent vacancy growth, suggesting that immigration-driven job creation may have helped resolve labor shortages by filling existing vacancies.

We show that the textbook Diamond-Mortensen-Pissarides (DMP) search-and-matching model—the workhorse model used to study the cyclical dynamics of labor markets—cannot rationalize the observed labor market dynamics in response to an immigration shock, as we discuss in detail below. To reconcile our empirical findings, we extend the standard DMP model with two key features: (i) a Leontief production technology, which creates labor market shortages by making high- and low-skill workers complementary in production, and (ii) a segmented labor supply, where immigrants provide low-skill labor and natives supply high-skill labor. This segmentation is consistent with empirical trends over the past four decades, during which an increasingly educated native workforce has concentrated in high-skill occupations (e.g., professionals, technicians), while immigrants have predominantly filled low-skill service jobs (e.g., caregiving, hospitality).[6]

The key mechanism in our model is the link between labor shortages and *job value*. As low-skilled workers become increasingly scarce, their role in production becomes more critical, which increases the value of a low-skill job. This, in turn, gives firms a strong incentive to post vacancies in the low-skill sector. A surge in immigration alleviates these shortages by expanding the pool of low-skill labor, which *reduces* the value of a job and the equilibrium tightness ratio and wage—consistent with our empirical findings.

In contrast, the textbook DMP model assumes that the value of a job is independent of labor shortages and is determined instead by labor demand factors such as labor productivity and the discount factor. In the textbook model, a surge in immigration increases "search unemployment" as newly arrived workers enter the labor force and search for jobs. Contrary to the facts discussed above, the model predicts that such an immigration induced rise in unemployment is matched by one-for-one *increase* in vacancies, as firms face lower hiring costs when unemployed workers become more abundant. Consequently, the textbook model predicts that key variables like labor market tightness (the vacancy-unemployment ratio) and wages for low-skilled workers remain unchanged in response to a rapid surge in immigration—a prediction at odds with the data. In Appendix E, we show that our model's predictions also align remarkably well with the observed outward shift in the Beveridge curve after 2020. The textbook model, by contrast, predicts a counterfactual upward-sloping Beveridge curve in this scenario.

Related literature. Our study relates to several strands of literature. First, on the macroeconomic effects of immigration, Hanson et al. (2017) documents the post-Great Recession slowdown, a trend linked to subsequent labor shortages by Cohen and dup Shampine (2022) and Mandelman et al. (2024). More recently, Cheremukhin et al. (2024) analyzes the post-pandemic immigration surge through a frictionless, Walrasian model. Our contribution is to document novel stylized facts and to develop a new theoretical framework, based on the textbook search-and-matching model, that explains the cyclical interplay between immigration fluctuations and labor shortages. In this aspect, our work builds on the literature establishing economic shortages as a key driver

[6] See Mandelman et al. (2024) for a discussion.

of business cycles, as shown by Michaillat and Saez (2015), Ghassibe and Zanetti (2022), and Bai et al. (2026a,b).

Second, we connect to studies with search-and-matching models that incorporate immigration. Examples include, Chassamboulli and Palivos (2014), Hauser and Seneca (2022) and Platonov (2023).[7] Our contribution to this strand of research is to introduce labor market segmentation and complementarities, capturing a key mechanism through which immigration alleviates labor bottlenecks.

Using rich disaggregated industrial data, Boehm et al. (2019) and Atalay (2017) show that short-run elasticities of substitution for different production inputs is not statistically different from zero—consistent with the *Leontief* production assumption in our model.[8] Baqaee and Farhi (2019) rationalize these empirical findings by developing a business-cycle model with such non-linearities in production. In line with our work, Farhi and Baqaee (2020) examines the COVID-19 pandemic under the lens of this model, showing that nonlinearities associated with strict complementarities in production amplify the effect of negative supply shocks by propagating supply bottlenecks.

The study by Michaillat (2024) is the closest to our analysis. It resolves the DMP model's inability to generate migration-induced unemployment by introducing a concave production function that produces "job rationing" as in Michaillat (2012), a mechanism most relevant in depressed economies. Our contribution complements this literature. In rationing models, immigration intensifies job scarcity by increasing an already excessive labor supply. In contrast, in our model with Leontief technology and skill complementarities, immigration alleviates existing shortages by expanding the scarce labor input, facilitating the filling of vacancies and reducing wage pressures.

The remainder of the paper is structured as follows. Section 2 presents the empirical evidence. Section 3 develops a modified DMP model to replicate the empirical regularities. Section 4 concludes.

[7]Fernández-Villaverde et al. (2021, 2024, 2025) emphasize the role of search complementarities and production synergies.

[8]Fernández-Villaverde et al. (2025) distinguishes between short- and long-run research labor supply elasticities.

2 Empirical evidence

In this section, we develop our measure of labor shortages based on the deviation of the sectoral employment shares from long-run trends and present the three key empirical facts linking immigration to labor market dynamics for the period 2020-2025. We show that industries with labor shortages exhibit higher vacancy growth (Fact 1) and higher wage growth (Fact 2). In turn, vacancies are filled more rapidly in sectors that attract immigrants (Fact 3). Facts 1 and 2 together validate our shortage measure by confirming that it predicts the vacancy and wage dynamics one would expect from labor market bottlenecks. Fact 3 is our central empirical finding: it establishes that immigration inflows are associated with a reduction in vacancy posting, a pattern that is puzzling under the textbook DMP model and that our theoretical framework is designed to explain.

We conceptualize sectoral labor market shortages as bottlenecks arising from low sectoral employment amid high vacancy posting. To quantify this idea, we define the sectoral labor shortage as a cyclical decline in a sector's employment share accompanied by robust vacancy posting.

Sectoral employment share and deviation from the trend. We measure the sectoral employment share (s_t^i) as the ratio of sectoral employment (N_t^i) to total employment (N_t); i.e., $s_t^i = N_t^i/N_t$, where $\sum_i s_t^i = 1$ for each time t.[9] We estimate the long-run trends in the logarithm of employment shares using the HP-filter and we interpret the trend as representing the slow-moving, structural transformation in sectoral employment shares of the U.S. economy.[10] We use the log-deviations of the labor share from the trend as representing the cyclical movements away from the long-run structure and denote them by $\widehat{s}_t^i$.

We interpret a negative $\widehat{s}_t^i$ (i.e., an employment share below trend) alongside high vacancy postings as evidence of sectoral labor shortages because it indicates a scarcity of labor input in the sector by leading to a low sectoral employment share despite firms' efforts to expand employment by posting vacancies. For our interpretation to hold, it is essential to observe a negative correlation between $\widehat{s}_t^i$ and vacancies posting, symptomatic of below trend employment

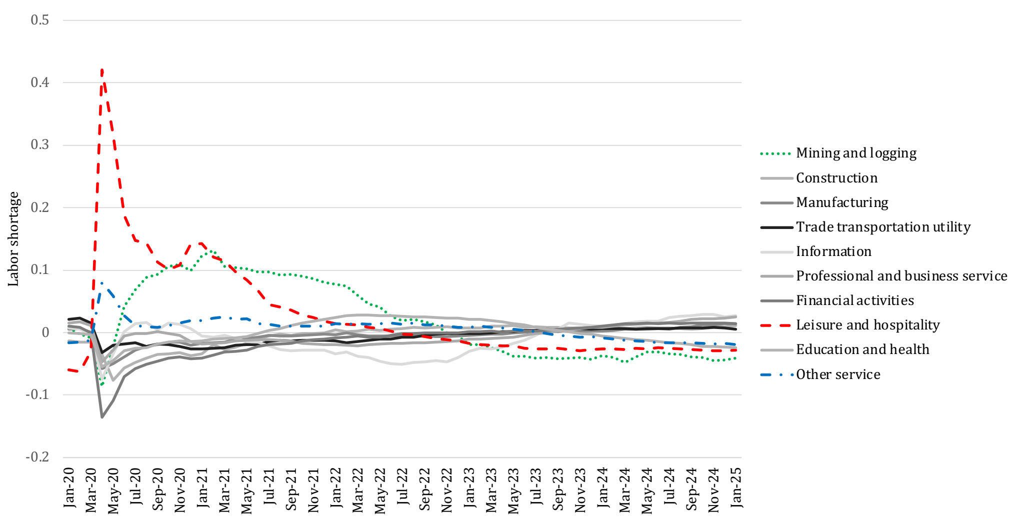
[9]Employment data is obtained from BLS Current Employment Statistics (Establishment Survey).

[10]Following Shimer (2005), we employ a high smoothing parameter ($\lambda = 10^6$) to isolate the very low-frequency trend. Appendix A.6 demonstrates the robustness of our results to alternative smoothing parameters (10^7 and $14,400$) and to a 120-month moving average.

share and simultaneous above vacancy postings.[11] A positive correlation would instead suggest a different dynamic, such as a fall in labor demand due to declining labor productivity, where a falling employment share is accompanied by reduced hiring. As Fact 1 will demonstrate, we find the negative correlation, validating our interpretation.

Measure of sectoral labor shortages from cyclical employment shares. We denote labor shortage in sector i at time t with Δ_t^i, and consistent with our interpretation, we set it equal to the inverse of the deviation of employment shares from their long-term trends; i.e., $\Delta_t^i = -\widehat{s}_t^i$. Thus, a positive labor shortage ($\Delta_t^i > 0$) indicates a temporary shortage of workers the sector i.[12]

Figure 2: Sectoral labor shortages (2020-2025) using $\Delta_t^i = -\widehat{s}_t^i$



Notes: This figure illustrates sectoral labor shortages across one-digit NAICS industries from 2020 to 2025. See the main text for details.

Figure 2 illustrates labor shortages, measured by $\Delta_t^i = -\widehat{s}_t^i$, across one-digit NAICS private industries from 2020 to 2025. It shows that the Leisure and Hospitality sector (red dashed line) experienced a sharp increase in labor shortages in Q1 2020. This sector accounts for 11 percent of total U.S. employment and serves as the largest employer of low-skilled immigrants (Chapuis et al., 2023). Most representative jobs in this sector include restaurant workers, hotel

[11] It is important to note that elevated vacancy postings or a high tightness ratio alone do not signify a labor shortage in our framework. They could simply reflect rising labor demand driven by increased productivity, which would simultaneously raise both employment shares and vacancy postings. These metrics indicate a shortage only when they occur concurrently with a below-trend employment share, which signals that firms are unable to attract sufficient workers despite their active recruiting efforts.

[12] Michaillat and Saez (2022) provide a theoretical rationale that the economy is efficient at the Beveridge threshold.

maids, housekeepers, and cleaners. While the Leisure and Hospitality sector contains a sizable share of "high-contact" jobs with high exposure to the Covid-19 pandemic, other industries with comparable exposure—such as Retail, Transportation, and Healthcare Assistance—did not experience similarly severe shortages. This divergence suggests that the sector's acute labor shortfalls were driven not entirely by health risks, but by a specific scarcity of its core workforce.

Importantly for our analysis, the U.S. largely reopened from the pandemic by the end of 2020, yet sectoral labor shortages persisted well beyond 2021. The increase in immigration starting around 2021 significantly reduced the severity of labor shortages in the Leisure and Hospitality sector. Immigrants arriving between 2022 and 2024 accounted for 6.5 percent of the sector's total employment, a period during which job openings in the sector decreased by 55 percent. Most other sectors (gray lines of varying shades), except for Mining and Other Services, experienced either a decline or stability in their labor shortages. By the end of 2024, labor shortages were almost entirely resolved across all sectors.

Since our interest is on the direct relationship between immigration with vacancy posting and wages during elevated labor shortages, we take 2020 as a reference year of an unprecedented increase in labor shortages, as evidenced by Figure 2. We calculate the average labor shortage across sectors for the year 2020 as: $\overline{\Delta}^i = \sum_{t \in [Jan20, Dec20]} \Delta_t^i / 12$, and examine the relationship between $\overline{\Delta}^i$ and the subsequent growth in vacancies and wages during 2021 (January to December 2021). This approach allows us to assess whether pre-existing labor shortages had significant predictive power for subsequent wage and vacancy dynamics.

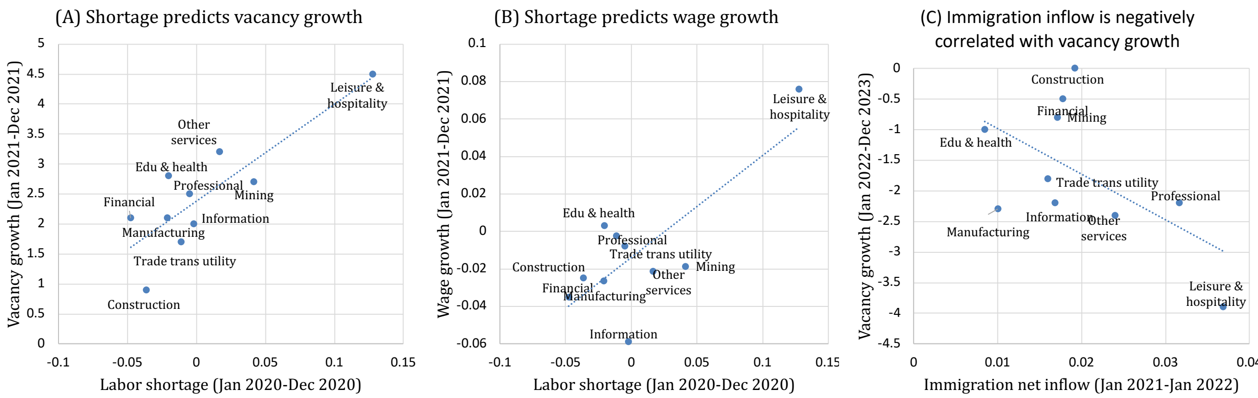
Fact 1: Labor shortage predicts vacancy growth. Panel (A) in Figure 3 shows labor shortages in 2020 ($\overline{\Delta}^i$, x-axis) and the growth rate of vacancy posting in 2021 (y-axis).[13] The significant positive correlation (at the 5% level) validates our measure of labor shortages: sectors with the most pronounced shortages—notably Leisure and Hospitality, Mining, and Other Services—are precisely those that experienced the strongest subsequent vacancy growth, consistent with our interpretation of sectoral labor shortages from the reduction in the cyclical employment shares amid robust vacancy posting in those industries.

Regression results including alternative forecasting horizons are reported in Appendix A.2. These results further reveal that labor shortages exhibit significant predictive power for future

[13] Vacancy data is obtained from the BLS' Job Openings and Labor Turnover Survey (JOLTS).

vacancy growth extending up to twelve months ahead. This significant predictive relationship validates our measurement of labor shortages and indicates that they are a persistent and important driver of labor demand.

Figure 3: Labor shortages, vacancy and wage growth rates, and immigration



Notes: The figure presents scatter plots illustrating the relationship between labor shortages and subsequent vacancy growth (Panel A), as well as future wage growth (Panel B), across one-digit NAICS private industries. Panel (C) displays the correlation between net immigration inflows and subsequent vacancy growth.

Fact 2: Labor shortage predicts wage growth. Panel (B) in Figure 3 plots the relationship between labor shortages (x-axis) in 2020 and the growth rate of wages in 2021 (y-axis). Wage is measured in dollars per hour, obtained from JOLTS. The result shows a strong positive correlation, significant at the 1% level, indicating that sectors with more severe labor shortages subsequently experienced higher wage growth. This is consistent with our earlier conjecture that labor shortages imply a surge in labor demand and demonstrates that labor shortages are significantly associated with positive wage growth. The Leisure and Hospitality sector, which had the most pronounced shortage, recorded the highest subsequent wage growth.

Table A.2 in Appendix A.3 reports regression results studying the link between sector-specific wage growth to labor shortages across several sample windows. The estimates reveal that shortages in 2020 were a strong and persistent predictor of wage increases in subsequent years.

Fact 3: Net immigration negatively predicts vacancy growth. Finally, we show that immigration acts as a strong equilibrating force, relieving sectoral labor shortages. Panel (C) of Figure 3 reveals a negative correlation (significant at 10% level) between the growth in the foreign-born employment share from January 2021 to January 2022 and sectoral vacancy growth from January 2022 to December 2023. Foreign-born employment data is obtained from IPUMS CPS data. Our preferred interpretation is that immigration inflows reduce vacancy posting by mitigating the underlying labor shortages.[14] An alternative interpretation is that immigrants are simply drawn to sectors where vacancy growth is already declining. However, this explanation is at odds with the findings of Cadena and Kovak (2016) and Furlanetto and Robstad (2019), who document that immigrants typically target sectors with growing job opportunities.

Under the lens of the canonical search-and-matching DMP model, Fact 3 presents a puzzle for the model. In that framework, an immigration-driven increase in labor supply should incentivize firms to post more vacancies to hire newly available workers and *increase* vacancy postings. However, the main idea of our analysis is that vacancies also respond to labor shortages, and immigration acts as an equilibrating force that lowers both shortages and the resulting labor demand and vacancy postings.

3 A simple model with labor shortages

In this section, we develop a simple model that accounts for the positive relationship between labor shortages, vacancy posting and wages, while allowing immigration to ease those shortages by filling job openings, consistent with the evidence in Section 2.

Our framework builds on the long-term trend of occupational sorting observed over the past four decades: Natives fill high-skilled occupations, while immigrants have mainly taken low-skilled service jobs, such as food preparation, cleaning, and child/elderly care.[15] We formalize the idea that these immigrant-provided services constitute *essential* needs that high-skilled household members must fulfil in order to join the labor force. The unavailability or high cost of these essential services can force household members to reduce their work hours or exit the labor market altogether as the evidence shows.[16] To capture the role of these essential services

[14]Our analysis is consistent in approach and results with Cohen (2024) who also show that industries experiencing higher immigrant inflows after January 2021 also saw a more rapid decline in job vacancies. This increase in foreign-born employment contributed to a 4.4% reduction in the vacancy rate in the sector, which itself represents 11% of total U.S. employment.

[15]The foreign-born alone accounts for most of the employment growth in these occupations over the past four decades (Mandelman and Zlate, 2022).

[16]Parker and Horowitz (2022) conducted a nationally representative survey of workers who quit their jobs in 2021 during the period known as the "Great Resignation." Among respondents with a child under 18, 48 percent reported that childcare issues were a primary reason for quitting, and roughly 45 percent cited a lack of scheduling flexibility.

in a reduced form manner, we introduce two complementary worker types—high-skill (native) and low-skill (immigrant)—into an otherwise standard DMP textbook model via a Leontief production function. This parsimonious extension generates dynamics consistent with Facts 1-3. In contrast, the textbook DMP model cannot explain these facts: as Appendix B illustrates and our quantitative analysis confirms, it predicts a fixed tightness ratio and wages, and an increase in tightness in response to an exogenous immigration surge.

3.1 Baseline environment

Time is discrete, $t = 1, 2, \ldots$. The economy has two sectors. One sector produces output by hiring native, high-skilled N_t^H workers. The other sector hires foreign-born, low-skilled N_t^L workers.[17] The output of each sector is a linear production function with respect to labor:

$$Y_t^H = z_t N^H, \quad Y_t^L = z_t N_t^L,$$

where z_t is the labor productivity equal across sectors. Importantly, the two sectors are complementary in the production of final output, which is manufactured according to the Leontief production function:[18]

$$Y_t = \min\left(Y_t^H, Y_t^L\right) = z_t \min\left(N^H, N_t^L\right). \tag{1}$$

Consequently, a labor shortage occurs when there is an imbalance (i.e., gap) between employment in the two sectors. A labor shortage in the low-skilled sector, forces members of the high-skilled sector to leave the labor force (or refrain from entering it) in order to meet some of

[17]The empirical counterpart to the model's low-skill sector is best approximated by Leisure and Hospitality and Other Services. In these sectors, only 16% and 23% of workers hold a college degree, respectively, compared to roughly 45-48% in high-skill sectors such as Professional and Business Services and Financial Activities (American Community Survey). Foreign-born workers also account for a substantial share of employment in these low-skill sectors—approximately 40%, according to Luxurylink calculations based on U.S. Census Bureau data, and exhibit weaker shortage dynamics during the post-pandemic period.

[18]Standard estimates of the elasticity of substitution between low- and high-skilled workers exceed unity (Katz and Murphy, 1992; Ciccone and Peri, 2005), implying a more than unitary degree of substitutability across skill groups in the long run. These estimates typically identify the average long-run response of relative wages to changes in relative labor supply. Our Leontief specification captures instead the short-run, within-cycle response to sudden changes in immigration flows, for which substitutability across skill groups is very limited. This distinction is consistent with a broader literature documenting that short-run elasticities of substitution are substantially smaller than their long-run counterparts. (see, e.g., Atalay, 2017; Boehm et al., 2019; Baqaee and Farhi, 2019; Fernández-Villaverde et al., 2025).

the essential needs mentioned. For simplicity, we assume that job creation and separation are always constant and equal to each other in the high-skilled sector, implying that high-skilled employment is fixed: $N_t^H \equiv N^H$. Instead, labor shortages for low-skilled labor can arise due to immigration restrictions, i.e., $N_t^L \leq N^H$.[19] By assumption, workers of different skills cannot move across sectors.

We define labor shortage as the gap between labor in the high-skilled and low-skilled sectors, formally equal to:

$$\Delta_t = N^H - N_t^L. \tag{2}$$

This reflects the unmet demand for low-skilled immigrant labor, which would prevent high-skilled natives to participate fully in the labor market.[20] By substituting equation (2) into equation (1), we derive the aggregate production function:

$$Y_t = z_t \left(N^H - \Delta_t \right), \tag{3}$$

which highlights that output diminishes as the labor shortage intensifies.

3.2 Search and matching in the low-skilled sector

Firms post vacancies in the low-skilled sector, while the high-skilled sector remains passive with no recruitment activities. The measure of new matches in the low-skilled sector is determined by the standard Cobb-Douglas matching function: $m_t = \phi v_t^\alpha u_t^{1-\alpha}$, where ϕ, v_t, and u_t are the matching efficiency, and measure of vacancy and unemployment, respectively. The job finding rate, $\mu_t(\theta_t)$, and vacancy filling rate, $f_t(\theta_t)$, are equal to:

$$\mu_t(\theta_t) = \phi\theta_t^\alpha \text{ and } f_t(\theta_t) = \phi\theta_t^{\alpha-1}, \tag{4}$$

[19]The assumptions $N_t^H \equiv N^H$ and $N_t^L \leq N^H$ are reduced-form representations of bottleneck resolution under strong complementarities. The static high-skill sector does not imply immobile labor supply but rather captures that effective high-skill input depends on the availability of low-skill services (e.g., childcare, elder care). When these services are scarce, high-skill workers reallocate time to home production, reducing their market labor supply. The ceiling $N_t^L \leq N^H$ then reflects that additional low-skill matches cannot be productively utilized when services are scarce. While endogenous adjustment of high-skill labor would smooth the transition, our core mechanism remains operative as long as some tasks are strongly complementary and difficult to automate.

[20]We define the model's labor shortage as the absolute gap, $\Delta_t = N^H - N_t^L$, rather than its share-based counterpart $\widehat{\Delta}_t = 0.5 - N_t^L/(N^H + N_t^L)$, which is the direct analogue of the empirical measure $-\hat{s}_t^i$. This choice is made for analytical tractability. The two measures are monotonically related and coincide exactly when shortages are zero ($\Delta_t = 0$ if and only if $\widehat{\Delta}_t = 0$), preserving all qualitative dynamics of the model.

respectively, where $\theta_t = v_t/u_t$ is the labor market tightness ratio, and $\mu_t(\theta_t)' > 0$ and $f_t(\theta_t)' < 0$.

3.3 Law of motion for low-skilled employment and labor shortages

The employment in the low-skilled sector evolves according to:

$$N_t^L = \max\{(1-\delta)N_{t-1}^L + m_t, N^H\}, \tag{5}$$

where current employment at time t results from employment from the previous period $t-1$ net of job separation at a rate of δ, plus job creation in the current period. Due to technological complementarities arising from the Leontief technology in equation (1), employment in the low-skill sector cannot exceed employment in the high-skill sector.

By subtracting N^H from both sides of Equation (5), the labor shortages are equal to:

$$\Delta_t = \min\{\Delta_{t-1} - (m_t - \delta N_{t-1}^L), 0\}, \tag{6}$$

where $m_t - \delta N_{t-1}^L$ is the net job creation in the low-skill sector. The law of motion of labor shortages can be partitioned into two cases, depending on whether the number of new matches is sufficiently high to resolve labor shortages.

Case 1 (unresolved labor shortages): $m_t < \Delta_{t-1} + \delta N_t^L$. In this case, the creation of new low-skilled jobs net of job separation is insufficient to resolve labor shortages. Thus, the law of motion of labor shortages is equal to:

$$\Delta_t = \Delta_{t-1} - m_t + \delta N_{t-1}^L. \tag{7}$$

Case 2 (resolved labor shortages): $m_t \geq \Delta_{t-1} + \delta N_t^L$. In this case, the labor shortages are resolved, implying that $\Delta_{t+j} = 0$ for $j \geq 0$. Without labor shortages, the low-skill sector satisfies the stationary steady state with $N_{t+j}^L = N^H$ and $\Delta_{t+j} = 0$ for $j \geq 0$.

In accordance with our assumption $N_t^L \leq N^H$, any "excess" match that causes the number of low-skilled workers to exceed the number of high-skilled workers—measured by $m_t - \delta N_{t-1}^L - \Delta_{t-1}$—is dissolved without contributing to production. This assumption is central to the role of labor shortages for the free-entry condition, as we describe in the next section.

3.4 Free-entry condition in the low-skilled sector

The free-entry condition for vacancy posting in the low-skilled sector is:

$$\frac{\kappa}{f_t(\theta_t)} = \beta p_t E_t\left(J_{t+1}\right), \tag{8}$$

which equates the expected costs (left-hand side) to the expected benefits of matching (right-hand side). The expected costs involve the cost of posting a vacancy κ divided by the rate of vacancy filling $f_t(\theta_t)$, as in the workhorse DMP model. The expected benefits depend on the firm's expected value of a filled vacancy, $E_t\left(J_{t+1}\right)$, discounted at the rate β (since it takes one period for the match to contribute to production), as in the standard DMP model. However, different from the canonical DMP model, in our setup the expected benefits are also discounted by the probability p_t that the new match will not generate a number of low-skilled workers in excess of the high-skilled workers, in accordance with the assumption $N_t^L \leq N^H$, as otherwise the match is dissolved (for this reason, we refer to p_t as the *match survival rate*). The match survival rate decreases when the new matches are close to becoming in excess of the full resolution of labor shortages (i.e., $m_t > \Delta_{t-1} + \delta N_{t-1}^L$), simultaneously reducing the expected value of the match and the firm's incentives to post vacancies.[21] To capture these intuitive forces, we define the match survival rate (p_t) as follows:

$$p_t = \begin{cases} 1 & \text{if } m_t < \widetilde{\Delta}_{t-1} \\ \frac{\widetilde{\Delta}_{t-1}}{m_t} & \text{if } m_t \geq \widetilde{\Delta}_{t-1} \end{cases}, \tag{9}$$

where $\widetilde{\Delta}_{t-1} \equiv \Delta_{t-1} + \delta N_{t-1}^L$ is the number of workers required to resolve labor shortage. Equation (9) implies that if the number of new matches is below the number of workers needed to resolve labor shortages (i.e., $m_t < \widetilde{\Delta}_{t-1}$), the match survival rate (p_t) is equal to one, as in the standard DMP model. Otherwise, if new matches are in excess to the full resolution of labor shortages (i.e., $m_t \geq \widetilde{\Delta}_{t-1}$), the probability is below one and it decreases with the number of excess matches.[22]

[21] The effect of p_t on the effective matching probability is conceptually similar to recruiting intensity (e.g., Davis et al., 2012). However, the underlying mechanism differs. In our model, this effect operates through labor supply-driven variation in the value of a job, which arises from production complementarities. By contrast, traditional recruiting intensity is independent of labor supply conditions.

[22] The term $(1 - p_t)m_t$ represents non-productive matches: matches formed in the search-and-matching process that fail to translate into productive employment because the low-skill employment constraint is binding.

Note that the match survival rate can be less than one due to our assumption of a Leontief production function, which creates the possibility of labor shortages. Under alternative production specifications, such as a CES function, all matched workers would be utilized, albeit potentially with a lower marginal product of labor. In Appendix F, we present an extended model that combines a Leontief production function with a linear production function—the latter being the standard specification in DMP models with worker skill heterogeneity (Fujita and Ramey, 2012; Bils et al., 2012). This hybrid specification allows us to preserve the concept of labor shortages while permitting imperfect substitution between the two skill groups. The results remain quantitatively similar to those in the benchmark case, which relies solely on a Leontief production function.

The match survival rate captures the effect of labor shortage on the value of vacancy posting, which is a central component in our model to replicate the observed positive correlation between labor shortages and both vacancies and wage growth (Facts 1 and 2) and the negative relationship between immigration and vacancy growth (Fact 3). When the match survival rate is equal to one ($p_t = 1$), Equation (8) nests the free-entry condition of the standard DMP model, and vacancy posting perfectly co-moves with immigration, since immigrants increase the availability of unemployed low-skill workers, reducing hiring costs and consequently fostering the growth of vacancy posting, leaving the equilibrium tightness ratio unchanged. In our model, instead, the match survival rate declines when new matches resolve the labor shortages, which reduce the expected benefits for firms of forming a match, such that vacancy posting declines with the resolution of shortages despite the increase in unemployment for low-skilled jobs resulting from immigration.

Our model introduces a direct link between labor shortages and vacancy posting associated with the resolution of the shortages that is absent in the standard DMP model. To highlight the important consequences for the link between vacancies and labor shortages, we rewrite the free-entry condition in Equation (8) by substituting Equations (4) and (9), and using the

Recruiting and matching occur, but some hires cannot materialize as employed workers since the economy has reached its effective capacity for low-skill labor.

definition of labor market tightness $v_t = \theta_t u_t$, which yields:

$$v_t = \begin{cases} \left[\frac{\phi\beta E_t(J_{t+1})}{\kappa}\right]^{\frac{1}{1-\alpha}} u_t & \text{if } m_t < \widetilde{\Delta}_{t-1} \\ \frac{\beta E_t(J_{t+1})\widetilde{\Delta}_{t-1}}{\kappa} & \text{if } m_t \geq \widetilde{\Delta}_{t-1} \end{cases}. \tag{10}$$

Equation (10) shows that when new hiring is below the full resolution of labor shortages ($m_t < \widetilde{\Delta}_{t-1}$), the number of vacancies posted v_t is proportional to unemployment u_t, as in the standard DMP model. In such a case, an exogenous increase in unemployment arising from an increase in immigration stimulates vacancy posting such that vacancy and unemployment perfectly comove. However, when new hiring resolves labor shortages $m_t \geq \widetilde{\Delta}_{t-1}$ and some matches are excessive, the number of vacancy postings is proportional to labor shortages.[23] Thus, a reduction in the labor shortage generates a decrease in vacancies. This mechanism is consistent with the strong negative comovement between vacancies and immigration during periods of elevated labor shortages (Fact 3), a puzzling empirical pattern if interpreted with the positive comovement between immigration and vacancies in the standard DMP model.

3.5 Unemployment and immigration in the low-skilled sector

The law of unemployment is equal to:

$$u_{t+1} = u_t - p_t m_t + im_t + \delta N_t^L, \tag{11}$$

where unemployment in the next period (u_{t+1}) is determined by the unemployment in the current period (u_t), net of the outflow into employment ($p_t m_t$), plus current immigration (im_t) and job separations (δN_t^L).[24]

At the beginning of each period t, immigration is linked to labor shortages and determined by:

$$im_t = \psi \Delta_t, \tag{12}$$

[23]Note that $m_t = \phi v_t^{\alpha} u_t^{1-\alpha}$. Based on equation (10), the condition $m_t < \widetilde{\Delta}_{t-1}$ is satisfied if $\phi^{\frac{1}{1-\alpha}} \left[\frac{\beta E_t(J_{t+1})}{\kappa}\right]^{\frac{\alpha}{1-\alpha}} < \frac{\widetilde{\Delta}_{t-1}}{u_t}$. Conversely, the condition, $m_t \geq \widetilde{\Delta}_{t-1}$, is satisfied if $\phi^{\frac{1}{1-\alpha}} \left[\frac{\beta E_t(J_{t+1})}{\kappa}\right]^{\frac{\alpha}{1-\alpha}} \geq \frac{\widetilde{\Delta}_{t-1}}{u_t}$.

[24]In line with Michaillat (2024), who provides a realistic framework for modeling immigration in models with search-and-matching frictions, equation (11) implies that current immigrants (im_t) contribute to unemployment in the subsequent period $t+1$, since they must wait one period before beginning their job search.

where ψ measures the stance of immigration policy, such that $\psi\Delta_t$ dictates how much immigration surges when labor shortages arise.[25]

3.6 Value functions and wage determination

We next define the Bellman equations that determine the value of a filled job for a firm (J_t), an employed worker (W_t), and an unemployed worker (U_t), which establish the total surplus from working that will be shared between workers and firms through the wage.

The value of a filled job is determined by:

$$J_t = z_t - w_t + \beta(1-\delta)E_t\left(J_{t+1}\right), \tag{13}$$

where z_t is output and w_t wages in period t. In the next period $t+1$, if the job survives separation at the rate $1-\delta$ the firm receives the discounted (at the rate β), expected job value.

The value of an employed low-skilled worker is determined by:

$$W_t = w_t + \beta E_t\left[(1-\delta)W_{t+1} + \delta U_{t+1}\right], \tag{14}$$

where the worker receives the wage in the current period t. In the next period $t+1$, the worker expects to receive the value of the job if it survives separation, or the value of being unemployed if the job terminates.

The value of an unemployed low-skilled worker is determined by:

$$U_t = h + \beta\left[p_t\mu_t E_t\left(W_{t+1}\right) + \left(1 - p_t\mu_t\right)E_t\left(U_{t+1}\right)\right], \tag{15}$$

where the unemployed worker receives home production h in the current period t. In the next period $t+1$, the worker finds a job with probability $p_t\mu_t$, receiving the expected value $E_t\left(W_{t+1}\right)$; otherwise, the worker remains unemployed and receives the expected value $E_t\left(U_{t+1}\right)$.

The total surplus of a job match is equal to: $TS_t = W_t - U_t + J_t$. During each period t, the wage is set by Nash bargaining that splits the total surplus between firm and worker, and the worker receiving the constant share τ, such that the share of the total surplus accruing to the

[25] The parameter ψ can be interpreted as representing forces like border enforcement policy and cross-country wage differentials linked with the flow of migration, which are treated as exogenous in our simple model.

worker is equal to $W_t - U_t = \tau TS_t$, while the share of the total surplus accruing to the firm is equal to: $J_t = (1-\tau) TS_t$.

We obtain an explicit solution for the total surplus of a job match by combining the Bellman equations (13)-(15) and the wage resulting from Nash bargaining:

$$TS_t = z_t - h + \beta \left(1 - p_t \mu_t \tau - \delta\right) E_t \left(TS_{t+1}\right). \tag{16}$$

Equation (16) shows that the total surplus increases with labor productivity z_t, but decreases with both the job finding rate $\mu_t(\theta_t)$ and the match survival rate determined by the resolution of labor shortages, specified by Equation (9). Intuitively, higher values of $\mu_t(\theta_t)$ or p_t increase the worker's bargaining position due to an increase in the tightness in the labor market that makes hiring more expensive to firms, thereby raising the wage and reducing the value of the firm. If labor shortages are not resolved and therefore $p_t = 1$, Equation (16) nests the standard Bellman equation for the total surplus in the canonical DMP model.

Equilibrium of the system. Equations (7), (10), (11), (12), and (16) determine the equilibrium values of unemployment (u_t), vacancies (v_t), immigration (im_t), labor shortages (Δ_t), and total surplus (TS_t). The wage in the low-skilled sector (w_t) is determined by Equation (13), while output (Y_t) is determined by Equation (3). If labor shortages are fully resolved, the low-skilled sector reaches the *no-shortage steady state*, characterized in Appendix C. Since the system is nonlinear, we resort to numerical simulation to obtain the equilibrium; Appendix D describes the solution method.

3.7 Quantitative analysis

Calibration. We calibrate the model on monthly U.S. data, primarily following Shimer (2005). We set the matching elasticity α to 0.28 and the worker's bargaining share τ to 0.72, which together satisfy the Hosios condition. We normalize the steady-state labor productivity z and vacancy cost κ to 1 and set the flow value of home production h to 0.4. Additionally, we calibrate the discount rate β to the standard value of 0.996.

We calibrate the parameter for the matching efficiency ϕ following Shimer (2005) and targeting the value for job-finding rate of 0.45 that applies in the absence of labor shortages (when the system approaches the steady state), implying $\phi = 1.01$.[26]

To study the transition dynamics towards the equilibrium, we need to calibrate the initial levels of unemployment and labor shortage (u_1 and Δ_1, respectively). The unemployment rate surged to 15% in April 2020, compared to 4% in March 2020. The employment share in the Leisure and Hospitality sector recorded a steady increase in the early part of the same sample period, peaking at 10.7% in March 2020 before dropping to 6.7% in April 2020 due to the COVID-19 pandemic (see Figure A.6 in Appendix A.7). We set the beginning period of our simulation to April 2020, and consequently set the initial values at $u_1 = 0.15$ and $\Delta_1 = 1 - 0.067/0.107 = 0.37$.

We set the immigration intensity parameter ψ to 0.18, implying that the cumulative inflow of immigrants along the transition path toward the no-shortage steady state is equal to approximately 50% of the initial labor shortfall, consistent with the data.[27]

Transition dynamics in the benchmark model. Our calibration implies that the economy begins with exceptionally high unemployment and labor shortages, as observed around March 2020, since $u_1 = 0.15$ and $\Delta_1 = 0.37$. Aside from the initial deviation from the zero-shortage steady state, the system is free of exogenous shocks, and its transitional dynamics evolve endogenously according to the equations in the model, ultimately converging to the no-shortage steady state.

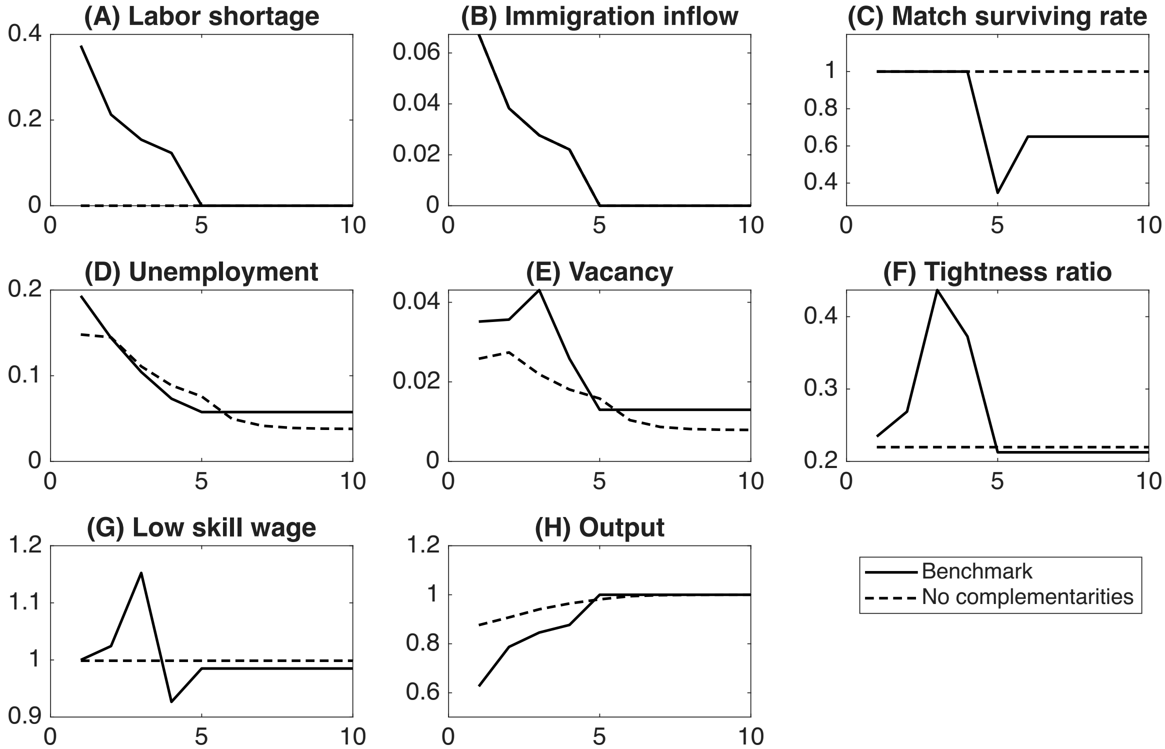
Figure 4 shows the transition dynamics, taking the variables in the system from the initial equilibrium with significant labor shortages to the steady-state equilibrium where labor shortages are resolved. The solid line shows the transition dynamics for the variables in our benchmark model, while the dashed line shows the transition dynamics for a counterfactual version of our model that nests the standard DMP model without labor shortages and complementarities (described below).

The initial surge in labor shortages (Panel A) triggers a rise in immigration inflows (Panel B). The initial shortage of labor implies that the match survival rate is equal to one (Panel C), while also increasing the pool of unemployed low-skilled workers, as it takes one period for new

[26] The object mapping to the job-finding rate in the data is the effective job-finding probability $p_t \mu_t(\theta_t)$ rather than $\mu_t(\theta_t)$ alone.

[27] The initial labor shortage across the Mining, Leisure and Hospitality, and other services sectors is estimated at 9.7 million workers, while the cumulative inflow of irregular immigrants is approximately 4.9 million, representing about 50% of the initial shortage.

Figure 4: Transition dynamics with initial labor shortage and endogenous immigration inflow



Notes: The figure shows the transition dynamics for labor shortage (Panel A), low skill immigration inflow (Panel B), match survival rate (Panel C), unemployment (Panel D), vacancy (Panel E), tightness ratio (Panel F), low skill wage (Panel G), and output (Panel H). Solid and dashed lines represent simulations from the benchmark model and from the standard DMP model without labor shortages or complementarities.

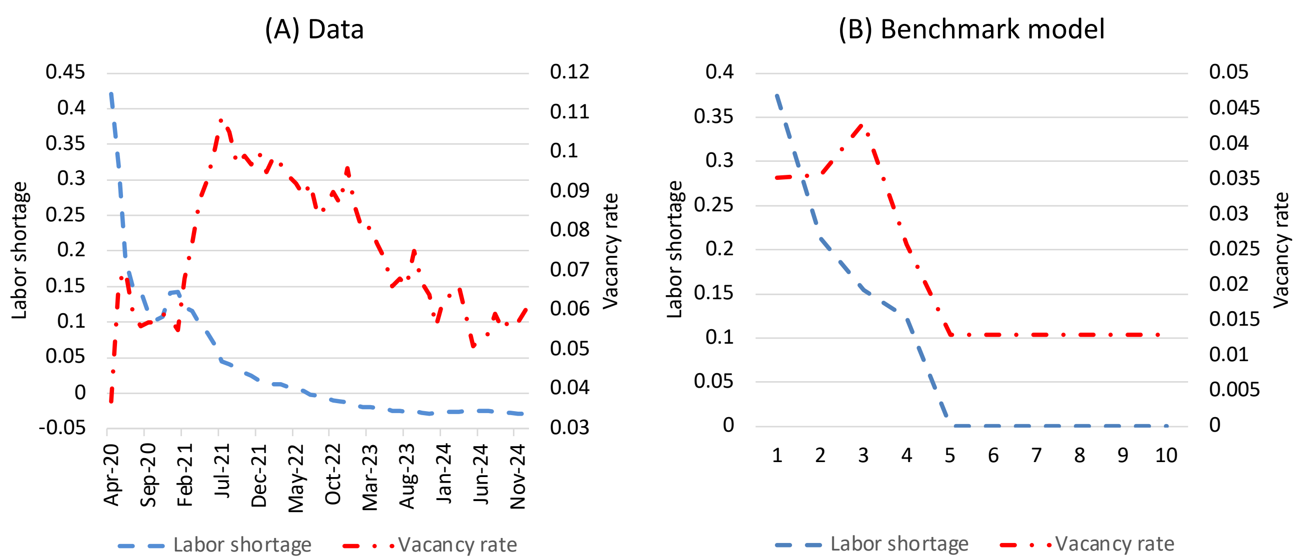
entrants to engage in the job market (Panel D). Firms respond to the labor shortage and the large immigration inflow by posting vacancies on impact (Panel E), and the resulting increase in labor market tightness (Panel F) raises wages in the first two periods (Panel G). Output expands (Panel H) in response to the increase in the inflows of low-skill workers and the ensuing pick-up in vacancy posting.

From the second period onward, the economy starts converging to the no-shortage steady state. The initial increase in vacancy postings decreases labor shortages, thereby curtailing the immigration inflow and decreasing unemployment for low-skilled workers. Labor shortages are resolved in period 5. Robust vacancy posting slows sharply in period 3. As labor shortages approach resolution, the match survival rate falls as fewer low-skilled workers are needed to alleviate labor shortages, discouraging firms from posting vacancies, so that vacancy posting remains positive but declines substantially after period 3 to reach the steady-state equilibrium in period 5.

The wage for the low-skilled workers raises in the first two periods, but it then fall afterwards, consequent to the resolution of labor shortages. Wages increase initially in response to the rise in labor market tightness, resulting from the growth rate of vacancy posting outpacing unemployment, thereby strengthening the outside option value for unemployed workers that leads the firm to increase the wage. However, wages decline subsequently as the labor shortage is expected to resolve, which in turn reduces total surplus and lowers workers' wages.

Unemployment and vacancies move in opposite directions in the first two periods of the transition dynamics as the labor shortage nears resolution, consistent with the empirical evidence in Section 2. Such response is driven by the *endogenous* reduction in the job value with the resolution of labor shortages, which induces the firm to decrease vacancy posting despite the increased unemployment of low-skilled workers. Central to our results, as we will show below, these equilibrium forces are absent in the standard DMP model that abstracts from labor shortages and complementarities. Output steadily increases until reaching the higher steady-state level associated with the permanent resolution of labor shortages.

Figure 5: Labor shortage and vacancy in Leisure & Hospitality sector



Notes: This figure compares the joint dynamics of labor shortages and vacancy postings as observed in the data (Panel A) and as generated by the benchmark model (Panel B).

Central to the analysis, our stylized model replicates the observed labor market dynamics, as documented in Facts 1-3 of Section 2. To facilitate comparison between the data and our model, Figure 5 shows the evolution of labor shortages and the vacancy rate for the Leisure and Hospitality sector in the data from April 2020 through December 2024 (Panel A) and in simulations from our benchmark model (Panel B). Consistent with the dynamics in the data, our model replicates the steady decline of labor shortages and the initial surge in vacancy posting followed by the gradual decline.[28]

Counterfactual analysis with no complementarities. In this part of the analysis, we focus on the transition dynamics in the standard DMP model, obtained as a special case of our model where the low-skilled and high-skilled sectors are substitutable and there are no labor shortages.

Formally, we assume that final output is determined by the linear production function $Y_t = z_t(N_t^L + N^H)/2$. Since the survival rate of new matches is no longer bounded by labor shortage, it yields $p_t = 1$, and equations defining labor market tightness (obtained by using $\theta_t = v_t/u_t$ in equation 10) and the total surplus (the corresponding equation to 16) become:

$$\theta_t = \left[\frac{\phi\beta(1-\tau)E_t(TS_{t+1})}{\kappa}\right]^{\frac{1}{1-\alpha}} \tag{17}$$

and

$$TS_t = z_t - h + \beta\left(1-\delta\right)E_t\left(TS_{t+1}\right), \tag{18}$$

respectively. Since the simulation is free of exogenous shocks, $z_t = 1$ for all periods t. It is straightforward to verify from equations (17) and (18) that θ_t and TS_t are constants and *independent* from the levels of unemployment and immigration. This is a standard property of the canonical DMP model: labor market tightness and job value depend uniquely on labor productivity in equilibrium.

To make the projections of our benchmark model comparable with those of the nested DMP model, we assume that immigration to the low-skilled sector follows the same path as in the benchmark model, such that:

$$u_{t+1} = (1-\mu_t)u_t + \delta N_t^L + \bar{im}_t, \tag{19}$$

where $\bar{im}_t$ is the immigration level determined by our benchmark model that serves as the

[28]Appendix A.5 provides further validation. Figure A.2 shows that the Mining and Other Services sectors, which also experienced severe labor shortages post-pandemic, exhibit joint dynamics of shortages and vacancy postings that are qualitatively similar to both the Leisure and Hospitality sector and our model simulation.

exogenous labor supply shock in the nested DMP model. The dashed line in Figure 4 shows the transition dynamics of the variables in the nested DMP model. By construction, in the nested DMP model there are no labor shortages, and immigration of low-skilled workers is the same as in the benchmark model. In the canonical model, volatile changes in labor supply have zero impact in labor market tightness and wages. The responses of unemployment and vacancies are perfectly proportional to each others, generating a strong positive correlation between these variables. Wages in the low-skilled sector remain constant in the nested DMP model, as they are governed by the labor market tightness ratio, which itself remains unchanged with the proportional increase in vacancies and unemployment during the transition dynamics. Finally, output converges to the unitary value of productivity, while employment in the low-skilled sector reaches the steady state.

Exogenous immigration inflow. The previous analysis assumes that immigration inflow is endogenously driven by labor shortages. As labor shortages are resolved, immigration inflow declines accordingly. We now consider an alternative scenario in which immigration inflows increase exogenously from a given period onward, capturing a sudden policy change such as that implemented by the Biden administration in 2021. This exercise demonstrates how an exogenous immigration surge generates different impulse responses in the two models.

Specifically, we assume immigration follows:

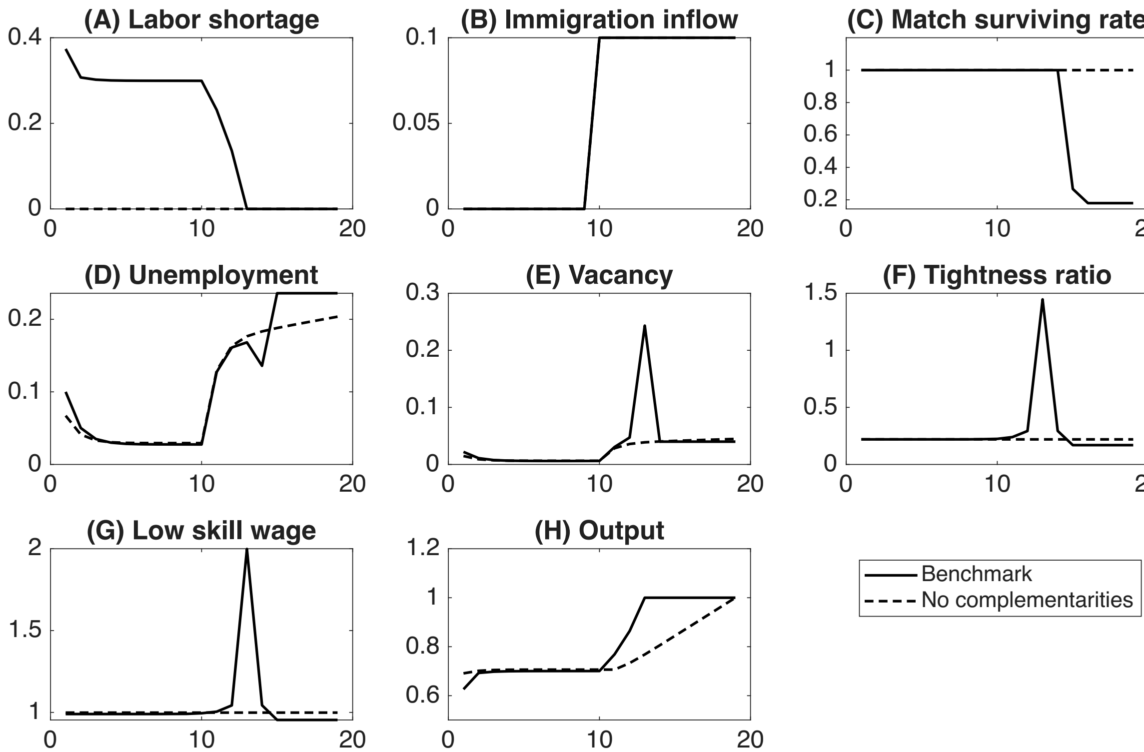
$$im_t = \begin{cases} 0 & \text{for } t < 10, \\ \bar{im} & \text{for } t \geq 10, \end{cases} \tag{20}$$

with $\bar{im} = 0.1$. Figure 6 plots the transition dynamics under this exogenous shock. Solid curves represent the benchmark model with complementarities, while dashed curves represent the counterfactual model without complementarities.

Notably, as shown in Panel (E), the exogenous immigration increase at $t = 10$ generates an initial rise followed by a subsequent drop in vacancies in our benchmark model. This pattern reflects the resolution of labor shortages: immigration initially alleviates bottlenecks, stimulating vacancy posting, but as shortages ease, the marginal value of additional matches declines, reducing vacancy creation.

In contrast, the counterfactual model without complementarities predicts a steady increase

Figure 6: Transition dynamics with an exogenous increase in immigration



Notes: Solid and dashed lines represent simulations from the benchmark model and from the standard DMP model without labor shortages or complementarities.

in vacancies. Intuitively, higher immigration raises unemployment, which lowers hiring costs and encourages firms to post more vacancies persistently, a prediction at odds with the empirical evidence.

Consistent with the endogenous immigration case, the benchmark model also produces a steady decline in labor shortage, an initial increase followed by a decline in the tightness ratio and low-skill wages (Panels F and G). The counterfactual model, by contrast, shows no change in these variables, and is unable to capture the cyclical interplay between labor shortage and labor market tightness documented in the data.

4 Conclusion

Since 2019, labor immigration has been the main driver of U.S. labor force growth. We show three new empirical findings that highlight the cyclical interplay between immigration, labor shortages, wage growth, and job openings during the high-immigration period from 2020 to 2024. The acute labor shortages and wage pressures that emerged in 2020 were concentrated in sectors reliant on low-skilled immigrant labor. The subsequent immigration surge served as a strong equilibrating force, easing labor shortages and decreasing both vacancy postings and wage growth.

The textbook search-and-matching model of the labor market yields counterfactual predictions in this context: immigration-driven increases in labor supply are fully offset by a proportional rise in job vacancies, as the abundance of workers reduces hiring costs, leaving labor market tightness and wages unchanged. To reconcile theory with evidence, we extend the textbook model with skill segmentation (natives in high-skill work, immigrants in low-skill services) and Leontief complementarity between the two groups. This complementarity makes low-skill workers essential for production. A shortage of these workers creates a bottleneck, increasing their job value and prompting firms to post more vacancies and raise wages. Immigration, by expanding this essential labor supply, directly alleviates the bottleneck.

Our research highlights that immigration is not a slow-moving phenomenon tied to demographic and social trends, but rather a powerful cyclical driver of labor supply and an equilibrating mechanism that helps resolve labor shortages. The interplay between immigration, sectoral shortages, and skill complementarities is a key mechanism for labor market stabilization. Future research should integrate these distinct forces into business cycle models that account for cyclical changes in labor supply. Our framework could also be extended to link immigration to inflation dynamics.[29] Moreover, our model deliberately isolates the labor-supply channel driven by complementarities. Immigration can simultaneously influence aggregate and sectoral demand, as newly arrived workers consume local goods and services, potentially raising labor demand in some sectors. These demand effects would work in the opposite direction of the bottleneck mechanism we emphasize, creating two offsetting forces whose net outcome depends on sectoral exposure to complementarities, immigrants' consumption patterns, and the degree of price and wage flexibility. We plan to pursue these extensions in future research.

[29] Thomas and Zanetti (2009), Ravenna and Walsh (2011), Zanetti (2011), and Christiano et al. (2021) embed search and matching in labor markets into models with nominal rigidities in goods markets, allowing for the joint study of labor and inflation dynamics. Extending this framework to incorporate immigration and labor shortages would be a valuable avenue for future research.

References

Atalay, E. (2017). How important are sectoral shocks? *American Economic Journal: Macroeconomics 9*(4), 254–280.

Bai, X., J. Fernández-Villaverde, Y. Li, and F. Zanetti (2026a). The causal effects of global supply chain disruptions on macroeconomic outcomes: Evidence and theory. *American Economic Review*. Forthcoming.

Bai, X., J. Fernández-Villaverde, Y. Li, and F. Zanetti (2026b). State dependence of monetary policy during global supply chain disruptions. Discussion paper, University of Oxford.

Baqaee, D. R. and E. Farhi (2019). The macroeconomic impact of microeconomic shocks: Beyond hulten's theorem. *Econometrica 87*(4), 1155–1203.

Bils, M., Y. Chang, and S.-B. Kim (2012). Comparative advantage and unemployment. *Journal of Monetary Economics 59*(2), 150–165.

Boehm, C. E., A. Flaaen, and N. Pandalai-Nayar (2019). Input linkages and the transmission of shocks: Firm-level evidence from the 2011 tohoku earthquake. *The Review of Economics and Statistics 101*(1), 60–75.

Cadena, B. C. and B. K. Kovak (2016). Immigrants equilibrate local labor markets: Evidence from the great recession. *American Economic Journal: Macroeconomics 8*(1), 257–290.

Chapuis, B., S. Murray, and B. Price (2023). The persistent urban shortfall in leisure and hospitality employment. *FEDS Notes*.

Chassamboulli, A. and T. Palivos (2014). A search-equilibrium approach to the effects of immigration on labor market outcomes. *International Economic Review 55*(1), 111–129.

Cheremukhin, A. A., S. Hur, R. Mau, K. Mertens, A. W. Richter, and X. Zhou (2024). The postpandemic u.s. immigration surge: New facts and inflationary implications. Working Papers 2407, Federal Reserve Bank of Dallas.

Christiano, L. J., M. Trabandt, and K. Walentin (2021). Unemployment and business cycles: A new keynesian perspective. *American Economic Journal: Macroeconomics 13*(2), 1–44.

Ciccone, A. and G. Peri (2005). Long-run substitutability between more and less educated workers: Evidence from U.S. states, 1950–1990. *Review of Economics and Statistics 87*(4), 652–663.

Cohen, E. (2024). Rising immigration has helped cool an overheated labor market. *Economic Bulletin*, 1–4.

Cohen, E. and S. dup Shampine (2022). Immigration shortfall may be a headwind for labor supply. *Economic Bulletin None*(May 11, 2), 1–4.

Congressional Budget Office (2024). The demographic outlook: 2024 to 2054. Report, Congressional Budget Office.

Davis, S. J., R. J. Faberman, and J. Haltiwanger (2012). Recruiting intensity during and after the great recession: National and industry evidence. *American Economic Review 102*(3), 584–588.

Farhi, E. and D. R. Baqaee (2020). Nonlinear production networks with an application to the covid-19 crisis. CEPR Discussion Papers 14742, C.E.P.R. Discussion Papers.

Fernández-Villaverde, J., F. Mandelman, Y. Yu, and F. Zanetti (2021). The "Matthew effect" and market concentration: Search complementarities and monopsony power. *Journal of Monetary Economics 121*, 62–90.

Fernández-Villaverde, J., F. Mandelman, Y. Yu, and F. Zanetti (2025). Search Complementarities, Aggregate Fluctuations, and Fiscal Policy. *Review of Economic Studies 92*(4), 2502–2536.

Fernández-Villaverde, J., Y. Yu, and F. Zanetti (2024). Technological Synergies, Heterogeneous Firms, and Uncertainty Shocks. Working Paper 32247, National Bureau of Economic Research.

Fernández-Villaverde, J., Y. Yu, and F. Zanetti (2025). Defensive hiring and creative destruction. Working Paper 33588, National Bureau of Economic Research.

Fujita, S. and G. Ramey (2012). Exogenous versus endogenous separation. *American Economic Journal: Macroeconomics 4*(4), 68–93.

Furlanetto, F. and Ø. Robstad (2019). Immigration and the macroeconomy: Some new empirical evidence. *Review of Economic Dynamics 34*, 1–19.

Ghassibe, M. and F. Zanetti (2022). State dependence of fiscal multipliers: The source of fluctuations matters. *Journal of Monetary Economics 132*, 1–23.

Hanson, G., C. Liu, and C. McIntosh (2017). The rise and fall of u.s. low-skilled immigration. Working Paper 23753, National Bureau of Economic Research.

Hauser, D. and M. Seneca (2022). Labor mobility in a monetary union. *Journal of International Economics 137*(C), None.

Katz, L. F. and K. M. Murphy (1992). Changes in relative wages, 1963–1987: Supply and demand factors. *Quarterly Journal of Economics 107*(1), 35–78.

Mandelman, F. S., Y. Yu, F. Zanetti, and A. Zlate (2024). Slowdown in immigration, labor shortages, and declining skill premia. Discussion Paper DP19212, CEPR.

Mandelman, F. S. and A. Zlate (2022). Offshoring, automation, low-skilled immigration, and labor market polarization. *American Economic Journal: Macroeconomics 14*(1).

Michaillat, P. (2012). Do matching frictions explain unemployment? not in bad times. *American Economic Review 102*(4), 1721–1750.

Michaillat, P. (2024). Modeling migration-induced unemployment.

Michaillat, P. and E. Saez (2015). Aggregate demand, idle time, and unemployment. *Quarterly Journal of Economics 130*(2), 507–569.

Michaillat, P. and E. Saez (2022). $u* = \sqrt{uv}$. Technical report, U.C. Santa Cruz.

Parker, K. and J. M. Horowitz (2022). Majority of workers who quit a job in 2021 cite low pay, no opportunities for advancement, feeling disrespected. Pew Research Center Short Reads.

Pissarides, C. A. (2000). *Equilibrium Unemployment Theory* (2nd ed.). Cambridge, MA: MIT Press.

Platonov, K. (2023). Post-pandemic recovery: Search and matching, labor productivity, and coordination effects.

Ravenna, F. and C. E. Walsh (2011). Welfare-based optimal monetary policy with unemployment and sticky prices: A linear-quadratic framework. *American Economic Journal: Macroeconomics 3*(2), 130–162.

Shimer, R. (2005). The cyclical behavior of equilibrium unemployment and vacancies. *American economic review 95*(1), 25–49.

Thomas, C. and F. Zanetti (2009). Labor market reform and price stability: An application to the Euro Area. *Journal of Monetary Economics 56*(6), 885–899.

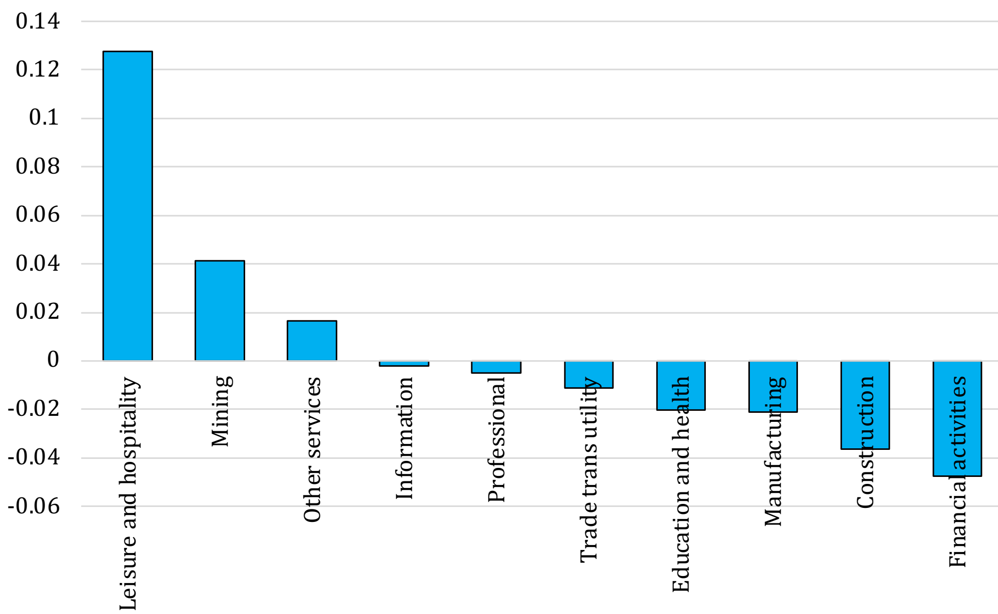
Zanetti, F. (2011). Labor market institutions and aggregate fluctuations in a search and matching model. *European Economic Review 55*(5), 644–658.

Online Appendix

A Additional Figures and Tables

A.1 Sectoral labor shortages in 2020

Figure A.1: Sectoral labor shortages in 2020



Notes: Labor shortages using $\Delta_t^i = -\widehat{s}_t^i$ obtained from one-digit NAICS private industries for the period 2020-2025.

Our core hypothesis is that labor shortages in specific sectors prior to the 2022 high-inflation episode partially explain the sharp rise in vacancies and wages in those sectors. To quantify these shortages, we calculate the average labor shortage for the year 2020 as: $\overline{\Delta}^i = \sum_{t\in[Jan20,Dec20]} \Delta_t^i/12$. Figure A.1 illustrates the average sectoral labor shortages in 2020. In particular, the sectors with the most notable shortages during this period are Leisure and Hospitality, Mining, and Other Services. As we will show, these sectors have had the highest vacancy rates and wage increases since 2020.

A.2 Labor shortages and vacancy growth

To formally investigate the dynamic relationship between labor shortages and vacancy growth across industries, we estimate the following predictive regression:

$$\Delta v^i_{t+k} = \alpha + \beta \Delta^i_t + \gamma^i + \chi_t + \epsilon^i_t, \tag{A-1}$$

where Δv^i_{t+k} represents the rate of change in sector i's vacancy rate from a year ago in period $t+k$, and Δ^i_t denotes sector i's labor shortage in period t. γ^i and χ_t denote the sector and time fixed effects, respectively. Data is monthly from January 2020 to December 2024.

Table A.1 presents the estimation results for $k = 0$ (current period), 1 (one month ahead), 6 (six months ahead), 12 (one year ahead), and 18 (one and a half years ahead). The findings show that labor shortages are positively linked to vacancy growth during the same period and are strong predictors of vacancy growth in the following periods up to one year ahead. For instance, a 1% increase in labor shortages (reflected as a 1% decline in the employment share) relative to the long-term trend predicts a 1.71% rise in the vacancy growth rate in the following year, which is economically significant.

Table A.1: Labor shortages and vacancy growth

	(1)	(2)	(3)	(4)	(5)
Dependent variable	Vacancy growth (t+k)				
k	0	1	6	12	18
Shortage (t)	1.28***	1.71***	1.62***	1.27***	0.17
	(0.27)	(0.27)	(0.28)	(0.31)	(0.30)
Industry FE	Yes	Yes	Yes	Yes	Yes
Time FE	Yes	Yes	Yes	Yes	Yes
Adj R^2	0.64	0.66	0.65	0.66	0.51
Observations	600	590	540	480	420

Notes: *p<0.10, **p<0.05, ***p<0.01

A.3 Labor shortages and wage growth

To formally analyze the dynamic relationship between labor shortages and wage growth across industries, using monthly wage growth data from January 2021 to December 2024, we estimate the following predictive regression:

$$\Delta w_t^i = \alpha + \beta \overline{\Delta}^i + \gamma^i + \epsilon_t^i, \tag{A-2}$$

where Δw_t^i represents the nominal wage growth rate for sector i compared to a year earlier, while $\overline{\Delta}^i$ denotes sector i's average labor shortage in 2020-a period marked by severe labor shortages that preceded the subsequent surge in inflation. It is important to note that the average labor shortage $\overline{\Delta}^i$ is used as the independent variable instead of the monthly labor shortage Δ_t^i because the dynamic relationship between wage growth and Δ_t^i is unstable. Due to staggered wage-setting mechanisms, wage growth does not consistently correlate with vacancy rates or labor shortages in the short term run.[30] Therefore, we examine how the average labor shortage in 2020 forecasts wage growth during periods of high inflation. χ_t represents the time fixed effects. Sector fixed effects are excluded from the regression because the key independent variable, $\overline{\Delta}^i$, remains constant over time.

Table A.2 shows the estimated results for wage growth across three different sample periods: January 2021-December 2021, which is the year after the 2020 base period as shown in Figure 3; January 2021-June 2022, capturing the period of increased inflation; and January 2021-December 2024, covering both the inflation spike and the cooling phase that followed.

The findings indicate that labor shortages in 2020 were a strong predictor of wage growth in later periods, with the most notable effects seen during the high-inflation period from January 2021 to June 2022. Specifically, a 1% increase in average labor shortages-equivalent to a 1% decline in the average employment share compared to the long-term trend-is linked to a 0.17% rise in the wage growth rate.

A.4 Immigration and vacancy growth

Formally, we estimate the following regression:

$$\Delta v^i = \alpha + \beta imm^i + \epsilon^i, \tag{A-3}$$

[30]With flexible wage, wage should positively comove with vacancy rate, as higher vacancy rate improves workers' bargaining position.

Table A.2: Labor shortages and wage growth

	(1)	(2)	(3)
Dependent variable		Wage growth	
Sample period	Jan 2021-Dec 2021	Jan 2021-Jun 2022	Jan 2021-Dec 2024
Average shortage in 2020	0.10**	0.17***	0.09***
	(0.05)	(0.04)	(0.02)
Time FE	Yes	Yes	Yes
Adj R^2	0.09	0.16	0.11
Observations	120	180	480

Notes: * $p<0.10$, ** $p<0.05$, *** $p<0.01$

where Δv^i represents the rate of change in sector i's vacancy rate between January 2022 and December 2023, and imm^i denotes sector i's change in foreign-born employment between January 2021 and January 2022. The results are shown in Table A.3, immigration inflow is negatively and significantly correlated with vacancy growth.

Table A.3: Immigration inflow and vacancy growth

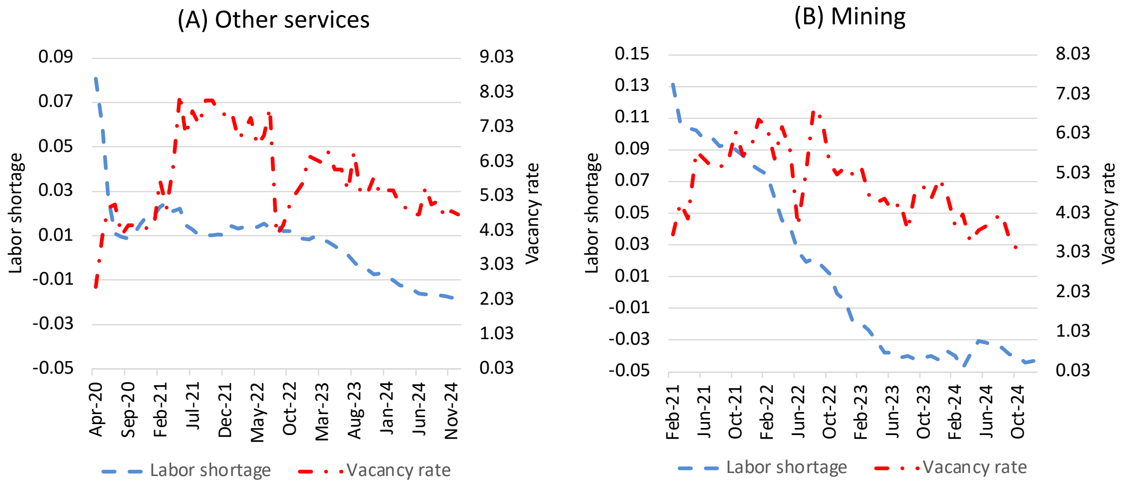
Dependent variable	Vacancy growth
Immigration net inflow	-0.74*
	(0.37)
Adj R^2	0.24
Observations	10

Notes: * $p<0.10$, ** $p<0.05$, *** $p<0.01$.

A.5 Labor shortage and vacancy rate in the Mining and Other services sectors

Figure A.2 shows the joint dynamics of labor shortages (dashed line) and vacancy postings (dash-dotted line) in the Mining and Other Services sectors.

Figure A.2: Labor shortage and vacancy rate in the Mining and Other services sectors

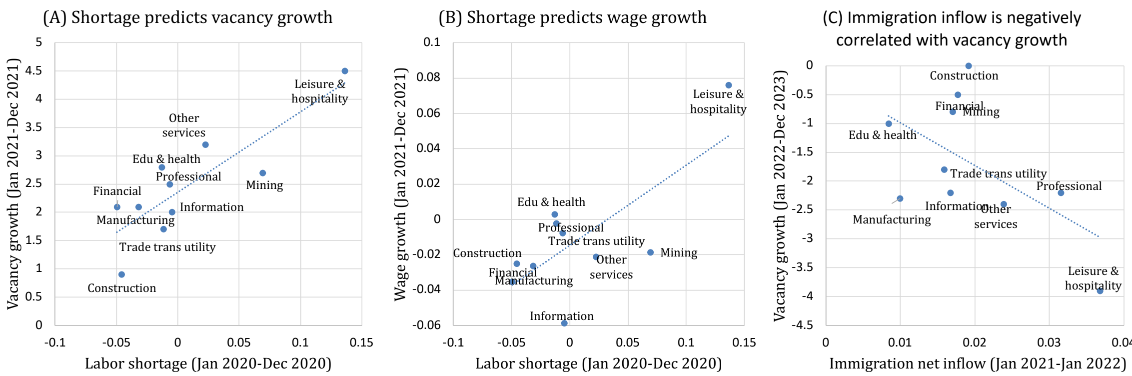


Note: This figure shows the joint dynamics of labor shortages and vacancy postings in the Mining and Other Services sectors.

A.6 Different filtering methods

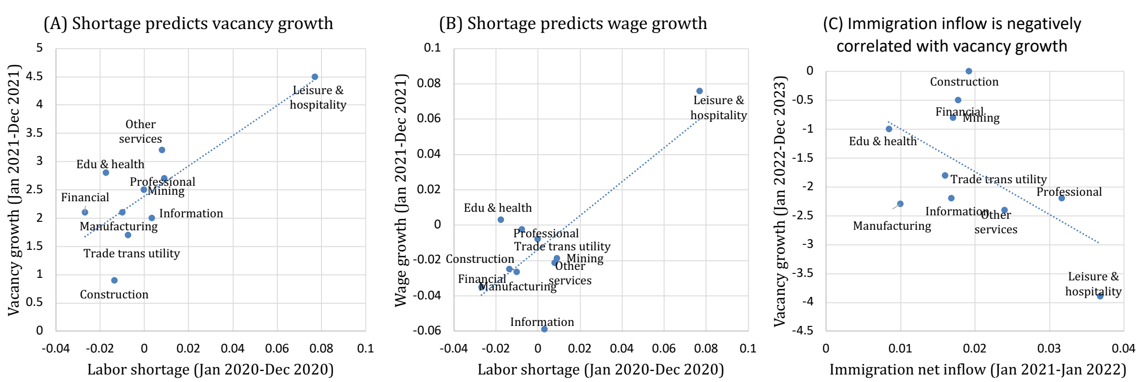
Figures A.3–A.5 show the relationships among labor shortages, vacancy growth, and wage growth when the labor shortage series is filtered using (1) an HP filter with $\lambda = 10^7$, (2) an HP filter with $\lambda = 14{,}400$, and (3) a 10-year moving average.

Figure A.3: HP filter with a smoothing parameter of 10^7



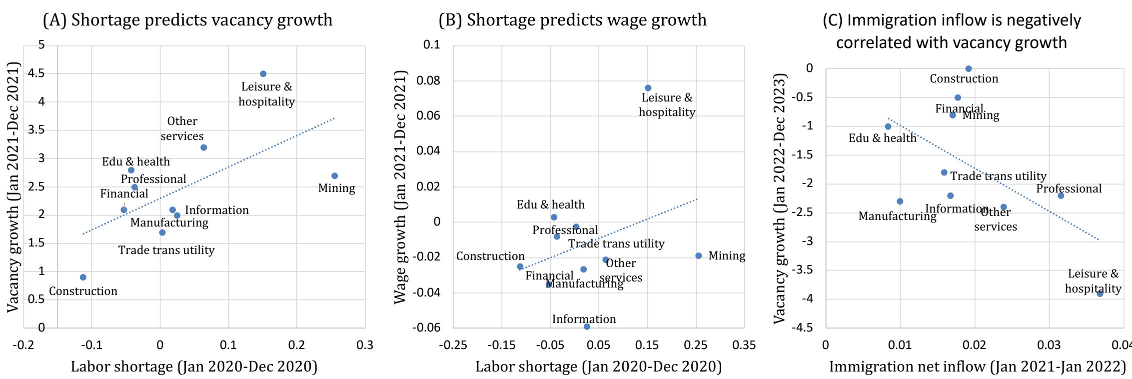
Note: This figure shows the results when the employment share is filtered with an HP with a smoothing parameter of 10^7.

Figure A.4: HP filter with a smoothing parameter of 14400



Note: This figure shows the results when the employment share is filtered with an HP with a smoothing parameter of 14400.

Figure A.5: Trend estimated with 10-year moving average

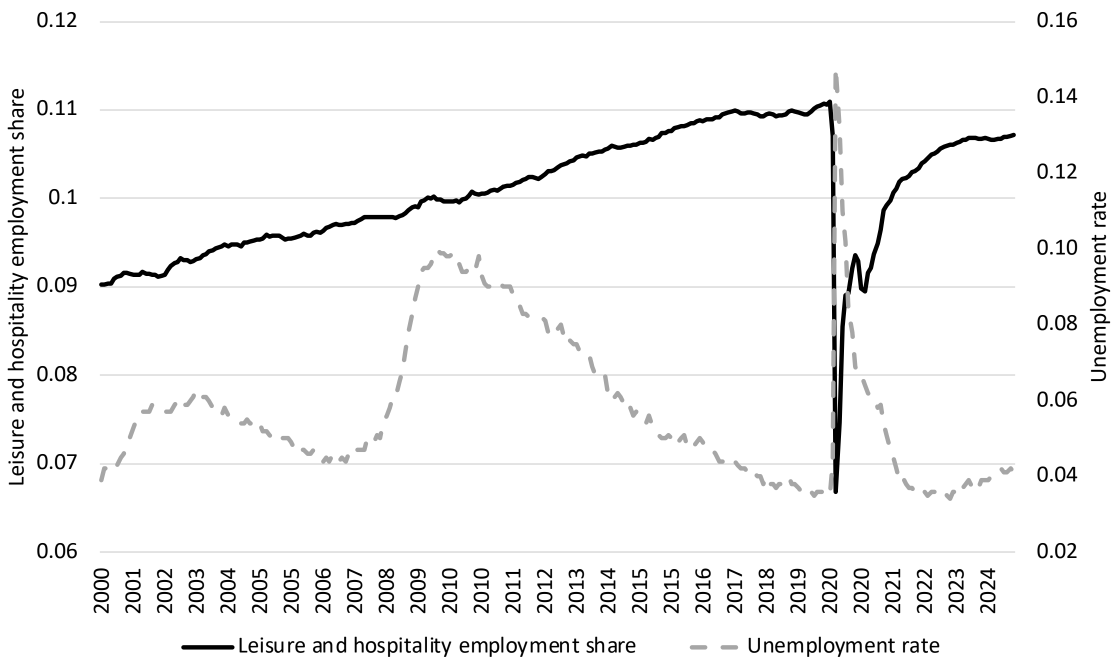


Note: This figure shows the results when the trend of log employment share is estimated with 10-year moving average.

A.7 Employment share in the Leisure & Hospitality sector

Figure A.6 shows the share of employment in the Leisure and Hospitality sector compared to total non-farm employment (solid line) and the non-farm unemployment rate (dashed line).

Figure A.6: Employment share of Leisure and Hospitality and unemployment rate



Source: Current Employment Statistics (Establishment Survey).

B Immigration in the Standard DMP Model

In this Appendix, we clarify why the canonical Diamond-Mortensen-Pissarides (DMP) model—the workhorse framework for studying labor market dynamics—cannot rationalize our empirical findings, particularly Fact 3's negative correlation between immigration and vacancy growth.

In the standard DMP model (e.g., Pissarides, 2000), consider an exogenous increase in labor supply due to immigration. Newly arrived immigrants enter the pool of unemployed workers searching for jobs. This increase in unemployment has two key effects. First, it raises the number of matches through the matching function $m_t = \phi v_t^{\alpha} u_t^{1-\alpha}$, where v_t denotes vacancies and u_t unemployment. Second, and crucially, it reduces the cost of hiring for firms: with more unemployed workers available, each posted vacancy is filled more quickly. The vacancy-filling rate $f_t(\theta_t) = \phi\theta_t^{\alpha-1}$ increases as the tightness ratio $\theta_t = v_t/u_t$ falls, while the job-finding rate $\mu_t(\theta_t) = \phi\theta_t^{\alpha}$ decreases.

The free-entry condition for vacancy posting equates the cost of posting a vacancy to its expected benefit:

$$\frac{\kappa}{f_t(\theta_t)} = \beta E_t(J_{t+1}), \tag{A-4}$$

where κ is the vacancy posting cost, β the discount factor, and J_t the firm's value of a filled job. The value of a filled job is determined by:

$$J_t = z_t - w_t + \beta(1-\delta)E_t(J_{t+1}), \tag{A-5}$$

where z_t is labor productivity, w_t the wage, and δ the job separation rate.

Under Nash bargaining with worker bargaining share τ, the total surplus of a match $TS_t = W_t - U_t + J_t$ (where W_t is the value of employment and U_t the value of unemployment) satisfies:

$$TS_t = z_t - h + \beta(1 - \mu_t(\theta_t)\tau - \delta)E_t(TS_{t+1}), \tag{A-6}$$

where h is the flow value of home production. Combining the free-entry condition with the Nash bargaining solution $J_t = (1-\tau)TS_t$ yields:

$$\theta_t = \left[\frac{\phi\beta(1-\tau)E_t(TS_{t+1})}{\kappa}\right]^{\frac{1}{1-\alpha}}. \tag{A-7}$$

In the absence of exogenous shocks to productivity z_t, the total surplus TS_t and hence the tightness ratio θ_t are constants, *independent of the unemployment level* u_t. This implies that vacancies satisfy $v_t = \theta_t u_t$—vacancies are proportional to unemployment.

The model therefore predicts that an immigration shock, which increases u_t, generates a proportional increase in vacancy posting v_t, leaving labor market tightness $\theta_t = v_t/u_t$ and wages unchanged. This produces a *positive* correlation between immigration (which increases unemployment) and vacancy posting—directly contradicting Fact 3, which documents a strong *negative* correlation between immigration inflows and vacancy growth during 2021-2024.

The root of this counterfactual prediction lies in the standard model's assumption that job values depend solely on labor productivity z_t and the discount factor β, but are invariant to labor market slack. There is no mechanism through which labor scarcity—or its resolution through immigration—can affect firms' valuation of jobs. Immigration simply shifts both unemployment and vacancies proportionally along a constant-tightness ray, leaving wages and the vacancy-unemployment ratio unchanged.

Our model introduces a fundamentally different mechanism by incorporating complementarities between high-skilled (native) and low-skilled (immigrant) workers through a Leontief production function. This creates labor shortages when low-skilled workers are scarce, which *increases the value of low-skill jobs*—firms value these jobs more highly precisely because low-skilled workers are bottlenecks in production. Immigration alleviates these shortages, reducing job values and dampening vacancy posting, consistent with Fact 3. The key innovation is captured in our match survival rate p_t (equation 9), which makes the expected value of a job endogenous to the degree of labor shortage. We now turn to the formal development of this framework.

C Zero-shortage steady state

Once the labor shortage is fully resolved, the low-skilled sector reaches a no-shortage steady state, which is affected by the unemployment that accumulated during the shortage period, denoted by u^*. In this zero-shortage steady state, the employment level in the low-skilled sector is fixed as

$$N^{L*} = N^H. \tag{A-8}$$

The rates of job creation and job separation are both constant and equal:

$$p^* u^* \mu(\theta^*) = \delta N^L, \tag{A-9}$$

where the left-hand side indicates the count of surviving matches, while the right-hand side indicates job separations. Note that the count of newly formed matches is "excessive," resulting in a positive probability of match dissolution and $p^* < 1$. This is due to the larger labor force in the low-skilled sector compared to the high-skilled sector, which results from immigration inflows into the former during transitional periods.

The condition for free entry in the zero-shortage steady state can be derived as:

$$\theta^* = \frac{\beta \delta N^H J^*}{\kappa u^*}, \tag{A-10}$$

which corresponds to the second case of the free entry condition equation (10), with $\widetilde{\Delta} = \delta N^H$.

The Bellman equation for the job value for firms is:

$$J^* = \frac{(1-\tau)(z-h)}{1-\beta(1-p^*\mu(\theta^*)\tau - \delta)}, \tag{A-11}$$

which corresponds to the Bellman equation (16).

Given u^*, the steady-state levels of N^{L*}, J^*, p^*, and θ^* are jointly determined by equations (A-8)-(A-11).

D Model solution

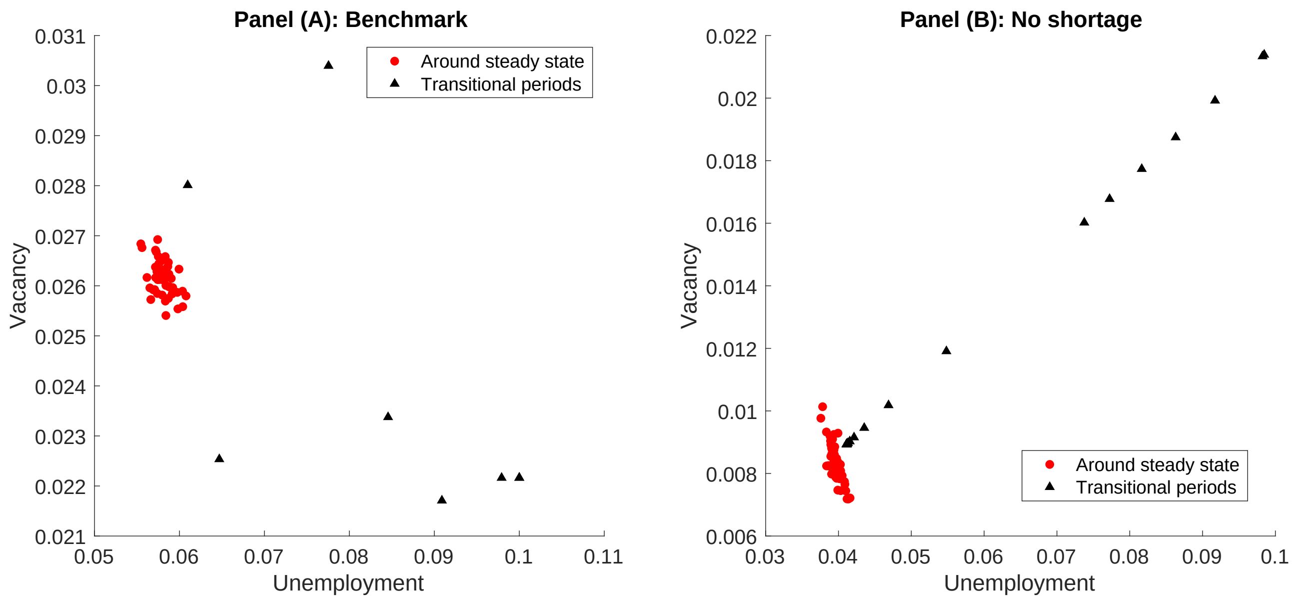
The model is nonlinear and solved numerically. The key unknowns to determine are the time when the labor shortage is fully resolved, called T, the probability that a new match stays intact throughout this period, called p_T, the series of job-finding rates before this period, represented as $\{\mu_t\}_{1\leq t\leq T}$, and the unemployment rate in the zero-shortage steady state, denoted by u^*. All other variables can be determined from these unknowns.

To solve for these parameters, we initially set T, which is 50 in our exercise, but any positive integer can be selected. For this initial value, the system is assumed to stay in its zero-shortage steady state beyond T. We also set an initial value for u^*, which is 0.05 in our exercise. Equations (A-9)-(A-11) then determine J^*, p^*, and θ^*.

Next, we initialize p_T along with the series $\{\mu_t\}_{1\leq t\leq T}$. Using these initial values, the series $\{J_t\}_{1\leq t\leq T}$ is computed via equation (16). Based on the trajectory of J_t, we simulate the corresponding series for u_t, v_t, and Δ_t. The updated Δ_t is then used to refine T and p_T. With the new values of T, p_T, and u^*, iterations continue until the model converges.

E Beveridge curve

Figure E.7: Beveridge curves, model



Notes: Beveridge curve in the benchmark model (Panel A) and the counterfactual model with no labor shortage (Panel B).

To examine the effects of labor shortages and immigration on the combined dynamics of vacancies and unemployment, Figure E.7 shows the model-implied Beveridge curves for two scenarios. Panel A displays the results for the standard model with moderate immigration levels, while Panel B presents the counterfactual model without inter-sectoral complementarities and labor shortages.

In Panel A, the black triangles show the simulated vacancies versus unemployment from period 1 to period $T^* + 1$, where T^* is the time when the labor shortage ends. To highlight the unique endogenous joint dynamics of vacancies and unemployment during labor shortage periods, we also simulate the model around the zero-shortage steady state using discount factor shocks: $\beta_t = \beta\xi_t$.[31] Following Fernández-Villaverde et al. (2025), We calibrate the discount factor shock using the Livingston Survey, which provides the median 12-month-ahead expected return r_t of the stock market index. The discount factor is computed as $\xi_t = 1/(1 + r_t)$. The

[31] Alternatively, we could simulate the model using productivity shocks. However, given a realistic calibration of the shock process, the impact of productivity shocks on vacancies and unemployment is relatively limited. See Shimer (2005) for a discussion

monthly AR(1) process that fits the series of ξ_t is specified as:

$$\log(\xi_t) = \rho_\xi \log(\xi_{t-1}) + \epsilon_{\xi,t}, \quad \epsilon_{\xi,t} \sim \mathbf{N}(0, \sigma_\xi^2),$$

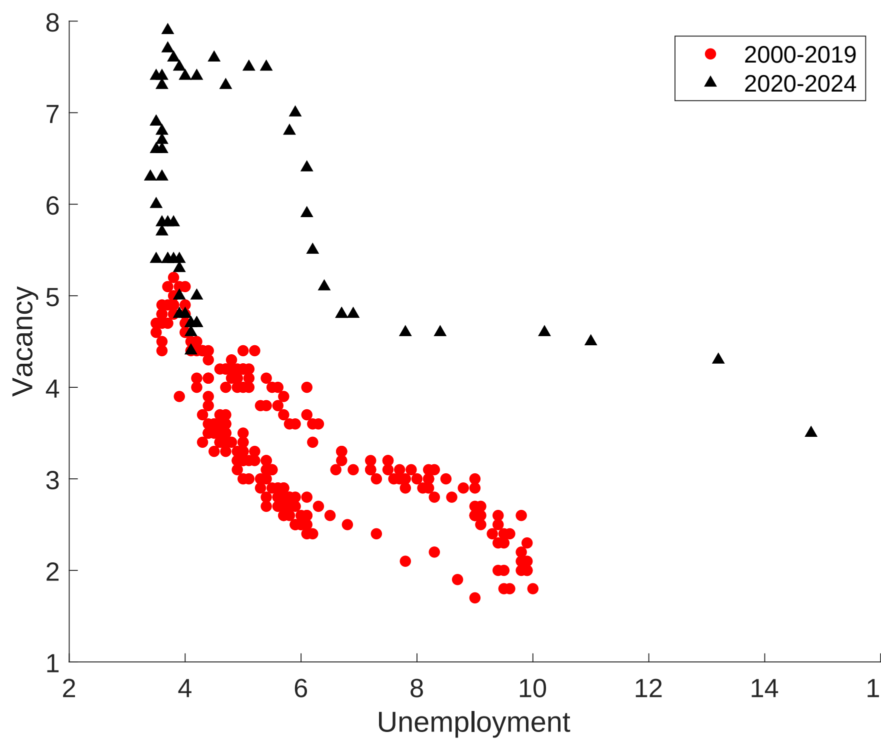
with parameters $\rho_\xi = 0.6$ and $\sigma_\xi = 0.054$. The red dots represent the scatter plot of the simulated vacancies against unemployment around the steady state for 50 periods.

The Beveridge curve shows distinct features during transitional periods (black triangles) and around the steady state (red dots). During transitional periods, the curve has a flat segment with low vacancies and relatively high unemployment, followed by a steep segment with low unemployment. This pattern is especially interesting because it closely matches the observed Beveridge curve since 2020, as shown in Figure E.8.

The counterfactual scenario without inter-sectoral complementarities and labor shortages is shown in Panel (B) of Figure E.7. The black triangles represent the initial 20 periods, during which the counterfactual model reaches the steady state, with the immigration inflow set equal to the benchmark case. The red dots illustrate the simulation around the steady state, driven by the discount factor shocks.[32] During the transition periods marked by the black triangles, the Beveridge curve shows an upward slope. This occurs because, when there are no labor demand shocks, the number of vacancies is directly related to the unemployment level.

[32]Note that the counterfactual model exhibits different steady states than the benchmark model.

Figure E.8: Beveridge curve, data



Notes: Beveridge curve data, 2000-2024.

F Two-segment economy with mixed production functions

F.1 Overview and motivation

In this appendix, we extend our benchmark model to consider an economy composed of two distinct segments that differ in their production technologies. The first segment, with share s, operates under the Leontief production technology as in our benchmark case, where high-skilled (native) and low-skilled (immigrant) workers are perfect complements. The second segment, with share $1 - s$, employs a linear production function as in the counterfactual analysis with no complementarity, where workers are perfect substitutes as standard in DMP models with worker skill heterogeneity (Fujita and Ramey, 2012; Bils et al., 2012).

This extension serves two important purposes. First, it allows us to study economies where only a subset of sectors experience complementarity-driven labor shortages, while others operate with standard production technologies. This mixed structure provides a more realistic representation of modern economies, where different industries exhibit varying degrees of skill complementarity. Second, it enables us to examine how the coexistence of complementary and non-complementary production technologies affects the aggregate labor market dynamics in response to immigration shocks. The parameter s controls the overall degree of complementarity in the economy: as s approaches 1, the economy behaves like our benchmark Leontief economy; as s approaches 0, it converges to the standard DMP model with linear production.

F.2 Model setup

Consider an economy divided into two segments indexed by $j \in \{\mathrm{a}, \mathrm{b}\}$, where a denotes the Leontief segment and b denotes the linear (substitutable) segment. In each segment, there are high-skilled (native) workers $N_t^{H,j}$ and low-skilled (immigrant) workers $N_t^{L,j}$.

Production technologies. For segment a (Leontief technology with share s), the production function is:

$$Y_t^a = z_t \min\left(N_t^{H,a}, N_t^{L,a}\right), \tag{A-12}$$

where z_t is labor productivity common across segments.

For segment b (linear technology with share $1-s$), the production function is:

$$Y_t^b = z_t \left(\frac{N_t^{H,b} + N_t^{L,b}}{2} \right). \tag{A-13}$$

Total output in the economy is the weighted sum of outputs from both segments:

$$Y_t = sY_t^a + (1-s)Y_t^b. \tag{A-14}$$

Labor allocation and shortages. We assume that high-skilled employment in each segment is fixed: $N_t^{H,a} = N^{H,a}$ and $N_t^{H,b} = N^{H,b}$, with $N^{H,a} = sN^H$ and $N^{H,b} = (1-s)N^H$, where N^H is the total high-skilled employment in the economy. This allocation ensures that high-skilled workers are distributed proportionally to the segment sizes.

Labor shortages only arise in segment a due to the Leontief complementarity. We define the labor shortage in segment a as:

$$\Delta_t^a = N^{H,a} - N_t^{L,a}. \tag{A-15}$$

In segment b, there is no labor shortage by construction since the production function is linear and workers are perfectly substitutable.

F.3 Labor market dynamics

Employment evolution. The employment of low-skilled workers in segment a evolves according to:

$$N_t^{L,a} = \max\{(1-\delta)N_{t-1}^{L,a} + m_t^a, N^{H,a}\}, \tag{A-16}$$

where m_t^a is the number of new matches in segment a. The matching function in segment a is $m_t^a = \phi(v_t^a)^\alpha(u_t^a)^{1-\alpha}$, with v_t^a and u_t^a denoting vacancies and unemployment in segment a.

In segment b, low-skilled employment follows:

$$N_t^{L,b} = (1-\delta)N_{t-1}^{L,b} + m_t^b, \tag{A-17}$$

where $m_t^b = \phi(v_t^b)^\alpha(u_t^b)^{1-\alpha}$.

Immigration allocation. Immigrants arrive in the economy and are allocated to the two segments according to their shares. The total inflow of immigrants is determined by the labor shortage in the Leontief segment:

$$im_t = \widehat{\psi}\Delta_t^a, \tag{A-18}$$

where $\widehat{\psi}$ is the immigration intensity parameter. A fraction s of immigrants enters segment a, while the remaining fraction $1-s$ enters segment b. The immigration flows to the two segments are:

$$im_t^a = s \cdot im_t \quad \text{and} \quad im_t^b = (1-s)im_t. \tag{A-19}$$

This allocation rule reflects the idea that immigration responds to economy-wide labor market conditions, with the Leontief segment's shortage serving as the primary signal for immigration flows.

F.4 Search-and-matching frictions

Free-entry conditions. The free-entry condition in segment a is identical to that in the benchmark model:

$$\frac{\kappa}{f_t^a(\theta_t^a)} = \beta p_t^a E_t\left(J_{t+1}^a\right), \tag{A-20}$$

where $f_t^a(\theta_t^a) = \phi(\theta_t^a)^{\alpha-1}$ is the vacancy filling rate, $\theta_t^a = v_t^a/u_t^a$ is the tightness ratio, and p_t^a is the match survival rate defined as:

$$p_t^a = \begin{cases} 1 & \text{if } m_t^a < \widetilde{\Delta}_{t-1}^a \\ \frac{\widetilde{\Delta}_{t-1}^a}{m_t^a} & \text{if } m_t^a \geq \widetilde{\Delta}_{t-1}^a \end{cases}, \tag{A-21}$$

where $\widetilde{\Delta}_{t-1}^a \equiv \Delta_{t-1}^a + \delta N_{t-1}^{L,a}$ is the number of workers required to resolve the labor shortage.

In segment b, the free-entry condition simplifies to the standard DMP form:

$$\frac{\kappa}{f_t^b(\theta_t^b)} = \beta E_t\left(J_{t+1}^b\right), \tag{A-22}$$

since there is no labor shortage and hence $p_t^b = 1$ for all t.

Value functions and wages. The value functions for firms and workers in each segment are defined similarly to equations (13)-(15) in the main text. The total surplus of a low-skilled job match in segment a is:

$$TS_t^a = z_t - h + \beta\left(1 - p_t^a \mu_t^a \tau - \delta\right) E_t\left(TS_{t+1}^a\right), \tag{A-23}$$

while in segment b, the total surplus is:

$$TS_t^b = z_t - h + \beta\left(1 - \mu_t^b \tau - \delta\right) E_t\left(TS_{t+1}^b\right), \tag{A-24}$$

where μ_t^a and μ_t^b are the job-finding rates in segments a and b, respectively. The key difference is that in segment b, the match survival probability is always 1, and the job value does not depend on labor shortages.

The equilibrium of the two-segment economy is characterized by the paths of $\{u_t^a, v_t^a, \Delta_t^a, u_t^b, v_t^b\}$ that satisfy the laws of motion for employment and unemployment, the free-entry conditions, and the immigration allocation rules.

F.5 Transition dynamics and quantitative implications

The economy begins with high unemployment and low low-skilled employment, which implies high labor shortages in segment a. As in the benchmark case in the main text, aside from the initial deviation from the zero-shortage steady state, the system evolves endogenously according to the model equations, ultimately converging to the zero-shortage steady state.

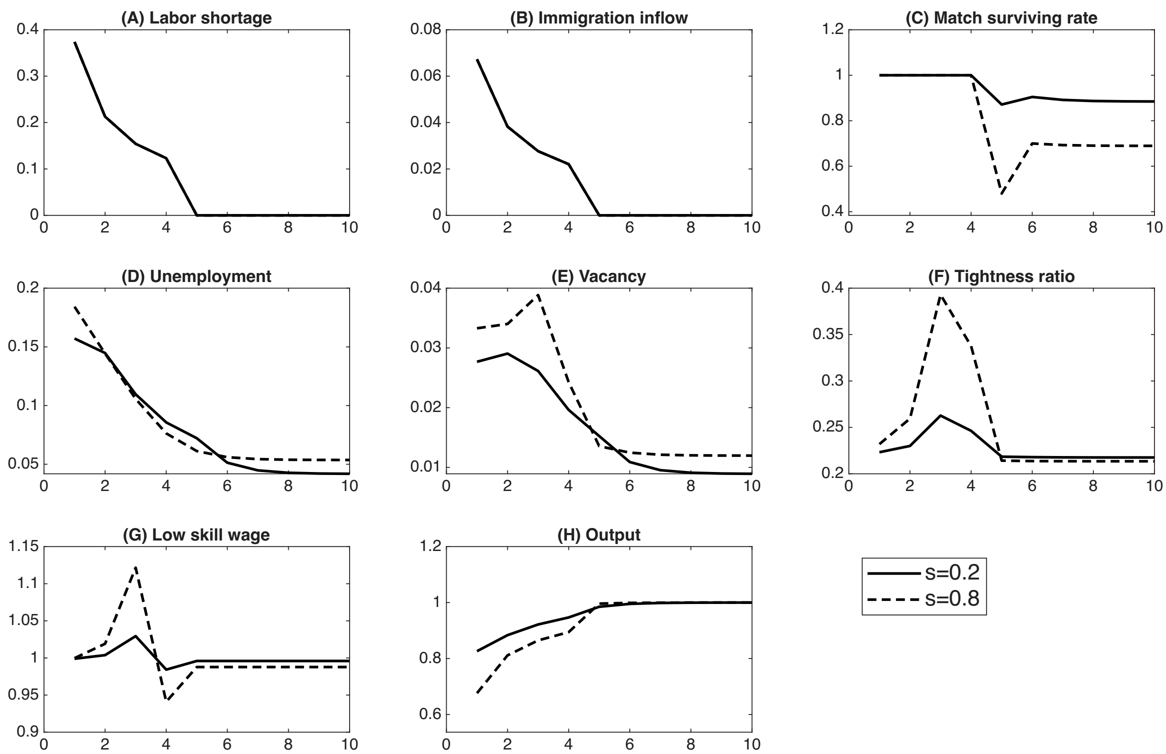
Figure F.9 illustrates the transition dynamics for two different values of s: $s = 0.8$ (dashed curves) and $s = 0.2$ (solid curves). A larger s makes the economy more similar to the Leontief benchmark with strong complementarity between immigrants and high-skilled natives, while a smaller s makes it more similar to the linear economy with higher elasticity of substitution. To ensure comparability with the benchmark model, we set the immigration intensity $\widehat{\psi} = \psi/s$, where ψ is the immigration intensity in the benchmark case. This implies that the elasticity of immigration inflow into segment a $(s\widehat{\psi})$ is the same as in the benchmark case. All other parameter values remain unchanged.

The transition dynamics exhibit several key features that align with the empirical evidence presented in Section 2 and the benchmark quantitative results shown in figure 4. The initial surge in labor shortages (Panel A) triggers a rise in immigration inflows (Panel B). With the initial shortage of labor, the match survival rate in segment a equals one (Panel C), while the pool of unemployed low-skilled workers increases as new entrants require one period to engage in job search (Panel D). Firms respond to the labor shortage and the large inflow of immigration by posting vacancies on impact (Panel E). The resulting increase in labor market tightness (Panel F) raises wages in the first two periods (Panel G). Output expands (Panel H) in response to the increase in low-skill worker inflows and the ensuing pickup in vacancy posting.

As the economy converges toward the steady state, labor shortages are gradually resolved. The resolution of shortages reduces the match survival rate, thereby dampening firms' incentives to post vacancies. This mechanism generates the negative correlation between immigration and vacancy growth observed in the data (Fact 3).

Due to different elasticity of substitution implied by s, there exists quantitative differences between the two cases: a higher s (stronger complementarity) leads to lower initial output but stronger output growth during the transition, along with more volatile paths for vacancies, tightness ratios, and low-skilled wages. These patterns reflect the amplifying role of complementarity in transmitting labor shortages to labor market outcomes.

Figure F.9: Transition dynamics in the two-segment economy



Notes: The figure shows the transition dynamics for labor shortage (Panel A), low-skill immigration inflow (Panel B), match survival rate (Panel C), unemployment (Panel D), vacancy (Panel E), tightness ratio (Panel F), low-skill wage (Panel G), and output (Panel H). Solid and dashed lines represent simulations with $s = 0.2$ and $s = 0.8$, respectively.

G Data Appendix

This appendix details all datasets used in the analysis, their sources, construction methods, and access links. All data are publicly available.

G.1 Data Sources and Descriptions

G.1.1 U.S. Employment Growth by Nativity Status

The statement that "Employment of foreign-born individuals increased by 12 percent, accounting for the entire 3 percent total employment growth in the United States" is based on data from the **Current Population Survey (CPS)** conducted by the U.S. Bureau of Labor Statistics (BLS).

G.1.2 Undocumented Immigrant Population Estimates

Figure 1 presents estimates of the stock of undocumented immigrants from three distinct sources. These data are used solely for motivational context and are not employed in the empirical analysis or model calibration.

- **Pew Research Center (1990–2017)**: Estimates based on residual methodology using CPS and American Community Survey data.
  - Unauthorized immigrant population trends interactive
  - State-level unauthorized immigrant estimates
  - Five facts about illegal immigration in the U.S.
  - Methodology: U.S. unauthorized immigrant population, 2017
- **Department of Homeland Security (2005–2022)**: Official estimates based on residual methodology.
  - Main page: Unauthorized Resident Population Estimates
  - 2005–2018 estimates: Unauthorized immigrant population estimates (2015-2018)
  - 2005–2022 estimates: Estimates of unauthorized immigrant population (2018-2022)

- **Congressional Budget Office (2022–2024)**: Projections from demographic outlook reports.
  - *The Demographic Outlook: 2024 to 2054* (updated regularly)

G.1.3 Empirical Analysis Variables (Sections 2 and 3)

All variables for the empirical analysis in Section 2 and model calibration in Section 3 are sourced from U.S. Bureau of Labor Statistics (BLS) surveys.

Table G.4: Data Sources for Empirical Analysis

Variable	Source and Survey	Units and Treatment	Frequency
Sectoral Employment	BLS; Current Employment Statistics (Establishment Survey)	Thousands of persons, seasonally adjusted	Monthly
Employment by Nativity	BLS; Current Population Survey (Household Survey)	Levels and percentages, seasonally adjusted	Monthly
Labor Shortage Measure	Constructed using sectoral employment shares (see Section 2.1)	Deviation from HP trend, seasonally adjusted	Monthly
Average Hourly Earnings	BLS; Current Employment Statistics (Establishment Survey)	Dollars per hour, seasonally adjusted	Monthly
Job Openings (Vacancies)	BLS; Job Openings and Labor Turnover Survey (JOLTS)	Level in thousands, seasonally adjusted	Monthly
Unemployment Rate	BLS; Current Population Survey (Household Survey)	Percent, not seasonally adjusted	Monthly
Foreign Employment	IPUMS; Current Population Survey	Person, not seasonally adjusted	Monthly

G.2 Data Construction Notes

Sectoral Classification: Employment, wage, and vacancy data are organized by NAICS industry sectors at the 2-digit level, consistent with JOLTS publication standards.

Foreign-Born Definition: Following BLS conventions, "foreign-born" includes anyone living in the United States who was not a U.S. citizen at birth, regardless of current legal status.

Labor Shortage Measure Construction: As detailed in Section 2.1, the sectoral labor shortage measure is calculated as the deviation of each sector's employment share from its Hodrick-Prescott trend (smoothing parameter $\lambda = 10^6$).

Data Availability: All data series are publicly accessible through:

- **BLS Data Tools**: U.S. Bureau of Labor Statistics Data Tools and Applications
- **FRED Economic Data**: Federal Reserve Economic Data (FRED) Database
- **IPUMS CPS**: IPUMS Current Population Survey Microdata