Review of Economics and Statistics Just Accepted MS.
https://doi.org/10.1162/rest_a_01252

Immigration Lottery Design: Engineered and Coincidental Consequences of H-1B Reforms*

Parag A. Pathak Alex Rees-Jones Tayfun Sönmez†

August 2022

Abstract

The H-1B Visa Reform Act of 2004 dictates an annual allocation of 85,000 visas with 20,000 reserved for advanced-degree applicants. We represent the main requirements of this legislation as formal axioms and characterize visa allocation rules consistent with the axioms. Despite the precise number reserved, we show that the range of implementations satisfying these axioms can change the allocation of advanced-degree visas by as much as 14,000 in an average year. Of all rules satisfying these axioms, the 2019 rule imposed by executive order is most favorable to advanced-degree holders. However, two earlier modifications resulted in larger changes, potentially unintentionally.

*We are grateful to David H. Autor, Sameer H. Doshi, and Ran Shorrer for helpful conversations. Pathak and Sönmez thank the National Science Foundation for support.

†Pathak: Department of Economics, Massachusetts Institute of Technology, and NBER, email: ppathak@mit.edu, Rees-Jones: Department of Business Economics and Public Policy, Wharton School, University of Pennsylvania, and NBER, email: alre@wharton.upenn.edu and Sönmez: Department of Economics, Boston College, email: sonmezt@bc.edu.

Review of Economics and Statistics Just Accepted MS.
https://doi.org/10.1162/rest_a_01252

1 Introduction

Since its introduction in the Immigration Act of 1990, the United States (U.S.) H-1B program has enabled American companies to temporarily employ educated foreign workers in occupations that require specialized knowledge.[1] As it is the largest temporary employment program for skilled immigration in the U.S., the H-1B program has drawn sustained attention from economists. This research has addressed the impact of skilled immigration programs on students (Kato and Sparber, 2013; Amuedo-Dorantes and Furtado, 2017), workers (Peri, Shih, and Sparber, 2015; Mayda, Ortega, Peri, Shih, and Sparber, 2018), firms (Doran, Gelber, and Isen, 2014; Kerr, Kerr, and Lincoln, 2015; Mayda, Ortega, Peri, Shih, and Sparber, 2020; Glennon, 2020), innovation (Kerr and Lincoln, 2010; Dimmock, Huang, and Weisbenner, 2021), and more. Papers within this literature have analyzed the consequences of legislated H-1B reforms, and some have assessed of the value of the program as a whole (e.g., Bound, Khanna, and Morales, 2017; Chassamboulli and Peri, 2018).

In this paper, we contribute to this literature by analyzing this program from the perspective of market design. We model the H-1B system in a manner inspired by recent market design research on reserve systems (Kominers and Sönmez, 2016; Dur, Kominers, Pathak, and Sönmez, 2018). Within this framework we formalize the main requirements of H-1B legislation with three simple axioms. This model allows us to characterize the range of visa allocation rules permitted under the minimal requirements of the law and to demonstrate that significantly different visa allocations may occur across this range. Our analysis allows us to identify important policy levers available within the H-1B system—levers that have often been ignored in both academic and political debate, and which have been modified in recent years in important ways.

Our model describes the system put in place by the H-1B Visa Reform Act of 2004.

[1] Examples include employment in engineering, computer science, or other STEM fields.

Review of Economics and Statistics Just Accepted MS.
https://doi.org/10.1162/rest_a_01252

This act set forth visa allocations for two classifications of applicants: 65,000 visas are made available for all eligible applicants and an additional 20,000 visas are reserved for applicants with a master's degree or higher academic credential from eligible U.S. institutions.[2] Popular discussions refer to these quotas as caps; we call the 20,000 visas for applicants with U.S. advanced degrees the *reserved cap* and the 65,000 visas available for all applicants the *unreserved cap*. Although the size of the caps were precisely specified and prominently advertised, details on how the caps should be implemented were left to the discretion of the U.S. Customs and Immigration Service (USCIS) (Federal Register, 2005, 2018).[3] The central focus of our analysis will be understanding how different means of implementation affect the number of visas granted to those who have documented an eligible degree in their H-1B petition (*reserved-category* applicants) and to those who did not (*general-category* applicants).

We model the set of visa allocation rules that are potentially in compliance with the statute as satisfying three simple axioms. First, they *accommodate the reserve policy* by restricting access to reserved visas to reserved-category applicants only. Second, they are *non-wasteful*, a minimal efficiency requirement that ensures visas do not go unused while there is eligible unmet demand. That means a general-category applicant should not be denied a visa unless all unreserved visas are exhausted; similarly, a reserved category applicant should not be denied a visa unless all visas (reserved or unreserved) are exhausted.[4] Finally, they *respect priorities*, which means an applicant qualified for a visa should not lose it to a candidate who has lower priority for that visa. When a visa allocation rule

[2]When discussing "applicants" we refer to the workers that would receive these visas. Note, however, that H-1B system is "employer driven," meaning that companies initiate the application process on behalf of the workers that they want to employ (for further discussion, see Kerr and Kerr, 2020). Also note that H-1Bs associated with certain employers (e.g., institutions of higher education, research- or education-related nonprofits, and government research organization) do not count towards the legislated caps.

[3]According to the Federal Register, "Congress did not specify any procedures for implementation or dictate the manner in which USCIS should allocate H-1B numbers made available pursuant to the new exemption" (Federal Register Vol. 70, No. 86, Thursday, May 5).

[4]Throughout the paper, an applicant refers to one who is qualified for a visa. Of course, unqualified applicants can be denied without violating the non-wastefulness property.

Review of Economics and Statistics Just Accepted MS.
https://doi.org/10.1162/rest_a_01252

satisfies all three properties, we say it *complies with the statute*.[5]

Within this framework, we compare the four visa allocation rules that have been implemented in the H-1B program since fiscal year (FY) 2005 (summarized in Table 1). These rules differ in how they determine priority—changing between determining priority by arrival time versus by random lotteries—and in the order in which they assign visas toward the reserved or unreserved caps. Despite these differences, these rules all comply with the statute as defined above. Our results characterize how these rules allocate visas between general- and reserved-category applicants and document significant differences. Across the visa rules that comply with the statute, the advantage given to applicants with an advanced degree (henceforth "*skill bias*") may be significantly altered by certain design decisions, and since FY2005 the H-1B program has at times enacted policies that either maximize and minimize this skill bias.

[Table 1 about here]

After establishing our main theoretical results, we reexamine the recent administrative history of the H-1B program. The potential importance of the issues that we model first became apparent in former President Trump's *Buy American and Hire American Executive Order* in 2017, which instructed the U.S. Department of Homeland Security to propose reforms to ensure that H-1B visas are awarded to the most-skilled or highest-paid petition beneficiaries. This declaration led to an adoption of a new visa allocation rule for FY2020, and the process of its enactment demonstrated some degree of understanding of the theoretical forces we have described. For example, a government press release stated:

> "Currently, [...] the advanced degree exemption is selected prior to the H-1B cap. The proposed rule would reverse the selection order and count all registration or

[5]We use the terminology "complies with statute" to summarize compliance with these three axioms, not to formally take a position on the legal status of specific proposals. Of course, the legislation lays out additional requirements that must be satisfied. We believe that the model we present captures the legal requirements of core importance to the final allocation, so we abstract from any other legal requirements to facilitate parsimonious analysis.

Review of Economics and Statistics Just Accepted MS.
https://doi.org/10.1162/rest_a_01252

> petitions towards the number projected as needed to the reach the H-1B cap first. Once a sufficient number of registration or petitions have been selected for the H-1B cap, USCIS would then select registration or petitions towards the advanced degree exemption."
>
> "The proposed process would result in an estimated increase of up to 16 percent (or 5,340 workers) in the number of selected H-1B beneficiaries with master's degree or higher." (USCIS, 2018)

As illustrated in this quote, the USCIS identified the role of processing order and then proposed a reform to it to maximize skill bias. Perhaps surprisingly then, our results establish that the allocation rule initially deployed after the H-1B Visa Reform Act of 2004 achieved the same degree of skill bias as the Trump administration's reform, and that administrative changes that occurred in FY2006 and FY2009 result in larger year-to-year changes to the degree of skill bias than did the FY2020 reform. Unlike the FY2020 reform, these prior reforms were not motivated by a desire to influence skill bias, and indeed were only minimally publicized or publicly scrutinized. Based on the discussions available in the Federal Register, it appears that these earlier reforms were driven simply by logistical considerations, and their significant impact on skill bias may not have been broadly appreciated.

This paper proceeds as follows. The next subsection discusses related literature. Section 2 defines the visa allocation problem, presents our axioms, and formally defines the four visa allocation rules that were summarized in Table 1. Section 3 presents our formal results characterizing the performance of the different visa allocation rules. Section 4 reexamines the recent history of H-1B reforms through the lens of the theory we have established. The last section concludes. All proofs are in the appendix. A secondary appendix contains additional information describing the four visa allocation rules, as pre-

Review of Economics and Statistics Just Accepted MS.
https://doi.org/10.1162/rest_a_01252

sented in the Federal Register.

1.1 Related Literature

Our paper relates and contributes to the literatures on market design and on the H-1B system.

Relation to Literature on Market Design

Within the market-design literature, our work is closely related to the growing literature on reserve systems. The role of processing order of different types of positions was first studied by Kominers and Sönmez (2016) in an abstract framework, and later by Dur, Kominers, Pathak, and Sönmez (2018) in the context of school choice. These papers emphasize that reserve size is insufficient for describing a reserve policy when the order of processing is not explicit. Dur, Kominers, Pathak, and Sönmez (2018) further establishes formal comparative static results comparing changes in reserve sizes to changes in the processing order of reserves. It also establishes two conceptual forces driving these differences, labeled *processing bias* and *random number bias*, that help one understand the importance of reforms to processing order and to the priority system in the H-1B context. Similar forces are relevant in the work of Dur, Pathak, and Sönmez (2020), which considers place-based affirmative action in Chicago and characterizes optimal and constrained optimal implementation of reserve policies in the presence of multiple reserve groups. These forces are also at play in the work of Sönmez and Yenmez (2022a), which studies the vertical and horizontal reservation policies present in India's constitutionally-mandated affirmative action system.[6] To eliminate a number of anomalies arising from a mechanism mandated by the Indian Supreme Court in 1995, Sönmez and Yenmez (2022a)

[6]When either policy is implemented on a stand-alone basis for non-overlapping protected groups, the vertical reservations considered in this work correspond to the Over-and-Above allocation rule we study, and the horizontal reservations correspond to the Exemptions-First allocation rule.

Review of Economics and Statistics Just Accepted MS.
https://doi.org/10.1162/rest_a_01252

propose a mechanism that integrates horizontal and vertical reservation policies when all positions are identical. Sönmez and Yenmez (2022b) further extend this analysis for field applications with position heterogeneity. Other related papers on reserve systems include Hafalir, Yenmez, and Yildirim (2013), Doğan (2017), Erdil and Kumano (2019), Aygün and Turhan (2020), Delacrétaz (2020), Imamura (2020), Pathak, Sönmez, Ünver, and Yenmez (2020), and Aygün and Bo (2021).

Our interpretation that elements of the H-1B reserve system were not fully appreciated relates to the work reported in Pathak, Rees-Jones, and Sönmez (2020). That paper presents an online experiment eliciting a representative U.S. sample's preferences over reserve systems. In scenarios related to school admission and visa allocation, approximately 40% of subjects chose to implement reserve systems in a way that could be fully rationalized by an incorrect belief that processing order is irrelevant. In that experiment, a trivially small fraction of subjects responded in a manner that revealed full understanding of these systems. This widespread misunderstanding of how reserve systems operate can rationalize why the elements of the H-1B system that we study received little public attention prior to their publicization by the Trump administration. Our analysis of the history of H-1B reforms served as a key motivation for the hypotheses tested by Pathak, Rees-Jones, and Sönmez (2020), and that paper's findings lend credence to elements of our interpretation of the history presented in Section 4.

Beyond the specific context of reserve system design, our paper relates to the large literature on market design under various classes of distributional constraints such as lower quotas, upper quotas, and regional quotas. A partial list includes Abdulkadiroğlu (2005), Biro, Fleiner, Irving, and Manlove (2010), Kojima (2012), Budish, Che, Kojima, and Milgrom (2013), Westkamp (2013), Ehlers, Hafalir, Yenmez, and Yildirim (2014), Echenique and Yenmez (2015), Kamada and Kojima (2015, 2017, 2018), Bo (2016), Doğan (2016), Fragiadakis and Troyan (2017), Tomoeda (2018), Ehlers and Morrill (2020), Abdulkadiroğlu and Grigoryan (2021), Doğan and Yıldız (2022), and Çelebi and Flynn (2022a,b).

Review of Economics and Statistics Just Accepted MS.
https://doi.org/10.1162/rest_a_01252

Our paper is also related to the literature studying the formal properties of allocation processes in the field. This literature includes studies of entry-level labor markets (Roth, 1984; Roth and Peranson, 1999), school choice (Balinski and Sönmez, 1999; Abdulkadiroğlu and Sönmez, 2003; Pathak and Sönmez, 2008, 2013), spectrum auctions (Milgrom, 2000), kidney exchange (Roth, Sönmez, and Ünver, 2004, 2005), internet auctions (Edelman, Ostrovsky, and Schwarz, 2007; Varian, 2007), course allocation (Sönmez and Ünver, 2010; Budish, 2011), cadet-branch matching (Sönmez and Switzer, 2013; Sönmez, 2013), assignment of airport arrival slots (Schummer and Vohra, 2013; Schummer and Abizada, 2017), refugee resettlement (Jones and Teytelboym, 2017; Delacrétaz, Kominers, and Teytelboym, 2016; Andersson, 2017), and more.

Relation to Literature on the H-1B System

As reviewed in the introduction, a significant empirical literature has examined the H-1B system (see, e.g., Kerr and Lincoln, 2010; Kato and Sparber, 2013; Doran, Gelber, and Isen, 2014; Kerr, Kerr, and Lincoln, 2015; Peri, Shih, and Sparber, 2015; Amuedo-Dorantes and Furtado, 2017; Bound, Khanna, and Morales, 2017; Chassamboulli and Peri, 2018; Mayda, Ortega, Peri, Shih, and Sparber, 2018, 2020; Glennon, 2020; Dimmock, Huang, and Weisbenner, 2021). Papers within this literature have commonly analyzed the consequences of the H-1B Visa Reform Act of 2004 or the role of H-1Bs in the post-reform regime. While many papers have presented the post-2004 system as if it were governed by a single stable policy, our work demonstrates that this window of time is best thought of as a series of policies that differ significantly in their degree of skill bias. This observation leads to two practical implications for empiricists operating within this literature.

First, our results illustrate a potential confounding factor that can arise in empirical analysis. Because the different visa allocation rules lead to different distributions of skill among successful H-1B applicants, controlling for the visa allocation rule can be important when studying the causes or consequences of skilled immigration.

Review of Economics and Statistics Just Accepted MS.
https://doi.org/10.1162/rest_a_01252

Second, our results indicate that the changes to skill bias occurring due to switches in the assignment rule can serve as a new, and largely untapped, source of policy variation. While papers cited above have leveraged the change in total caps imposed in the 2004 reform or rules regarding the randomization of priority for identification, we are not aware of papers making similar use of changes in processing order or changes in the number of priority orders used. By documenting the changes of these design elements and the fact that some are plausibly exogenously driven by logistical issues, we provide a new source of identifying variation for this literature.

2 Model

There are q slots of immigration visas to be awarded to members of a set I of applicants, where each applicant can be awarded at most one slot. The set of applicants is partitioned into two sets as the *general-category* applicants I_G and the *reserved-category* applicants I_R. While all slots are identical otherwise, $q_r \leq q$ slots are exclusively set aside for the set of reserved-category applicants. We refer these slots as *reserved* slots. The remaining $q_u = q - q_r$ *unreserved* slots can be awarded to any applicant. To simplify the analysis, we assume that there is excess demand for the visas; that is

$$|I_G| \geq q_u \text{ and } |I_R| \geq q_r.$$

This assumption holds for all years since the reserved slots were introduced in the H-1B Visa Reform Act of 2004.

We refer to the triple $E = \langle I, q_u, q_r \rangle$ as a *visa allocation problem*, and assume that it is fixed throughout our analysis. Let $\mathcal{E}$ denote the set of visa allocation problems.

A *priority order* π is a linear order on the set of applicants I. Let Π denote the set of priority orders on the set of applicants I.

Review of Economics and Statistics Just Accepted MS.
https://doi.org/10.1162/rest_a_01252

Motivated by U.S. H-1B visa allocation policies since 2004, we focus on allocation rules that rely on two priority orders $\pi_u, \pi_r \in \Pi$, one for each type of slot. Here,

- π_u identifies the claims of all applicants for the unreserved slots, and
- π_r identifies the claims of the reserved-category applicants for the reserved slots.[7]

These priority orders can depend on factors such as the timing of arrival of applications, exam scores, salary of the applied jobs, or simply a random lottery draw. While the two priority orders can be identical, they can also be different. In the rest of this section, we fix the priority orders $\pi_u, \pi_r \in \Pi$.

2.1 Matchings and Visa Allocation Rules

Given a visa allocation problem $E \in \mathcal{E}$, a matching is a function $\mu : I \to \{r, u\} \cup \{\emptyset\}$ such that

$$|\mu^{-1}(r)| \leq q_r \text{ and } |\mu^{-1}(u)| \leq q_u.$$

Let $\mathcal{M}(E)$ denote the set of all matchings for the visa allocation problem $E = \langle I, q_u, q_r \rangle$. Since $E \in \mathcal{E}$ is fixed throughout our analysis, we will suppress the argument in $\mathcal{M}(E)$ and simply denote it as $\mathcal{M}$ whenever there is no ambiguity.

For any matching $\mu \in \mathcal{M}$ and applicant $i \in I$,

- $\mu(i) = r$ indicates that applicant i is awarded a reserved slot,
- $\mu(i) = u$ indicates that applicant i is awarded an unreserved slot, and
- $\mu(i) = \emptyset$ indicates that applicant i is not awarded a slot.

Since all slots are identical, each applicant is assumed to be indifferent between receiving a reserved slot and an unreserved slot. We further assume that each applicant strictly prefers receiving a slot to not receiving one.

[7] Since the reserved slots are exclusively set aside for the reserved-category applicants, only the relative priority order of these applicants is relevant under the priority order π_r.

Review of Economics and Statistics Just Accepted MS.
https://doi.org/10.1162/rest_a_01252

For any matching $\mu \in \mathcal{M}$, let

- $|\mu| = |i \in I : \mu(i) \neq \emptyset|$ denote the number of applicants who are allocated a slot,
- $|\mu_r| = |i \in I : \mu(i) = r|$ denote the number of applicants who are allocated a reserved slot,
- $|\mu_u| = |i \in I : \mu(i) = u|$ denote the number of applicants who are allocated an unreserved slot,
- $\mu(I_R) = \{i \in I_R : \mu(i) \neq \emptyset\}$ denote the set of reserved-category applicants who are each allocated a slot, and
- $\mu(I_G) = \{i \in I_G : \mu(i) \neq \emptyset\}$ denote the set of general-category applicants who are each allocated a slot.

A *visa allocation rule* is a function $\varphi : \mathcal{E} \to \bigcup_{E \in \mathcal{E}} \mathcal{M}(E)$ that selects a matching $\mu \in \mathcal{M}(E)$ for each visa allocation problem $E \in \mathcal{E}$.

2.2 Desiderata for Matchings and Visa Allocation Rules

We study matchings and visa allocation rules that satisfy the following three axioms.

Definition 1 *A matching $\mu \in \mathcal{M}$* ***accommodates reservation policy*** *if, for any $i \in I_G$,*

$$\mu(i) \neq r.$$

Likewise, a visa allocation rule ***accommodates reservation policy*** *if its outcome accommodates reservation policy for each visa allocation problem.*

Our first axiom ensures that only reserved-category applicants can be awarded the slots set aside for them.

Review of Economics and Statistics Just Accepted MS.
https://doi.org/10.1162/rest_a_01252

Definition 2 *A matching $\mu \in \mathcal{M}$ is* ***non-wasteful*** *if,*

1) for any $i \in I_R$,

$$\mu(i) = \emptyset \implies |\mu| = q, \text{ and}$$

2) for any $i \in I_G$,

$$\mu(i) = \emptyset \implies |\mu_u| = q_u.$$

Likewise, a visa allocation rule is ***non-wasteful*** *if its outcome is non-wasteful for each visa allocation problem.*

Our second axiom ensures that each slot is to be allocated, provided that there are eligible applicants.

Definition 3 *A matching $\mu \in \mathcal{M}$* ***respects priorities*** *if,*

1) for any $i, j \in I$,

$$\Big(\mu(i) = \emptyset \text{ and } \mu(j) = u\Big) \implies j \,\pi_u\, i, \text{ and}$$

2) for any $i, j \in I_R$,

$$\Big(\mu(i) = \emptyset \text{ and } \mu(j) = r\Big) \implies j \,\pi_r\, i.$$

Likewise, a visa allocation rule ***respects priorities*** *if its outcome respects priorities for each visa allocation problem.*

Our third axiom ensures that allocation of both type of slots respects their given priority orders.

It is convenient to collect all three axioms into the following condition.

Definition 4 *A matching $\mu \in \mathcal{M}$* ***complies with the statute*** *if and only if (i) it accommodates reservation policy, (ii) it is non-wasteful, and (iii) it respects priorities.*

Review of Economics and Statistics Just Accepted MS.
https://doi.org/10.1162/rest_a_01252

Likewise, a visa allocation rule φ ***complies with the statute*** *if and only if (i) it accommodates the reservation policy, (ii) it is non-wasteful, and (iii) it respects priorities.*

2.3 Comparisons Between Visa Allocation Rules

We now explain how we compare visa allocation rules. First, given two visa allocation rules φ and ψ, we say rule φ is **more favorable for the reserved-category applicants** than rule ψ if, for any $E \in \mathcal{E}$, $\mu = \varphi(E)$, and $\nu = \psi(E)$,

$$|\mu(I_R)| \geq |\nu(I_R)|.$$

Definitions of less favorable for the reserved-category applicants, more favorable for general-category applicants, and less favorable for the general-category applicants are analogous (see Appendix **??** for formal presentation of these other definitions).

Next, we say a visa allocation rule φ that complies with the statute is **reserved-category-maximal** if, for any problem $E \in \mathcal{E}$ and rule ψ that complies with the statute, rule φ is more favorable for the reserved-category applicants than rule ψ. Definitions of reserved-category-minimal, general-category-maximal, and general-category minimal are analogous (see Appendix **??** for formal presentation of these other definitions).

2.4 Post-2004 Visa Allocation Rules in the U.S.

As we have discussed in the Introduction, four visa allocation rules have been used to allocate H-1B visas in the U.S. since the inception of the H-1B Visa Reform Act of 2004. We next describe the matching produced by each of the four rules for a given visa allocation problem $E = \langle I, q_u, q_r \rangle$.

The first two rules rely on an identical priority order for reserved slots and unreserved slots. That is, $\pi_u = \pi_r = \pi$. More precisely, these priority orders depend on the arrival

Review of Economics and Statistics Just Accepted MS.
https://doi.org/10.1162/rest_a_01252

time of H-1B applications, giving priority to earlier applications.[8] When two applications arrive at the same date, ties are randomly broken.

For the following two visa allocation rules, fix a priority order $\pi \in \Pi$, and let $\pi_u = \pi_r = \pi$.

Exemptions-First Visa Allocation Rule φ^{ef}:

Consider all applicants one-at-a-time based on the priority order π, until either all applicants are considered or all slots are exhausted.

- If the applicant in consideration is a member of the reserved category, allocate her
  - a reserved slot provided that not all reserved slots are exhausted,
  - an unreserved slot provided that there still remains at least one unreserved slot and all reserved slots are exhausted.
- If the applicant is a member of the general category, allocate her an unreserved slot, provided that not all unreserved slots are exhausted.

An applicant who fails to receive a slot at the end of this process is not awarded a slot.

Over-and-Above Visa Allocation Rule φ^{oa}:

Step 1: Consider all applicants one-at-a-time based on the priority order π. Allocate an unreserved slot to the applicant in consideration, provided that not all unreserved slots are exhausted. Proceed to Step 2 either when all applicants are already considered or all unreserved slots are exhausted.

Step 2: Consider all remaining reserved-category applicants one-at-a-time based on the priority order π. Allocate a reserved slot to the applicant in consideration, pro-

[8] Implicit in our interpretation is the assumption that time spent assessing an application for a reserved-category position does not influence the ranking of the applicant under the priority order π_u for unreserved positions.

Review of Economics and Statistics Just Accepted MS.
https://doi.org/10.1162/rest_a_01252

vided that not all reserved slots are exhausted. Terminate the procedure either when all reserved-category applicants are already considered or all reserved slots are exhausted.

An applicant who fails to receive a slot in either step is not awarded a slot.

For the next two visa allocation rules, fix two priority orders $\pi_u, \pi_r \in \Pi$.

Reserved-Initiated Visa Allocation Rule $\boldsymbol{\varphi^{ru}}$:

Step 1: Consider all reserved-category applicants one-at-a-time based on the priority order π_r. Allocate a reserved slot to the reserved-category applicant in consideration, provided that not all reserved slots are exhausted. Proceed to Step 2 either when all reserved-category applicants are already considered or all reserved slots are exhausted.

Step 2: Consider all remaining applicants one-at-a-time based on the priority order π_u. Allocate an unreserved slot to the applicant in consideration, provided that not all unreserved slots are exhausted. Terminate the procedure either when all applicants are already considered or all unreserved slots are exhausted.

An applicant who fails to receive a slot in either step is not awarded a slot.

Unreserved-Initiated Visa Allocation Rule $\boldsymbol{\varphi^{ur}}$:

Step 1: Consider all applicants one-at-a-time based on the priority order π_u. Allocate an unreserved slot to the applicant in consideration, provided that not all unreserved slots are exhausted. Proceed to Step 2, either when all applicants are already considered or all unreserved slots are exhausted.

Step 2: Consider all remaining reserved-category applicants one-at-a-time based on the priority order π_r. Allocate a reserved slot to the applicant in consideration, provided that not all reserved slots are exhausted. Terminate the procedure either when all reserved-category applicants are already considered or all reserved slots are exhausted.

An applicant who does not receive a slot in either step is not awarded a slot.

Review of Economics and Statistics Just Accepted MS.
https://doi.org/10.1162/rest_a_01252

Observe that all four rules allocate all slots sequentially to the extent there are qualified applicants, they all restrict access to unreserved slots for applicants from reserved category, and they all allocate both types of slots based on the relevant priority order. Hence, they all satisfy each of the three axioms we formulated; i.e. they each comply with the statute.

Observation 1 *Visa allocation rules φ^{oa}, φ^{ef}, φ^{ru}, and φ^{ur} comply with the statute.*

3 Results

In this section, we present our results comparing the outcomes of the four visa allocation rules given in Section 2.4 with each other and with any other rule that complies with the statute. All our results are presented for a fixed visa allocation problem $E = \langle I, q_u, q_r \rangle$ and consequently also for a fixed set of applicants I. Therefore, when we relate our analytical results to actual H-1B visa allocation reforms, we are implicitly assuming away any possible change in the set of applicants due to these reforms.

3.1 Visa Allocation Rules for FY2005-FY2008

From FY2005 through FY2008, visa allocation rules were based on a single priority order that is induced by the arrival date of H-1B petitions. For the purposes of Theorem 1 below, therefore, we also fix $\pi_r = \pi_u = \pi$.

For FY2005 the mechanism of choice for H-1B allocation was the Over-and-Above visa allocation rule φ^{oa}, whereas for FY2006-FY2008 the mechanism of choice was the Exemptions-First visa allocation rule φ^{ef}. Focusing on rules based on the same priority order for both types of positions, our first result establishes that the rule φ^{oa} is reserved-category-maximal and general-category-minimal. In contrast, the rule φ^{ef} is reserved-category-minimal and general-category-maximal.[9]

[9]Strictly speaking the result is slightly stronger, since relations hold not only in terms of the number applicants who receive positions from each group, but rather in terms of set inclusion.

Review of Economics and Statistics Just Accepted MS.
https://doi.org/10.1162/rest_a_01252

Theorem 1 *Given any priority order $\pi \in \Pi$, let $\pi_u = \pi_r = \pi$. Let $\mu^{ef} = \varphi^{ef}(E)$ be the outcome of the Exemptions-First visa allocation rule, $\mu^{oa} = \varphi^{oa}(E)$ be the outcome of the Over-and-Above visa allocation rule, and matching $\mu \in \mathcal{M}$ be any matching that complies with the statute. Then,*

1. $\mu^{ef}(I_R) \subseteq \mu(I_R) \subseteq \mu^{oa}(I_R)$ *and*

2. $\mu^{oa}(I_G) \subseteq \mu(I_G) \subseteq \mu^{ef}(I_G)$.

There is a simple intuition for Theorem 1. Consider any matching μ that satisfies the three axioms, and focus on the number of "successful" reserved-category applicants under μ who each secure a slot. Since matching μ accommodates reservation policy, all reserved slot are awarded to reserved-category applicants. Therefore, the total number of successful applicants from this group depends on how many from the group can secure an unreserved slot. Since they compete with the general-category applicants for these units and the allocation is based on priority, it is critical which subset of the reserved-category applicants is in competition for the unreserved slots. On the one extreme is the case where the highest priority members of the group are all out of the competition, because an explicit effort is made to award them the reserved slots before any attempt is made to award them the unreserved slots. This is what happens under the Exemptions-First rule, thereby resulting in the least competitive group against members of the general-category for allocation of unreserved slots. On the other extreme is the case where the highest priority members of the reserved-category all compete against the general-category candidates, and only then the reserved slots are allocated to relatively lower-priority members of the group. This is what happens under the Over-and-Above rule. Since allocation is non-wasteful, what is best for the reserved-category applicants is the worst for the general-category applicants, and vice versa. Finally, since both types of slots are allocated based on a single priority order (subject to eligibility), the number of successful

Review of Economics and Statistics Just Accepted MS.
https://doi.org/10.1162/rest_a_01252

applicants from each group uniquely determines who among them receives the units. As a result, the comparisons can be made in terms of set inclusion.

3.2 FY2009 H-1B Allocation Reform

Prior to FY2009, the use of a single priority order that relies on arrival date of H-1B petitions had resulted in employers spending significant effort and money to send petitions by expedited overnight delivery for receipt on the first day petitions would be allowed. In FY2008, this resulted in more than 150,000 petitions being delivered on the same day and burdening employers, delivery services, and USCIS offices.

Consequently, USCIS abandoned the practice of relying on a single priority order that depends on the arrival of the petitions. Instead, USCIS allowed a period of five days for all petitions to be submitted. Submissions recieved in this window were prioritized through two random lotteries, one for the general-category applicants and the other for the reserved-category applicants. We refer the resulting two priority orders as π_u and π_r respectively. As USCIS adopted two priority orders rather than one, they also adopted a new visa allocation rule φ^{ru}, abandoning rule φ^{ef} that they relied upon for FY2006-FY2008.

We next show that, even though it was the result of the above-described logistical considerations, this reform resulted in a visa allocation rule that is more favorable for the reserved-category applicants and less favorable for the general-category applicants. To have a meaningful comparison of the rules φ^{ru} and φ^{ef}, we assume that

1. both rules rely on the same priority order π for allocation of the unreserved slots,

2. the rule φ^{ef} also relies on the same priority order π for allocation of the reserved slots,

3. whereas the rule φ^{ru} relies on a possibly distinct priority order π^* for allocation of

Review of Economics and Statistics Just Accepted MS.
https://doi.org/10.1162/rest_a_01252

the reserved slots.

Theorem 2 *Fix any pair of priority orders $\pi, \pi^* \in \Pi$. Assuming $\pi_u = \pi_r = \pi$, let $\mu^{ef} = \varphi^{ef}(E)$ be the outcome of the Exemptions-First visa allocation rule. Assuming $\pi_u = \pi$ and $\pi_r = \pi^*$, let $\mu^{ru} = \varphi^{ru}(E)$ be the outcome of the Reserved-Initiated visa allocation rule. Then,*

1. $|\mu^{ef}(I_R)| \leq |\mu^{ru}(I_R)|$ *and*
2. $\mu^{ru}(I_G) \subseteq \mu^{ef}(I_G)$.

The following observation is key for understanding the mechanics behind Theorem 2. Under the Exemptions-First rule, a single priority order π is used to allocate both types of slots, applicants are considered sequentially following this priority order, and an applicant receives a slot provided that one remains that is fit for her category. Importantly, for the case of a reserved-category applicant, precedence is given to assign her a reserved slot whenever both types of slots are available, which means no reserved-category applicant receives an unreserved slot under the Exemptions-First rule before all reserved slots are exhausted. But since only applicants from the reserved-category are eligible for the reserved slots, it would have made no difference in the outcome if the reserved slots were instead allocated to reserved-category applicants in a first step based on priority order π, and the unreserved units were allocated subsequently to remaining individuals in a second step, again based on the same priority order π. But this is exactly the description of the Reserved-Initiated rule when the priority order is the same for both types of slots. Therefore, the Exemptions-First rule is equivalent to a special case of the Reserved-Initiated rule when the priority order for unreserved slots in the second step is the same as the priority order used for reserved slots in the first round. This relation between the two visa allocation rules is the driving force behind Theorem 2. Remember that reliance of a single priority order for allocation of both types of slots was resulting

Review of Economics and Statistics Just Accepted MS.
https://doi.org/10.1162/rest_a_01252

in the highest-priority members of the reserved-category dropping from the competition for the unreserved positions under the Exemptions-First rule. When a distinct priority order is used for the two categories, members of the reserved category who receive the reserved units in the first step of the Reserved-Initiated rule (and thus drop from the competition for the unreserved units) are no longer the highest-priority members of the group under the priority order that is used to allocate unreserved units. Therefore as a group they receive at least as many unreserved units under the Reserved-Initiated rule as the Exemptions-First rule, assuming the same priority order is to allocate the unreserved slots under both rules. Since both visa allocation rules are non-wasteful, this also means that members of the general-category receive at least as many slots under the Exemptions-First rule as the Reserved-Initiated rule, again assuming the same priority order is to allocate the unreserved slots under both rules. Moreover, since allocation of unreserved slots is made using the same priority order under both rules, the comparison can be made in terms of set inclusion for members of the general-category.

3.3 FY2020 H-1B Allocation Reform

In contrast to previous reforms in H-1B visa allocation rules where the changes were officially justified based on logistical considerations, the reform of 2019 was motivated by an officially-stated objective of increasing the fraction of reserved-category applicants who receive H-1B visas. In 2019, USCIS adopted the Unreserved-Initiated visa allocation rule φ^{ur} starting in FY2020, thus abandoning the rule φ^{ru} that was used for over a decade.

Consistent with its officially-stated objective, our next result establishes that the 2019 reform resulted in a visa allocation rule that is more favorable for the reserved-category applicants and less favorable for the general-category applicants. Moreover, for any pair of fixed priority orders for reserved and unreserved slots, our result also establishes that the rule φ^{ur} is reserved-category-maximal and general-category-minimal, whereas the rule

Review of Economics and Statistics Just Accepted MS.
https://doi.org/10.1162/rest_a_01252

φ^{ru} is reserved-category-minimal and general-category-maximal.

Theorem 3 *Fix any pair of priority orders $\pi, \pi^* \in \Pi$. Let $\mu^{ru} = \varphi^{ru}(E)$ be the outcome of the Reserved-Initiated visa allocation rule, and $\mu^{ur} = \varphi^{ru}(E)$ be the outcome of the Unreserved-Initiated visa allocation rule. Let $\mu \in \mathcal{M}$ be any matching that complies with the statute. Then*

1. $|\mu^{ru}(I_R)| \leq |\mu(I_R)| \leq |\mu^{ur}(I_R)|$ *and*
2. $\mu^{ur}(I_G) \subseteq \mu(I_G) \subseteq \mu^{ru}(I_G)$.

The intuition for Theorem 3 is more straightforward than the intuition for Theorems 1 and 2. While reserved slots are exclusive to reserve-category applicants, both groups compete for the the unreserved slots. Also note that two (potentially distinct) priority orders π, π^* are used under both Reserved-Initiated and Unreserved-Initiated visa allocation rules. Therefore, allocation of the reserved slots to highest π-priority reserved-category applicants in Step 1 under the Reserved-Initiated visa allocation rule does not necessarily mean its remaining members (who compete in Step 2 for the unreserved slots) have lower priorities under π^* (unless there is a strong positive correlation between the two priority orders). But the allocation of reserved slots prior to unreserved ones under the Reserved-Initiated visa allocation rule still means that, while only some of the applicants from the reserved-category compete for the unreserved slots under this visa allocation rule, all of them compete for the unreserved slots under the alternative Unreserved-Initiated visa allocation rule. And for an arbitrary matching which satisfies the three axioms, the representation of this group has to be between these two extremes. Moreover, since allocation of unreserved slots is made using the same priority order under both rules, the comparison can be made in terms of set inclusion for members of the general-category.

Review of Economics and Statistics Just Accepted MS.
https://doi.org/10.1162/rest_a_01252

3.4 Comparison of Post-2004 H-1B Visa Allocation Rules

Consider all four post-2004 visa allocation rules φ^{ef}, φ^{oa}, φ^{ru}, and φ^{ur}. Given any pair of priority orders $\pi, \pi^* \in \Pi$, fix

1. the priority order for unreserved slots of each of the four rules at $\pi_u = \pi$,
2. the priority order for reserved slots of each of the two single-priority rules φ^{ef} and φ^{oa} at $\pi_r = \pi$, and
3. the priority order for reserved slots of each of the two dual-priority rules φ^{ru} and φ^{ur} at $\pi_r = \pi^*$.

Observe that Step 1 of the two rules φ^{oa} and φ^{ur} are identical. Therefore, unreserved slots are allocated to the same set of applicants under both rules. Not only do both rules match an identical set of general-category applicants, but they also match an identical number of reserved-category applicants. The set of reserved-category applicants matched in Step 2 potentially differ under these rules since they rely on different priority orders to fill the reserved slots. We next summarize these observations formally.

Observation 2 *Fix a pair of priority orders $\pi, \pi^* \in \Pi$. Assuming $\pi_u = \pi_r = \pi$, let $\mu^{oa} = \varphi^{oa}(E)$ be the outcome of the Over-and-Above visa allocation rule and $\mu^{ef} = \varphi^{ef}(E)$ be the outcome of the Exemptions-First visa allocation rule. Assuming $\pi_u = \pi$ and $\pi_r = \pi^*$, let $\mu^{ru} = \varphi^{ru}(E)$ be the outcome of the Reserved-Initiated visa allocation rule and $\mu^{ur} = \varphi^{ur}(E)$ be the outcome of the Unreserved-Initiated visa allocation rule. Then,*

1. *$|\mu^{oa}(I_R)| = |\mu^{ur}(I_R)|$ and*
2. *$\mu^{oa}(I_G) = \mu^{ur}(I_G)$.*

The following result immediately follows from Theorems 1-3 and Observation 2.

Review of Economics and Statistics Just Accepted MS.
https://doi.org/10.1162/rest_a_01252

Corollary 1 *Fix a pair of priority orders $\pi, \pi^* \in \Pi$. Assuming $\pi_u = \pi_r = \pi$, let $\mu^{oa} = \varphi^{oa}(E)$ be the outcome of the Over-and-Above visa allocation rule and $\mu^{ef} = \varphi^{ef}(E)$ be the outcome of the Exemptions-First visa allocation rule. Assuming $\pi_u = \pi$ and $\pi_r = \pi^*$, let $\mu^{ru} = \varphi^{ru}(E)$ be the outcome of the Reserved-Initiated visa allocation rule and $\mu^{ur} = \varphi^{ur}(E)$ be the outcome of the Unreserved-Initiated visa allocation rule. Then,*

1. $|\mu^{ef}(I_R)| \leq |\mu^{ru}(I_R)| \leq |\mu^{ur}(I_R)| = |\mu^{oa}(I_R)|$ *and*
2. $\mu^{oa}(I_G) = \mu^{ur}(I_G) \subseteq \mu^{ru}(I_G) \subseteq \mu^{ef}(I_G)$.

3.5 Estimating Outcomes Across Rules

In this section, we assess the quantitative differences in the degree of skill bias imposed by the different visa allocation rules. To simplify the analysis, in this section we work with a continuum version of our model derived from that in Dur, Pathak, and Sönmez (2020). There exist

- a continuum set of general-category applicants I_G with mass $|I_G|$,
- a continuum set of reserved-category applicants I_R with mass $|I_R|$,
- a continuum set of unreserved slots with mass q_u, and
- a continuum set of reserved slots with mass q_r.

So far, our formal analysis has not placed any structure on the distribution of the two priority orders for unreserved and reserved slots. To quantify the effects of the four policies used in practice, assumptions about that structure are needed. We model the two priority orders used under the Reserved-Initiated and Unreserved-Initiated rules as two independent uniform draws, consistent with the practice in the U.S. since FY2009. For

Review of Economics and Statistics Just Accepted MS.
https://doi.org/10.1162/rest_a_01252

the case of the Over-and-Above and Exemptions-First rules, we assume a single uniform draw.[10]

Suppose that each applicant $i \in I_G \cup I_R$ has two priority scores $\sigma(i)$ and $\sigma^*(i)$, which are independent and uniformly distributed draws from the closed interval $[0, 1]$. Priority orderings over individuals for unreserved slots depend on the priority score function σ for all four rules. Given two applicants $i, j \in I_G \cup I_R$,

- applicant i has higher priority for unreserved slots than applicant j if and only if $\sigma(i) > \sigma(j)$.

General-category applicants are ineligible for the reserved slots, and priority of reserved-category applicants depend on the priority score function $\sigma(\cdot)$ for the Over-and-Above and Exemptions-First rules whereas it depends on the priority score function $\sigma^*(\cdot)$ for the Reserved-Initiated and Unreserved-Initiated rules. Therefore, given two reserved-category applicants $i, j \in I_R$,

- applicant i has higher priority for reserved slots than applicant j if and only if $\sigma(i) > \sigma(j)$ under rules Over-and-Above and Exemptions-First, and
- applicant i has higher priority for reserved slots than applicant j if and only if $\sigma^*(i) > \sigma^*(j)$ under rules Reserved-Initiated and Unreserved-Initiated.

For the Over-and-Above rule, in Step 1 the mass of q_u unreserved slots are allocated to members of both groups in proportion to the sizes of both groups. Subsequently in Step 2, the mass of q_r reserved slots are awarded to reserved-category applicants, unless of course less than a mass of q_r reserved-category applicants remain who are unmatched. In that case, each remaining reserved-category applicant is awarded a reserved slot. Therefore,

[10]By conducting our calculations under these assumptions, we isolate changes in allocations that are attributable to the changes in processing order and changes in the number of priorities used. Our calculations do not assess the role of differences in the distribution of priority scores across groups (as could occur when priority is determined by arrival time).

Review of Economics and Statistics Just Accepted MS.
https://doi.org/10.1162/rest_a_01252

the expected masses of reserved-category and general-category applicants matched under the Over-and-Above visa allocation rule are:

$$|\mu^{oa}(I_R)| = \frac{|I_R|}{|I|}q_u + \min\left\{q_r, |I_R| - \left(\frac{|I_R|}{|I|}q_u\right)\right\},$$
$$|\mu^{oa}(I_G)| = \frac{|I_G|}{|I|}q_u.$$

The following observation is helpful to derive the expected mass of reserved-category and general-category applicants matched under the Exemptions-First visa allocation rule. Under this rule, the reserved cap provides a benefit to reserved-category applicants only if their proportional share is less than the reserved cap. Otherwise all slots (reserved or unreserved) are allocated in proportion to the sizes of both groups. If, on the other hand, the proportional share of the reserved-category applicants is less than the reserved cap, then the entire mass q_r of reserved slots (which is more than their proportional share of all slots) is awarded to reserved-category applicants, whereas the entire mass q_u of unreserved slots (which is less than their proportional share of all slots) is awarded to general-category applicants. Therefore, the expected masses of reserved-category and general-category applicants matched under the Exemptions-First allocation rule are:

$$|\mu^{ef}(I_R)| = \max\left\{q_r, \frac{|I_R|}{|I|}(q_u + q_r)\right\},$$
$$|\mu^{ef}(I_G)| = \min\left\{q_u, \frac{|I_G|}{|I|}(q_u + q_r)\right\}.$$

Under the Reserved-Initiated allocation rule, in Step 1 the mass of q_r reserved slots is awarded to the q_r highest σ^*-priority score reserved-category applicants. Therefore, the remaining masses of $|I_R| - q_r$ reserved-category applicants and $|I_G|$ general-category applicants compete for the mass of q_u unreserved positions in Step 2, each group receiving

Review of Economics and Statistics Just Accepted MS.
https://doi.org/10.1162/rest_a_01252

their proportional share from this mass. Hence, the expected masses of of reserved-category and general-category applicants matched under the Reserved-Initiated allocation rule are:

$$|\mu^{ru}(I_R)| = q_r + \left(\frac{|I_R| - q_r}{|I| - q_r}\right) q_u,$$
$$|\mu^{ru}(I_G)| = \left(\frac{|I_G|}{|I| - q_r}\right) q_u.$$

Under the Unreserved-Initiated allocation rule, all applicants compete for the mass of q_u unreserved slots in Step 1, each group receiving their proportional share from this mass. Subsequently in Step 2, the entire mass q_r of reserved slots are awarded to reserved-category applicants, unless of course fewer than a mass of q_r reserved-category applicants remain who are unmatched. In that case, each remaining reserved-category applicant is awarded a reserved slot. Therefore, the expected masses of reserved-category and general-category applicants matched under the Unreserved-Initiated visa allocation rule are:

$$|\mu^{ur}(I_R)| = \frac{|I_R|}{|I|} q_u + \min\left\{q_r, |I_R| - \left(\frac{|I_R|}{|I|} q_u\right)\right\},$$
$$|\mu^{ur}(I_G)| = \frac{|I_G|}{|I|} q_u.$$

[Table 2 about here]

In Table 2, we use these formulas together with data from the 2019 Federal Register on application rates by general and advanced-degree applicants to quantify the effect of different rules. These data cover the most recently available year and a five-year average. Data from these years are of particular interest because they formed the basis of the calculations in the USCIS government press release announcing the Trump admin-

Review of Economics and Statistics Just Accepted MS.
https://doi.org/10.1162/rest_a_01252

istration's modification of the allocation rule (USCIS, 2018). The table shows that the share of advanced-degree applications has increased over time since the count for FY2017 is greater than the five-year average. The 2006 replacement of Over-and-Above with Exemption-First resulted in a reduction of about 14,000 visa awards to advanced-degree applicants, using the numbers from the five-year average. The 2008 switch to Reserved-Initiated with two separate lotteries increased the number of awards to advanced-degree applicants by about 8,800 to 33,495. As mentioned above, with two lotteries, the scope for changing the number of advanced-degree applicants by changing processing of applicants shrinks. Even though Reserved-Initiated generates the least favorable outcome for advanced-degree applicants, it generates an outcome that is only about 5,339 applications worse for this group than Unreserved-Initiated, the rule which generates the most favorable outcome for advance-degree applicants.[11] This pattern shows that the rule changes in 2006 and 2008 were each quantitatively more significant than the 2019 change. We also observe the same phenomenon using application data from FY2017 as our benchmark.

4 Revisiting the History of Visa Allocation Rule Modifications

The H-1B Visa Reform Act of 2004 mandated the introduction of the advanced-degree reserve explicitly to favor higher-skilled applicants—i.e., to influence the skill bias reflected in allocations. Our analysis demonstrates that the range of implementations that comply with this statute differ in their degree of skill bias, and that the quantitative differences in skill bias among the four allocation rules that were adopted are non-negligible. In this section we present a brief review of the history and motivation for these changes. While the FY2020 rule change was explicitly motivated by desire to influence the degree of skill

[11] This number differs from the 5,340 reported in the USCIS press release because of rounding.

Review of Economics and Statistics Just Accepted MS.
https://doi.org/10.1162/rest_a_01252

bias, the previous reforms were not. Given the focus on logistical considerations that motivated these prior reforms, it appears that their important influence on skill bias was potentially unintended and unappreciated.

Prior to the H-1B Visa Reform Act of 2004, allocation of H-1B visas was carried out annually on a first-in first-out basis. This practice induced a natural priority order between applicants based on the time a petition arrived at a USCIS processing center. The use of this priority introduced a temporal element to the reserve implementation decision. If the USCIS received an advanced-degree application before the unreserved cap had been exhausted, would this visa count towards the reserved or unreserved cap? A USCIS press release offered their interpretation:

> "The first 20,000 H-1B beneficiaries who have earned a master's degree or higher from a U.S. institution of higher education are not subject to the annual congressionally mandated H-1B visa cap of 65,000. After those 20,000 slots are filled, USCIS is required to count those cases against the cap for the remainder of the fiscal year."[12] (USCIS, 2004)

In the terminology introduced in Section 2.4, the USCIS interpreted the legislation to dictate the Exemptions-First visa allocation rule. This rule was adopted by USCIS for FY2006-FY2008.

Despite this interpretation, the USCIS adopted a different visa allocation rule in the first year of implementation (FY2005). The justification offered by the USCIS for this difference was based on how the application timeline intersected with the passage of the Visa Reform Act. In the U.S., the federal government's fiscal year starts on October 1 of the previous calendar year and runs through September 30 of the calendar year. The Act was announced in December 2004 and took effect mid-fiscal-year in March 2005. By the time the additional reserved cap of 20,000 took effect, applications for FY2005 were

[12]The USCIS's initial interpretation that the reserve cap should be processed first can be justified by the use of the word "until" in 8 USC §1184(g)(5)(C)).

Review of Economics and Statistics Just Accepted MS.
https://doi.org/10.1162/rest_a_01252

already evaluated and the unreserved cap of 65,000 was already allocated. The USCIS indicated that they had no way to identify which of the 65,000 awarded applications would qualify for the advanced-degree exemption, and instead they stated:

> "[. . .], for FY 2005, USCIS has determined that the only appropriate way to implement the H-1B Visa Reform Act of 2004 is to apply the 20,000 exemptions prospectively." (Federal Register, 2005)

While the justification for using a different visa allocation rule for FY2005 than the rule adopted for subsequent years had been clearly articulated, the distributional implications of this one-time implementation have not been analyzed prior to our study. The analysis in Section 3.1 shows that, of all the rules that comply with the statute and utilize a single priority, the two rules implemented in FY2005 and FY2006-FY2008 play special roles: the Over-and-Above visa allocation rule is reserved-category-maximal and general-category-minimal, whereas the Exemptions-First visa allocation rule is reserved-category-minimal and general-category-maximal. The analysis of Section 3.5 indicates that this difference is quantitatively important, with the Over-and-Above rule allocating 16.7% more of annual slots to advanced-degree applicants (compared to the Exemptions First rule) in our analysis of FY2013-FY2017 averages. Given that influencing skill bias was a key motivation of the H-1B Visa Reform Act of 2004, the fact that such large changes in skill bias were implemented for logistical convenience partially motivates our belief that the impact of these implementation decisions was not appreciated at the time.

During the period when the Exemptions-First rule was used, changing application patterns created difficulties in using an arrival-time-based priority order. Over the three years from FY2006-FY2008 applications arrived earlier and caps were reached sooner.[13]

[13]The H-1B petition filing period for any fiscal year typically begins on April 1st of the previous calendar year. The Federal Register reports that in FY2006 the general cap was reached on August 10, 2005 and the advanced-degree cap was reached on January 17, 2006; in FY2007 the general cap was reached on May 26, 2006 and the advanced-degree cap was reached on July 26, 2006; and in FY2008 the general cap was reached on April 1, 2007 and the advanced-degree cap was reached on May 4, 2007. (Federal Register, 2008).

Review of Economics and Statistics Just Accepted MS.
https://doi.org/10.1162/rest_a_01252

In FY2008, a number of general-category applications sufficient to meet the 65,000 unreserved cap arrived on the first day that applications were accepted by the USCIS.[14] Anticipating this may happen, employers spent significant effort and money to send petitions by expedited overnight delivery for receipt on the first day petitions would be allowed, resulting in more than 150,000 petitions being delivered on the same day and burdening employers, delivery services, and USCIS offices.[15] This development made clear that the use of arrival time as a priority measure was no longer tenable.

Consequently, in March 2008 USCIS abandoned its use of arrival time for priority. Under their new rule, applications must be submitted in a five day window. Valid applications submitted within this window had priority assigned randomly, and a second independent and random priority was assigned to all advanced-degree applicants.[16] Under the new procedure, the USCIS continued to process the reserved cap first. This group of decisions results in the Reserved-Initiated allocation rule introduced in Section 2.4. This rule remained in effect from FY2009-FY2019.

The change in the allocation rule implemented in FY2009 again influenced the degree of skill bias reflected in visa allocations. While it is natural to assume that some change could arise due to differences in arrival times of reserved-category and general-category applications, a large and more subtle effect arises from the mere addition of a separate independent priority for reserved-category applicants. When a single priority is used, the practice of allocating the 20,000 highest-priority reserved-category applicants to the reserve cap results in comparatively low-priority reserved-category applicants competing for the general-cap positions. In contrast, when separate and independent priorities are

[14]In the USCIS's implementation of the arrival-time priority order, day of arrival determined priority and ties were resolved with a random lottery. As a result, though FY2008 still fell under the arrival-time priority regime, in effect priority was fully determined by random lottery among individuals tied for top priority under arrival time.

[15]This information comes from the United States District Court Case *Walker Macy (2017) vs. U.S. Citizenship and Immigration Services*.

[16]If sufficient applications from either category was not received within five days, the reform allowed for additional petitions that arrived later. When this condition is triggered it returns some influence of arrival time into the priority order.

Review of Economics and Statistics Just Accepted MS.
https://doi.org/10.1162/rest_a_01252

used, the reserved-category applicants who do not receive a visa under the reserve cap are not selected for low priority when considered for the general cap. This absence of selection results in a greater number of visas going to reserved-category applicants, as we formalized in Section 3.2. The analysis of Section 3.5 again indicates that this difference is quantitatively important, with the Reserved-Initiated rule allocating 10.4% more of annual slots to advanced-degree applicants (compared to the Exemptions First rule) in our analysis of FY2013-2017 averages. Given that this change was transparently made to address the logistical problems with arrival-time-based priority, changing the degree of skill bias through the decisions to use two independent lotteries may have been unintended. We are not aware of any indication that it was an explicit design decision, and the lack of publicity surrounding this effect suggests that the impact was unappreciated.

In stark contrast to these earlier rule modifications, the changes proposed in response to President Trump's *Buy American and Hire American Executive Order* demonstrate an unambiguous and deliberate attempt to influence skill bias through the mechanisms studied here. This 2017 executive order instructed the U.S. Department of Homeland Security to propose reforms to ensure that H-1B visas are awarded to the most-skilled or highest-paid petition beneficiaries. In response, the USCIS proposed maintaining the general structure of the FY2009-FY2019 Reserved-Initiated visa allocation rule, but reversing the processing order of reserved and unreserved slots: the Unreserved-Initiated rule introduced in Section 2.4. The analysis of Section 3.3 establishes that the allocation from the FY2020 Unreserved-Initiated visa allocation rule exhibits more skill bias than the FY2009-FY2019 Reserved-Initiated visa allocation rule. Moreover, Section 3.4 demonstrates that its outcome awards the same number of advanced-degree visas as in FY2005 Over-and-Above visa allocation rule, and thus it is reserved-category-maximal even including single-priority-order rules.

Review of Economics and Statistics Just Accepted MS.
https://doi.org/10.1162/rest_a_01252

5 Conclusion

Former President Trump's 2017 *Buy American and Hire American Executive Order* led the USCIS to reform the H-1B visa allocation system in 2019. We show that the newly-adopted Unreserved-Initiated rule is the most favorable for advanced-degree applicants among all rules satisfying our three axioms capturing compliance with the statute. Surprisingly, of the three modifications to the H-1B visa allocation rule since the Act of 2004, the 2019 reform causes the smallest year-to-year change in the number of advanced-degree awards. Despite that, the distributional implications of the 2019 reform were much more widely publicized compared to the more consequential (but possibly accidental) changes in FY2006 and FY2009.

Beyond shedding light on this recent history, our results also inform debates on potential future reforms. One class of reform proposals involves changes to the priority structure used; for example, prioritizing applicants based on their wage or based on firms' willingness to pay for a visa in an auction. Our theoretical results on single-priority systems remain valid if these priorities are used, and thus provide guidance on how the reserve system may be concurrently modified to better pursue the goals motivating such a reform. When considering the importance placed on being highly paid versus highly educated, the over-and-above allocation rule or the exemptions-first allocation rule would reflect two extremes. The enacted rule can be chosen to best reflect the optimal tradeoff as assessed by the policy maker, offering a means of fine-tuning that is not easily achieved through modification of the single priority alone. Another class of reform proposals involves changes to reserved-category classification; for example, having caps specific for regions or occupations. Our theoretical results provide immediate guidance on how the processing order of these caps, and how the choice to apply a single priority or to implement independent priorities, would influence the rate of admission of the workers targeted by such a cap. For more detailed discussion of these (and other) reform proposals, see

Review of Economics and Statistics Just Accepted MS.
https://doi.org/10.1162/rest_a_01252

Kerr and Kerr (2020).

An important caveat to the interpretation of our results is that they do not, taken alone, indicate the optimal program design. Instead, our results merely clarify how several design decisions affect the degree of preferential treatment extended to reserved-category applicants. The optimal degree of preferential treatment—or skill bias, when the relevant reserved category is based on advanced-degree status—must be determined through judgments and analyses quite different from our own, which are themselves the subject of a great deal of debate. The Trump administration was relatively clear in their stated desire to maximize skill bias, and the reserved-category-maximal rule they imposed is optimal contingent on accepting that goal. The degree of skill bias that was viewed as optimal at other points in the H-1B program's history is often less clear, beyond the fact that the imposition of reserved caps itself reflects a clear desire for some degree of this bias. While we remain silent on these underlying normative issues, we note that our findings provide a means of determining the normative values that implicitly rationalize administrations' choices going forward. Of course, doing so requires imposing the assumption that administrations deliberately vary the design elements that we have highlighted to achieve their desired policy outcomes. This assumption appears to not have held at times in the past, but it may hold in the future now that these issues have been clearly analyzed.

References

Abdulkadiroğlu, A. (2005): "College Admissions with Affirmative Action," *International Journal of Game Theory*, 33(4), 535–549.

Abdulkadiroğlu, A., and A. Grigoryan (2021): "Priority-Based Assignment with Reserves and Quotas," Working Paper.

Review of Economics and Statistics Just Accepted MS.
https://doi.org/10.1162/rest_a_01252

Abdulkadiroğlu, A., and T. Sönmez (2003): "School Choice: A Mechanism Design Approach," *American Economic Review*, 93, 729–747.

Amuedo-Dorantes, C., and D. Furtado (2017): "Settling for Academia? H-1B Visas and the Career Choices of International Students in the United States," *Journal of Human Resources*, 54(2), 401–429.

Andersson, T. (2017): "Refugee Matching as a Market Design Application," Working paper.

Aygün, O., and I. Bo (2021): "College Admission with Multidimensional Reserves: The Brazilian Affirmative Action Case," *American Economic Journal: Microeconomics*, 13(3), 1–28.

Aygün, O., and B. Turhan (2020): "Dynamic Reserves in Matching Markets," *Journal of Economic Theory*, 188, 105069.

Balinski, M., and T. Sönmez (1999): "A Tale of Two Mechanisms: Student Placement," *Journal of Economic Theory*, 84, 73–94.

Biro, P., T. Fleiner, R. Irving, and D. Manlove (2010): "The College Admissions Problem with Lower and Common Quotas," *Theoretical Computer Science*, 411(34-26), 3136–3153.

Bo, I. (2016): "Fair Implementation of Diversity in School Choice," *Games and Economic Behavior*, 97, 54–63.

Bound, J., G. Khanna, and N. Morales (2017): "Understanding the Economic Impact of the H-1B Program on the U.S.," Working Paper 23153, National Bureau of Economic Research.

Review of Economics and Statistics Just Accepted MS.
https://doi.org/10.1162/rest_a_01252

Budish, E. (2011): "The Combinatorial Assignment Problem: Approximate Competitive Equilibrium from Equal Incomes," *Journal of Political Economy*, 119(6), 1061–1103.

Budish, E., Y.-K. Che, F. Kojima, and P. R. Milgrom (2013): "Designing Random Allocation Mechanisms: Theory and Applications," *American Economic Review*, 103(2), 585–623.

Çelebi, O., and J. Flynn (2022a): "Adaptive Priority Mechanisms," Working paper.

——— (2022b): "Priority Design in Centralized Matching Markets," *Review of Economic Studies*, 89(3), 1245–1277.

Chassamboulli, A., and G. Peri (2018): "The Economic Effect of Immigration Policies: Analyzing and Simulating the U.S. Case," Working Paper 25074, National Bureau of Economic Research.

Delacrétaz, D. (2020): "Processing Reserves Simultaneously," Working Paper.

Delacrétaz, D., S. D. Kominers, and A. Teytelboym (2016): "Refugee Resettlement," Working paper.

Dimmock, S. G., J. Huang, and S. J. Weisbenner (2021): "Give Me Your Tired, Your Poor, Your High-Skilled Labor: H-1B Lottery Outcomes and Entrepreneurial Success," *Management Science*, forthcoming.

Doran, K., A. Gelber, and A. Isen (2014): "The Effects of High-Skilled Immigration Policy on Firms: Evidence from H-1B Visa Lotteries," Working Paper 20668, National Bureau of Economic Research.

Doğan, B. (2016): "Responsive Affirmative Action in School Choice," *Journal of Economic Theory*, 165, 69–105.

Review of Economics and Statistics Just Accepted MS.
https://doi.org/10.1162/rest_a_01252

——— (2017): "How to Control Controlled School Choice: Comment," *American Economic Review*, 107(4), 1362–1364.

Doğan, B., and K. Yildiz (2022): "Choice with Affirmative Action," *Management Science*, forthcoming.

Dur, U., S. Kominers, P. Pathak, and T. Sönmez (2018): "Reserve Design: Unintended Consequences and The Demise of Boston's Walk Zones," *Journal of Political Economy*, 126(6), 2457–2479.

Dur, U., P. Pathak, and T. Sönmez (2020): "Explicit vs. Statistical Preferential Treatment in Affirmative Action: Theory and Evidence from Chicago's Exam Schools," *Journal of Economic Theory*, 187, 104996.

Echenique, F., and M. B. Yenmez (2015): "How to Control Controlled School Choice," *American Economic Review*, 105(8), 2679–2694.

Edelman, B., M. Ostrovsky, and M. Schwarz (2007): "Internet Advertising and the Generalized Second-Price Auction: Selling Billions of Dollars Worth of Keywords," *American Economic Review*, 97(1), 242–259.

Ehlers, L., I. E. Hafalir, M. B. Yenmez, and M. A. Yildirim (2014): "School Choice with Controlled Choice Constraints: Hard Bounds versus Soft Bounds," *Journal of Economic Theory*, 153, 648–683.

Ehlers, L., and T. Morrill (2020): "(Il)legal Assignments in School Choice," *Review of Economic Studies*, 87(4), 1837–1875.

Erdil, A., and T. Kumano (2019): "Efficiency and Stability under Substitutable Priorities with Ties," *Journal of Economic Theory*, 184, 104950.

Review of Economics and Statistics Just Accepted MS.
https://doi.org/10.1162/rest_a_01252

Federal Register (2005): "Allocation of Additional H-1B Visas Created by the H-1B Visa Reform Act of 2004," Vol. 70, No. 86, Thursday, May 5.

——— (2008): "Petitions Files on Behalf of H-1B Temporary Workers Subject to or Exempt From the Annual Numerical Limitation," Vol. 73, No. 57, Monday March 24.

——— (2018): "Registration Requirement for Petitioners Seeking to File H-1B Petitions on Behalf of Cap-Subject Aliens," Vol. 83, No. 232, Monday December 3.

Fragiadakis, D., and P. Troyan (2017): "Improving Matching under Hard Distributional Constraints," *Theoretical Economics*, 12(2), 863–908.

Glennon, B. (2020): "How Do Restrictions on High-Skilled Immigration Affect Offshoring? Evidence from the H-1B Program," Working Paper 27538, National Bureau of Economic Research.

Hafalir, I. E., M. B. Yenmez, and M. A. Yildirim (2013): "Effective Affirmative Action in School Choice," *Theoretical Economics*, 8(2), 325–363.

Imamura, K. (2020): "Meritocracy versus Diversity," Working paper.

Jones, W., and A. Teytelboym (2017): "The Local Refugee Match: Aligning Refugees' Preferences with the Capacities and Priorities of Localities," *Journal of Refugee Studies*, 31(2), 152–178.

Kamada, Y., and F. Kojima (2015): "Efficient Matching under Distributional Constraints: Theory and Applications," *American Economic Review*, 105(1), 67–99.

——— (2017): "Stability Concepts in Matching with Distributional Constraints," *Journal of Economic Theory*, 168, 107–142.

——— (2018): "Stability and Strategy-proofness for Matching with Constraints: A Necessary and Sufficient Condition," *Theoretical Economics*, 13(2), 761–794.

Review of Economics and Statistics Just Accepted MS.
https://doi.org/10.1162/rest_a_01252

Kato, T., and C. Sparber (2013): "Quotas and Quality: The Effect of H-1B Visa Restrictions on the Pool of Prospective Undergraduate Students from Abroad," *The Review of Economics and Statistics*, 95(1), 109–126.

Kerr, S. P., W. Kerr, and W. Lincoln (2015): "Skilled Immigration and the Employment Structures of U.S. Firms," *Journal of Labor Economics*, 33:S1, S147–S186.

Kerr, S. P., and W. R. Kerr (2020): "Immigration Policy Levers for US Innovation and Startups," in *Innovation and Public Policy*, ed. by A. Goolsbee, and B. Jones. University of Chicago Press, forthcoming.

Kerr, W. R., and W. F. Lincoln (2010): "The Supply Side of Innovation: H-1B Visa Reforms and U.S. Ethnic Invention," *Journal of Labor Economics*, 28(3), 473–508.

Kojima, F. (2012): "School Choice: Impossibilities for Affirmative Action," *Games and Economic Behavior*, 75(2), 685–693.

Kominers, S. D., and T. Sönmez (2016): "Matching with Slot-specific Priorities: Theory," *Theoretical Economics*, 11(2), 683–710.

Macy, W. (2017): "Walker Macy v. U.S. Citizenship and Immigration," 243 F.Supp.3d (1156), United States District Court, D. Oregon, March 17.

Mayda, A. M., F. Ortega, G. Peri, K. Shih, and C. Sparber (2018): "The Effect of the H-1B Quota on the Employment and Selection of Foreign-Born Labor," *European Economic Review*, 108(C), 105–128.

Mayda, A. M., F. Ortega, G. Peri, K. Y. Shih, and C. Sparber (2020): "Coping with H-1B Shortages: Firm Performance and Mitigation Strategies," Working Paper 27730, National Bureau of Economic Research.

Review of Economics and Statistics Just Accepted MS.
https://doi.org/10.1162/rest_a_01252

Milgrom, P. R. (2000): "Putting Auction Theory to Work: The Simultaneous Ascending Auction," *Journal of Political Economy*, 108, 245–272.

Pathak, P., T. Sönmez, U. Ünver, and B. Yenmez (2020): "Fair Allocation of Vaccines, Ventilators and Antiviral Treatments: Leaving No Ethical Value Behind in Health Care Rationing," arXiv:2008.00374.

Pathak, P. A., A. Rees-Jones, and T. Sönmez (2020): "Reversing Reserves," *Management Science*, forthcoming.

Pathak, P. A., and T. Sönmez (2008): "Leveling the Playing Field: Sincere and Sophisticated Players in the Boston Mechanism," *American Economic Review*, 98(4), 1636–1652.

——— (2013): "School Admissions Reform in Chicago and England: Comparing Mechanisms by their Vulnerability to Manipulation," *American Economic Review*, 103(1), 80–106.

Peri, G., K. Shih, and C. Sparber (2015): "STEM Workers, H-1B Visas, and Productivity in US Cities," *Journal of Labor Economics*, 33(S1), S225–S255.

Roth, A. E. (1984): "The Evolution of the Labor Market for Medical Interns and Residents: A Case Study in Game Theory," *Journal of Political Economy*, 92, 991–1016.

Roth, A. E., and E. Peranson (1999): "The Redesign of the Matching Market for American Physicians: Some Engineering Aspects of Economic Design," *American Economic Review*, 89, 748–780.

Roth, A. E., T. Sönmez, and U. Ünver (2004): "Kidney Exchange," *Quarterly Journal of Economics*, 119, 457–488.

Review of Economics and Statistics Just Accepted MS.
https://doi.org/10.1162/rest_a_01252

——— (2005): "Pairwise Kidney Exchange," *Journal of Economic Theory*, 125, 151–188.

Schummer, J., and A. Abizada (2017): "Incentives in Landing Slot Problems," *Journal of Economic Theory*, 170, 29–55.

Schummer, J., and R. V. Vohra (2013): "Assignment of Arrival Slots," *American Economic Journal: Microeconomics*, 5(2), 164–185.

Sönmez, T. (2013): "Bidding for Army Career Specialties: Improving the ROTC Branching Mechanism," *Journal of Political Economy*, 121(1), 186–219.

Sönmez, T., and T. Switzer (2013): "Matching with (Branch-of-Choice) Contracts at the United States Military Academy," *Econometrica*, 81(2), 451–488.

Sönmez, T., and M. U. Ünver (2010): "Course Bidding at Business Schools," *International Economic Review*, 51(1), 99–123.

Sönmez, T., and M. B. Yenmez (2022a): "Affirmative Action in India via Vertical, Horizontal, and Overlapping Reservations," *Econometrica*, 90(3), 1143–1176.

——— (2022b): "Constitutional Implementation of Affirmative Action Policies in India," arXiv:2203.01483.

Tomoeda, K. (2018): "Finding a Stable Matching under Type-specific Minimum Quotas," *Journal of Economic Theory*, 176, 81–117.

USCIS (2004): "USCIS to Implement H-1B Visa Reform Act of 2004," December 9.

——— (2018): "DHS Proposes Merit-Based Rule for More Effective and Efficient H-1B Visa Program," November 30; Available at: https://www.uscis.gov/archive/dhs-proposes-merit-based-rule-for-more-effective-and-efficient-h-1b-visa-program.

Review of Economics and Statistics Just Accepted MS.
https://doi.org/10.1162/rest_a_01252

VARIAN, H. R. (2007): "Position Auctions," *International Journal of Industrial Organization*, 25(6), 1163–1178.

WESTKAMP, A. (2013): "An Analysis of the German University Admissions System," *Economic Theory*, 53(3), 561–589.

Review of Economics and Statistics Just Accepted MS.
https://doi.org/10.1162/rest_a_01252

Table 1: H-1B Visa Allocation Rules

Years	Allocation Rule	Priorities Used	Reserves Processed	Publicized
FY2005	Over-and-Above (φ^{oa})	One	Last	N
FY2006-08	Exemptions-First (φ^{ef})	One	First	N
FY2009-19	Reserved-Initiated (φ^{ru})	Two	First	N
FY2020	Unreserved-Initiated (φ^{ur})	Two	Last	Y

Notes: This table summarizes the four visa allocation rules used by the USCIS since the H-1B Visa Reform Act of 2004. The "Allocation Rule" column provides the label for this rule used in our theory. Section 2.4 provides a complete description of each rule. The following two columns indicate 1) whether the rule applies one single priority across both caps or two independent priorities for each cap, and 2) whether the rule processes the reserved cap first or last. The final column indicates which rules were significantly publicized upon adoption (by prominent press releases and comments/discussion in the Federal register). Documentation for each allocation rule from the Federal Register is recorded in the Appendix.

Review of Economics and Statistics Just Accepted MS.
https://doi.org/10.1162/rest_a_01252

Table 2: Number of Slots Awarded to Reserved-Category Applicants Under a 65,000 General Cap and a 20,000 Reserve Cap

	# of Applicants		Reserved-Category Allocation			
	General Category	Reserved Category	φ^{oa}	φ^{ef}	φ^{ru}	φ^{ur}
5-yr Average (FY2013-17)	137,017	55,900	38,834	24,630	33,495	38,834
FY2017	111,080	87,380	48,619	37,425	44,542	48,619

Notes: Calculations are based on data from the 2019 Federal Register, assuming same arrival time distribution between reserved-category and general-category applicants, and identical lottery distribution for π_r and π_u.