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

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Abstract

In 2005, the U.S. Congress legislated that the H-1B visa program create 20,000 annual slots reserved for advanced-degree applicants. Since then, the U.S. Customs and Immigration Service (USCIS) has used visa allocation rules that comply with this legislation. Following a directive in the April 2017 *Buy American and Hire American Executive Order* by President Trump, USCIS tweaked its H-1B visa allocation rule in 2019. While remaining in compliance with the legislation set forth in 2005, the USCIS estimated that the 2019 rule change would increase the number of higher-skill awards by more than 5,000 annually at the expense of lower-skill awards. The rule change was explicitly engineered for this objective. In this paper we characterize all visa allocation rules that comply with the 2005 legislation and use this framework to analyze the rules that have been deployed in the interim. Despite specifying rigid caps, we show that the legislation permits a range of rules that can change the number of high-skill awards by as many as 14,000 in an average year. Of all rules that comply with the legislation, the 2019 rule adopted by the Trump administration maximizes the rate of high-skill awards and minimizes the rate of low-skill awards. However, two previous and relatively unknown changes to the H-1B visa allocation rule resulted in more substantial changes to this distribution. These earlier reforms, however, were motivated by logistical considerations, potentially without understanding of their distributional consequences.

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1 Introduction

Since its introduction in the Immigration Act of 1990, the U.S. H-1B program has enabled American companies to temporarily employ educated foreign workers in occupations that require highly specialized knowledge.[1] Each year, statutory law enacted by the U.S. Congress mandates the total number of visas to be granted. The U.S. Customs and Immigration Service (USCIS), a part of the Department of Homeland Security, is charged with implementing this mandate. Because the H-1B program is the largest temporary employment program for skilled immigration to the U.S., there are many contentious debates about the number and type of visas allocated.[2] H-1Bs are also a focal point in broader discussions about the appropriate skill-bias of U.S. immigration policy.[3]

This paper studies the **visa allocation problem** from the perspective of market design, motivated by the last 15 years of H-1B visa allocation reforms. During this time, visas were allocated according to the H-1B Visa Reform Act of 2004.[4] This act established an annual system in which 65,000 visas were made available for all eligible applicants and an additional 20,000 visas were reserved for applicants with advanced degrees. Popular discussions refer to these reserves as caps; we call the 20,000 visas for those with advanced degrees the *reserved cap* and the 65,000 visas available for all applicants the *unreserved cap*. We say that *reserved-category* applicants are those that have earned a master's or higher degree from a U.S. institution of higher education. We refer to applicants who are not qualified for these slots as *general-category* applicants. Although the advanced-degree reserve cap was prominently advertised, according to the Department of Homeland Security, details on how the cap should be implemented were left to the discretion of the USCIS (Register, 2005, 2018).[5]

At the time of the H-1B Visa Reform Act of 2004, visa allocation was carried out by the USCIS on a first-in first-out basis, up to total annual capacity. That is, the allocation was based on a single priority order, which in this case was induced by the arrival time of applications. In systems using a single priority order, intuition may suggest that merely specifying an additional cap for a subgroup of applicants is sufficient to uniquely determine the allocation.[6] Perhaps that is why the Congress has left the details of implementation

[1] Examples include such as engineering, computer science, or other STEM fields.

[2] A March 30, 2006 the Congressional Subcommittee on Immigration, Border Security, and Claims debated whether Congress should raise the H-1B cap (Judiciary, 2006). More recently, in 2018, Senators Orrin Hatch and Jeff Flake introduced legislation to increase the quota from 65,000 to 85,000 (O'Brien, 2018).

[3] Becker and Lazear (2013) argue that a market-based system where the U.S. sells the right to be a citizen would be fairer than current immigration rules.

[4] This act was signed in December 2004 and took effect in March 2005.

[5] 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).

[6] After all, in the absence of the cap for the subgroup, the allocation is uniquely determined through

of the advanced-degree cap to the USCIS. However, this intuition is misguided: a wide range of outcomes can be obtained through a range of visa allocation rules subject to an identical reserved cap.

Of course, any allocation rule applied must be consistent with existing legislation. The statutory text in the U.S. Code (8 USC §1184(g)(5)(C))) states that the annual 65,000 unreserved cap

> "shall not apply to any alien [...] who [...] has earned a master's or higher degree from a United States institution of higher education [...], until the number of aliens who are exempted from such numerical limitation during such year exceeds 20,000."

Based on this code, we argue that any plausible visa allocation rule should satisfy three properties. First, it should be *non-wasteful*, a minimal efficiency requirement. That means a general-category applicant should not be denied a slot unless all unreserved slots are exhausted; similarly, a reserved category applicant should not be denied a slot unless all slots (reserved or unreserved) are exhausted.[7] Second, it should *accommodate the reserve policy* by restricting the access for reserved slots to reserved category applicants only. Finally, it should *respect priorities*, which means an applicant who is qualified for a slot should not lose it to a candidate who has lower priority for this slot. When a visa allocation rule satisfies all three properties, we say it *complies with the statute*.

Table 1 summarizes the four visa allocation rules that have been implemented in the H-1B program since 2005, all of which comply with the statute as defined above. Our formal results characterize how these rules distribute access between general and advanced-degree applicants. In addition to analyzing these visa allocation rules, we also document previously unemphasized implications of the transitions between these rules.

The potential importance of these issues first became apparent in 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 was widely touted as increasing the number of advanced-degree applicants. For example, a government press release stated (USCIS, 2019):

> "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 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

a simple first-in first-out procedure.

[7]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.

Table 1: H-1B Visa Allocation Rules

Years	Allocation Rule	Priority	Publicized[§]
2005	Over-and-Above (φ^{oa})	Arrival time[†]	N
2006-08	Exemptions-First (φ^{ef})	Arrival time[†]	N
2009-19	Reserve-Initiated (φ^{ru})	Random	N
2020	Unreserved-Initiated (φ^{ur})	Random	Y

Notes: Years are fiscal years. Appendix provides documentation for each allocation rule from the Federal Register. §While each rule was described in public documents such as the Federal Register, by Publicized we mean the presence of prominent press releases and comments/discussion in the Federal Register. [†]If the cap is reached on a given day when there are more petitions than slots, a random lottery is used as a tie-breaker for the remaining slots.

> 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."

Given the publicity and debate regarding the objectives of the 2019 reform, our examination of the theoretical performance of the earlier iterations of this policy revealed two surprising findings. First, the degree of skill bias conferred by the FY2020 policy is identical to that that arises from the system employed immediately after the passage of the H1-B Visa Reform Act of 2004. Second, two reforms that occurred in the interim (in 2005 and 2008, respectively) had larger effects on the degree of skill bias. Strikingly, neither the reform in 2005 nor in 2008 were meaningfully publicized, and appear to have been enacted to overcome logistical hurdles surrounding the timing of visa applications. While the distributional consequences of the reform of 2019 was explicitly engineered, the larger distributional consequences of the reforms of 2005 and 2008 appear to be coincidental.

The next section provides additional detail on the H-1B Visa program and recent policy changes. It also discusses related literature. Section 3 defines the visa allocation problem and formally presents our axioms that characterize it. Section 4 studies visa allocation rules in a setting with one priority order, and then considers visa allocation rules when there are two separate priority orders for reserved slots and unreserved slots. The last section concludes. All proofs are in the appendix. A secondary appendix contains additional information describing the four visa allocation rules used in practice from the official Federal Register.

2 Causes and Consequences of H-1B Reforms

2.1 H-1B Visa Reform Act of 2004

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 arrives at the USCIS or a processing center. Perhaps due to this practice, the Congress introduced the additional 20,000 advanced-degree visas and the USCIS provided the following interpretation (USCIS, 2004):

> "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."

If this mandate is interpreted in relation to the existing first-in first-out procedure, it suggests the following visa allocation rule that we refer to as **Exemptions-First**:

> Process each application one-at-a-time following its arrival time.[8]
>
> 1. For each qualified application from a member of the general category, accept the application counting it against the unreserved cap of 65,000 until all unreserved slots are exhausted. Reject the application if all unreserved slots are exhausted.
> 2. For each qualified application from a member of the reserved category,
>   (a) exempt the application from the unreserved cap of 65,000 counting it against the reserved cap of 20,000 until all reserved slots are exhausted,
>   (b) count the application against the unreserved cap of 65,000 if all reserved slots are exhausted although there are remaining unreserved slots, and
>   (c) reject the application if all slots (reserved or unreserved) are exhausted.

In our view, this procedure reflects how the intended implementation of H-1B Visa Reform Act of 2004 was interpreted at the time by the USCIS. Supporting this perspective, the

[8]Time priority is based on the day the visa application is received. For the date on which new applications cause the annual cap to be exceeded, a random lottery is used among applicants for that date. Doran, Gelber, and Isen (2015) report that in FY2006 and FY2007 combined, a total of 4,180 visa applications were allocated through lottery. This represents about 2.5% of the 85,000 total annual slots.

Exemptions-First visa allocation rule was adopted by USCIS for FY2006 and the next two years.

For FY2005, however, the USCIS used the following rule, which we refer to as **Over-and-Above**:

> Process each application one-at-a-time following their arrival time.
>
> 1. For each qualified application, award the applicant a slot counting it against the unreserved cap of 65,000 until all unreserved slots are exhausted.
> 2. Once all unreserved slots are exhausted,
>   (a) reject all applications from subsequent general-category applicants;
>   (b) process only applications from reserved-category applicants, and award the qualified applicant a slot counting it against the reserved cap of 20,000 until all reserved slots are exhausted;
>   (c) reject the application if all slots (reserved or unreserved) are exhausted.

The justification offered by the USCIS for using a different visa allocation rule for FY2005 than the one adopted for subsequent years is based on how the application timeline intersected with the passage of the 2004 H-1B Visa Reform Act. In the U.S., the federal government's fiscal year starts on October 1 of the previous year and runs through September 30 of the year. The Act was announced in December 2004 and took effect in March 2005. By the time the additional reserved cap of 20,000 took effect, applications for FY2005 were 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 (Register, 2005)

> "[. . .], 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."

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. Even though both rules comply with the statute, their outcomes are very different. Consider a scenario with 87,380 reserved-category applications and 111,080 general-category applications. These numbers are the five year averages for FY2013-2017. The number of admitted advanced-degree applicants is 38,834 under the 2005 Over-and-Above rule and

24,630 under the Exemptions-First rule.[9] The difference, 16.7% of all annual 85,000 slots, is large given that both rules implement the same legislation. Therefore, the implementation of H-1B Visa Reform Act of 2004 significantly influences the distribution of H-1B visas between reserved-category and general-category applicants.

In our formal model, we show that, of all the rules that comply with the statute, the two rules implemented in FY2005 and FY2006-08 play special roles. Of all rules that comply with the statute, the Over-and-Above visa allocation rule is the most favorable rule for the reserved-category applicants and the least favorable rule for the general-category applicants. In striking contrast, the Exemptions-First visa allocation rule is the least favorable rule for the reserved-category applicants and the most favorable rule for the general-category applicants. This fact partially motivates our belief that the importance of these details of implementation was not appreciated at this time.

2.2 2008 Reform

In each of the three years H-1B allocation was implemented using the Exemptions-First rule, applications arrived earlier than the previous year.[10] In FY2008, the number of general-category applications sufficient to meet the 65,000 unreserved cap arrived the first day applications were accepted by the USCIS. Indeed, 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.[11] This development made clear that the use of arrival time as a priority measure was breaking down.

Consequently, in March 2008 USCIS changed its procedure in three important ways:

1. It abandoned the practice of processing the applications on a first-in first-out basis, instead allowing five days from April 1 for all petitions for the upcoming fiscal year to be submitted.[12]

2. To replace the naturally induced first-in first-out based priority order for all slots, USCIS adopted two independent random priority orders π_r and π_u; the former for the reserved slots and the latter for the unreserved slots.

[9] Section 5.2 details these calculations.

[10] 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. (Register, 2008).

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

[12] If sufficient applications from either category was not received within five days, the reform allowed for additional petitions that arrived later.

3. Under the new procedure, H-1B allocation is determined in two steps: first allocate the 20,000 reserved slots to highest π_r-priority reserved-category applicants, and next allocate the 65,000 unreserved slots to highest π_u-priority applicants considering all applicants except those who already received the reserved slots.

We refer to the resulting visa allocation rule as **Reserved-Initiated**. USCIS allocated H-1B visas using the Reserved-Initiated visa allocation over the next decade during FY2009-19. As we have already emphasized, logistical considerations made it necessary to abandon a system based on first-in first-out evaluation of the applications.

The choice of using two independent and random lotteries to determine the priority order for reserved and unreserved slots has one unexplored implication. For two different scenarios, consider all rules that comply with the statute.

- In Scenario 1, a single priority order π_u is used for both unreserved and reserved slots. Scenario 1 corresponds to FY2005-08, where the priority for both types of slots was carried out on a first-in first-out basis.

- In Scenario 2, maintain the priority order π_u for unreserved slots, but adopt a different priority order π_r for the reserved slots.

We have already stated that the difference between the "reserved-category optimal" and "reserved-category pessimal" extremes of all visa allocation rules that comply with the statute is significant when there is a single priority order for both types of slots, i.e under Scenario 1. In Theorem 3 below, we show that there exists analogous "reserved-category optimal" and "reserved-category pessimal" outcomes under Scenario 2 as well. Moreover, under both scenarios, the "reserved-category optimal" outcome assigns exactly the same number of reserved-category applicants. However, as we show in Theorem 2, the "reserved-category pessimal" outcome is more favorable for reserved-category applicants in Scenario 2 than Scenario 1.

Not only does the difference between the two extreme outcomes shrink under Scenario 2, but it does so in a way that eliminates some of the least favorable outcomes for the reserved-category applicants. What makes this observation more important is that the Reserved-Initiated visa allocation rule gives the "reserved-category pessimal" outcome under Scenario 2 (Theorem 3). Therefore, while the H1-B reform in 2008 resulted in replacing the reserve-category pessimal outcome under single priority order with the reserve-category pessimal outcome of two priority orders, it still provided a boost to representation of reserved-category applicants simply because a second independent priority order is employed for reserved slots.

Consider the same numbers of applications we considered before with 87,380 reserved-category applications and 111,080 general-category applications. (Recall that these are the five year averages for FY2013-17.) The number of admitted advanced-degree applicants

in Scenario 2 is 38,834 under the reserved-category optimal outcome (as in the Over-and-Above rule), and it is 33,495 under the reserved-category pessimal outcome given by the Reserved-Initiated rule. The corresponding reserved-category pessimal outcome was a much lower 24,630 under the Exemptions-First rule. Therefore, while possibly unintentional, the 2008 reform had a greater distributional impact on H-1B allocation than the 2019 reform.

Why is there such a big difference between prioritizing the applicants on a first-in first-out basis versus through two independent lotteries when reserved slots are processed prior to unreserved slots? The key aspect of prioritizing applicants on a first-in first-out basis is that it induces a single priority order for both reserved and unreserved slots. The earlier an application arrives, the higher priority it has. The purpose of creating reserved slots for advanced-degree applicants, while simultaneously maintaining their access to unreserved slots, is to provide these candidates with a second chance for a visa. In principle, advanced-degree applicants may have access to this second chance regardless of whether priority is determined by a first-in first-out system or by two lotteries. However, the access of these applicants to unreserved slots is either diminished or totally absent when allocation is based on a single priority order. To illustrate, when a single priority order is determined by arrival time, this second chance becomes available for the advanced-degree applicants only after all reserved slots are exhausted. By this point some of the unreserved slots are already allocated, and advanced-degree applicants are never considered for these slots. Moreover, this second chance completely disappears if unreserved slots are exhausted prior to reserved slots. And indeed, this is what happened in the period FY2006-08, rendering this second chance worthless in these years.[13] As a result, advanced-degree applicants received precisely 20,000 slots—all reserved—in all the years Exemptions-First visa allocation rule was used. In contrast, the advanced-degree applicants have a true second chance under the Reserved-Initiated visa allocation rule, since any reserved-category applicant who failed to receive a reserved slot is still as likely to receive an unreserved slot as any general-category applicant.

2.3 2019 Reform

President Trump's *Buy American and Hire American Executive Order* in 2017 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. To the best of our knowledge, this is the first time the impact of the visa allocation rule on the distribution of H-1B visas is explicitly explored by the USCIS.

The USCIS proposed maintaining the general structure of the FY2009-19 Reserve-

[13]The Federal Register reports that in FY2008 the advanced degree cap was reached on May 4, 2007, in FY2007 the advanced degree cap was reached on July 26, 2006, in FY2006 the advanced degree cap was reached on January 17, 2006 (Register, 2008).

Initiated visa allocation rule, but reversing the processing order of reserved and unreserved slots to increase the number of visas awarded to reserved-category applicants. We refer to this visa allocation rule as **Unreserved-Initiated** because it processes unreserved slots prior to reserved slots. Intuitively, it results in a more favorable outcome for the reserved-category applicants compared to Reserved-Initiated visa allocation rule, because these applicants have greater representation (with 20,000 additional applicants) under Unreserved-Initiated visa allocation rule for the lottery-based competition for unreserved slots. The outcome of the FY2020 Unreserved-Initiated visa allocation rule is more favorable than the FY2009-19 Reserved-Initiated visa allocation rule for the reserved-category applicants. Moreover, its outcome awards the same number of visas as in FY2005 Over-and-Above visa allocation rule, and thus it is reserved-category optimal even including single priority order rules.

2.4 Related literature

Our work is closely related to questions about reserve design, first studied in the context of school assignment by Dur, Kominers, Pathak, and Sönmez (2018). That paper emphasizes that reserve size is insufficient for describing a reserve policy, when the order of processing is not explicit. It establishes formal comparative static results comparing changes in reserve sizes to changes in the processing order of reserves. Those results played a role in discussions about Boston's walk zone policy and identified two biases in reserve design. The first, processing order bias, corresponds to the difference between between Unreserved-Initiated and Reserved-Initiated. The second, randomization bias, corresponds to the difference between Reserved-Initiated and Exemptions-First.

Aside from this paper, our work contributes to a growing literature on reserve design. Dur, Pathak, and Sönmez (2019) consider situations with multiple reserve groups and characterize optimal and constrained optimal implementation of reserve policies, when the goal is to favor a particular group. Their study provides formal results for place-based affirmative action in Chicago. Motivated by affirmative action policies in India, Sönmez and Yenmez (2019a) study both vertical and horizontal reservation policies, where vertical reservation correspond to Over-and-Above, and horizontal reservation correspond to Exemptions-First policies here. Sönmez and Yenmez (2019b) propose a centralized assignment mechanism that integrates both types of reserves. Pathak, Rees-Jones, and Sönmez (2020) study perceptions of reserve policies among the general U.S. population.

There is a large literature on market design under various classes of distributional constraints such as minimum guarantee reserves (or 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), Hafalir, Yenmez, and Yildirim (2013), Westkamp (2013), Ehlers, Hafalir, Yenmez, and Yildirim (2014), Echenique and Yenmez (2015), Kamada and Kojima (2015), Kamada and Kojima

(2017) Kamada and Kojima (2018), Aygün and Turhan (2016), Aygün and Bo (2016), Bo (2016), Dogan (2016), Kominers and Sonmez (2016), and Fragiadakis and Troyan (2017).

By introducing the visa allocation as a market design problem, our paper is also related to several other papers that study the formal properties of specific allocation processes in the field and propose alternatives. 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, 2013b), 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) and refugee resettlement (Jones and Teytelboym, 2017; Delacrétaz, Kominers, and Teytelboym, 2016; Andersson, 2017).

Finally, this paper is related to several studies of the H-1B visa system. Our focus is on the allocation of H-1B visas to petitioners. Two other studies empirically study the effect of H-1B visas on firms. Doran, Gelber, and Isen (2015) study the effect of winning an H-1B visa on firm employment, patenting, research and development expenditure, and profits. Kerr, Kerr, and Lincoln (2015) study the effects of a firm's expansion in young, skilled immigrants on other aspects of firm employment.

3 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 easily holds for all years since the reserved slots are introduced with the H-1B Visa Reform Act of 2004.

A matching is a function $\mu : I \to \{r, u\} \cup \{\emptyset\}$ such that

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

Given a matching μ, for any applicant $i \in I$,

- $\mu(i) = r$ indicates applicant i is awarded a reserved slot,

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

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

For any matching μ, 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.

3.1 Desiderata for Visa Allocation Rules

A *priority order* π is a linear order on the set of applicants I, where for any $i, j \in I$

$$i \, \pi \, j$$

indicates applicant i has "higher claims" to a slot than applicant j.

Motivated by U.S. H-1B visa allocation policies since 2004, we focus on allocation rules that rely on two *priority orders* π_u and π_r, where the former identifies the claims for the unreserved slots and the latter identifies the claims for the reserved slots. These priority orders can depend on factors such as the timing of arrival of applications, exam scores, or simply a random lottery draw. While the two priority orders can be identical, they can also be different.

A *visa allocation rule* is a function that assigns a matching for each set of applicants. Throughout the paper, we fix the set of applicants, and simply refer to properties of matchings rather than properties of visa allocation rules. We study matchings that satisfy the following three properties.

Definition 1 *A matching μ is **non-wasteful** if,*

1) for any $i \in I_R$,

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

2) for any $i \in I_G$,

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

That is, each slot is to be allocated, provided that there are eligible applicants.

Definition 2 *A matching μ* ***accommodates reservation policy*** *if, for any $i \in I_G$,*

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

That is, only qualified applicants can be awarded slots reserved for advanced-degree applicants.

Definition 3 *A matching μ* ***respects priorities*** *if,*

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

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

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

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

That is, allocation of both type of slots is to respect their given priority orders.

It is convenient to collect all three properties into the following definition.

Definition 4 *A matching μ* ***complies with the statute*** *if and only if (i) it is non-wasteful, (ii) it accommodates reservation policy, and (iii) it respects priorities.*

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

As we have discussed in the Introduction, four visa allocation rules have been relied upon to allocate H-1B visas in the U.S. since the H-1B Visa Reform Act of 2004. We next describe the matching produced by each of the four rules for a given set of applicants I.

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

For the next two visa allocation rules, fix a priority order π.

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 although 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^{ao}:

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, 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 fails to receive a slot in either step is not awarded a slot.

For the next two visa allocation rules, fix two priority orders π_u and π_r.

Reserved-Initiated Visa Allocation Rule φ^{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 φ^{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.

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 *The outcome of each of the visa allocation rules φ^{oa}, φ^{ef}, φ^{ru}, and φ^{ur} complies with the statute.*

4 Results

Throughout this section, the set of applicants I, the number of reserved slots q_r, and the number of unreserved slots q_u are fixed.

4.1 Visa Allocation Rules for Fiscal Years 2005-2008

In fiscal years 2005-2008, 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, therefore, we also fix $\pi_r = \pi_u = \pi$.

For fiscal year 2005 the mechanism of choice for H-1B allocation was the Over-and-Above visa allocation rule φ^{oa}, whereas for fiscal years 2006-2008 the mechanism of choice was the Exemptions-First visa allocation rule φ^{ef}. Our first result establishes that, focusing on rules that comply with the statute and given a single priority order, the visa allocation rule φ^{oa} is the least favorable rule for general-category applicants and the most favorable one for the reserved-category applicants. In contrast, the visa allocation rule φ^{ef} is the least favorable rule for reserved-category applicants and the most favorable one for the general-category applicants. Moreover, any other allocation that complies with the statute must be between these two extreme outcomes.

Theorem 1 *Let $\mu^{ef} = \varphi^{ef}(I)$ be the outcome of the Exemptions-First visa allocation rule, $\mu^{oa} = \varphi^{oa}(I)$ be the outcome of the Over-and-Above visa allocation rule, and matching μ 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. $\mu^{oa}(I_G) \subseteq \mu(I_G) \subseteq \mu^{ef}(I_G)$.

4.2 2008 H-1B Allocation Reform

In 2008, USCIS discovered that 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, resulting 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, and prioritized petitions 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} they relied upon for FY2006-2008.

We next show that this reform benefitted the reserved-category applicants at the expense of the general-category applicants.

To have a meaningful comparison of the two visa allocation rules φ^{ru} and φ^{ef}, we assume that

- both rules rely of the same priority order π for allocation of the unreserved slots,
- the rule φ^{ef} also relies on the same priority order π for allocation of the reserved slots,
- whereas the rule φ^{ru} relies on a possibly distinct priority order π^* for allocation of the reserved slots.

Theorem 2 *Let $\mu^{ef} = \varphi^{ef}(I)$ be the outcome of the Exemptions-First visa allocation rule that is induced by the priority order*

$$\pi_u \;=\; \pi_r \;= \pi,$$

and, $\mu^{ru} = \varphi^{ru}(I)$ be the outcome of the Reserved-Initiated visa allocation rule that is induced by the two priority orders

$$\pi_u \;= \pi \;\; and \;\; \pi_r \;= \pi^*.$$

Then,

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

4.3 2019 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 FY2020 abandoning the rule φ^{ru} that was used for over a decade.

In our next result, we show that this reform increases the selection of the reserved-category applicants at the expense of the general-category applicants, and it is has the highest selection rate of reserved-category applicants among all rules that comply with the statute.

Theorem 3 *Given two priority orders $\pi_u = \pi$ and $\pi_r = \pi^*$, let $\mu^{ru} = \varphi^{ru}(I)$ be the outcome of the reserved-initiated visa allocation rule, and $\mu^{ur} = \varphi^{ru}(I)$ be the outcome of the unreserved-initiated visa allocation rule. Let μ 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. $\mu^{ur}(I_G) \subseteq \mu(I_G) \subseteq \mu^{ru}(I_G)$.

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

5.1 Summary of Formal Results

Consider all four post-2004 visa allocation rules φ^{ef}, φ^{oa}, φ^{ru}, and φ^{ur}. Fix

- the priority order for unreserved slots of each of the four rules at $\pi_u = \pi$,
- the priority order for reserved slots of each of the two single-priority rules φ^{ef} and φ^{oa} at $\pi_r = \pi$, and
- 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 are 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.

Observation 2 *Let $\mu^{oa} = \varphi^{oa}(I)$ be the outcome of the Over-and-Above visa allocation rule that is induced by the priority order*

$$\pi_u \ = \ \pi_r \ = \pi,$$

and, $\mu^{ur} = \varphi^{ur}(I)$ be the outcome of the Unreserved-Initiated visa allocation rule that is induced by the two priority orders

$$\pi_u \ = \pi \ \textit{and} \ \pi_r \ = \pi^*.$$

Then,

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

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

Corollary 1 *Given a priority order π, let $\mu^{oa} = \varphi^{oa}(I)$ be the outcome of the Over-and-Above visa allocation rule and $\mu^{ef} = \varphi^{ef}(I)$ be the outcome of the Exemptions-First visa allocation rule. Given a pair of priority orders (π, π^*), let $\mu^{ru} = \varphi^{ru}(I)$ be the outcome of the Reserved-Initiated visa allocation rule and $\mu^{ur} = \varphi^{ur}(I)$ 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. $\mu^{oa}(I_G) = \mu^{ur}(I_G) \subseteq \mu^{ru}(I_G) \subseteq \mu^{ef}(I_G)$.

5.2 Estimated Outcomes Across Rules

So far, our formal results have not placed any structure on the distribution of the two priority orders π_u and π_r. To quantify the effects of these four different policies in practice, we must place additional structure on the priority orders. Suppose both priority orders are independent uniform draws, as is the practice in the U.S. since 2008, from the set of all priority orders. For the Over-and-Above and Exemptions-First rules, the derivations utilize priority order π_u only. For the Reserved-Initiated and Unreserved-Initiated rules, the derivations utilize both priority orders.

For Over-and-Above rule, in Step 1 the q_u unreserved slots are allocated to members of both groups in proportion to the sizes of both groups. Subsequently in Step 2, all q_r reserved slots are awarded to reserved-category applicants, unless of course fewer than 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 numbers

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 number 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 all q_r reserved slots (which is more than their proportional share of all slots) are awarded to reserved-category applicants, whereas all q_u unreserved slots (which is less than their proportional share of all slots) are awarded to general-category applicants. Therefore, the expected numbers 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 q_r reserved slots are awarded to the q_r highest π_r-priority reserved-category applicants. Therefore, the remaining $|I_R| - q_r$ reserved-category applicants and $|I_G|$ general-category applicants compete for the q_u unreserved positions in Step 2, each group in expectation receiving their proportional share from these slots. Hence, the expected numbers 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 q_u unreserved slots in Step 1, each group in expectation receiving their proportional share from these slots. Subsequently in Step 2, all q_r reserved slots are awarded to reserved-category applicants, unless of course fewer than q_r reserved-category applicants remain who are

Table 2: Allocation of Advanced Degrees under a 65,000 General Cap and a 20,000 Master Cap

	# of Applicants		Advanced-Degree Allocation			
	General	Advanced Degree	φ^{oa}	φ^{ef}	φ^{ru}	φ^{ur}
5-yr Average (2013-17)	137,017	55,900	38,834	24,630	33,495	38,834
2017	111,080	87,380	48,619	37,425	44,542	48,619

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

unmatched. In that case, each remaining reserved-category applicant is awarded a reserved slot. Therefore, the expected numbers of reserved-category and general-category applicants matched under the Unreserved-Initiated visa allocation rule are:

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

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 in Table 2. The table shows that the share of advanced-degree applications has increased over time since the count for 2017 is greater than the five-year average. We report numbers from these years because they are the basis of the calculations in the USCIS government press release (USCIS, 2019). 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 Reserve-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 candidates by changing processing of applicants shrinks. Even though Reserve-Initiated is the worst outcome for advanced-degree applicants, it is only about 5,339 applications worse than Unreserve-Initiated, the best possible outcome for advanced-degree candidates.[14] 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 2017 as our benchmark.

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

6 Conclusion

In response to President Trump's 2017 *Buy American and Hire American Executive Order*, the USCIS reformed the H-1B visa allocation rule in 2019. The stated objective of increasing the share of advanced-degree visa awards was applauded by some groups and contested by others, and its compliance with the statute has been thoroughly debated (see Federal Register (2018), pp 894-918). We show that the newly-adopted Reserve-Initiated rule is best for advanced-degree applicants among all rules that we consider to comply with the statute. Ironically, of the three modifications to the H-1B visa allocation rule since the Act of 2004, the 2019 reform had the smallest effect on the number of advanced-degree awards. Despite that, the distributional implications of the 2019 reform were much more widely publicized compared to the more significant (but possibly accidental) changes occuring in FY2006 and FY2009.

Our results are also related to the debate about walk-zone priority in Boston Public Schools. As of 2013, each Boston school reserved half of its seats for applicants from the school's walk-zone, and a single lottery-based priority order breaks ties. Boston's rules had the unintended effect of diluting the walk-zone reserve. In public forums and school committee meetings, several alternative implementations of the reserve were proposed and discussed (Pathak and Sönmez, 2013a; Dur, Kominers, Pathak, and Sönmez, 2018). The USCIS's four different visa allocation rules are equivalent to several of these proposals. For example, Walk-Open with One Lottery is similar to Exemptions-First and Walk-Open with Two Lotteries policy is similar to the Reserve-Initiated. Boston ultimately eliminated the reserve system, motivated partially by a concern that these issues were too complex and partially by potential interactions with other contemporaneous reforms (Shi, 2014; Pathak and Shi, 2017). It is interesting that the USCIS independently considered and deployed closely related solutions to their similar problems and faced a similar period of uncertainty regarding these policies functioning. In contrast to Boston, however, the USCIS ultimately came to rely on the reserve system and to administer it based on an understanding of its implications for the advantage conferred to the reserve group.

The policy changes in the H-1B visa program are related to two broader debates in market design. The first involves whether a market's design will naturally evolve to efficiently meet its goals without expert intervention. The U.S. residency match demonstrates a classic example of such an evolution: Roth (1984) showed that a procedure equivalent to the deferred acceptance algorithm was adopted in the residency match about a decade before Gale and Shapley (1962) first proposed the procedure. Market unravelling had spurred the market organizers to innovate in a manner that was theoretically unguided, but ultimately reasonably sophisticated. This observation is sometimes used to argue that market designs will evolve if problems are significant enough.[15] The history of the

[15]In the context of frequent-batch auctions for stocks, Budish, Lee, and Shim (2019) formally study

H1-B program provides qualified support for this idea. Ultimately, the USCIS discovered the rule that best implements the administration's stated goal of advantaging advanced-degree applicants. We believe this provides only qualified support, however, because this evolution took place after fifteen years involving several steps of trial-and-error. Furthermore, evolution may have been hasten by somewhat fortuitous logistical issues that forced experimentation with new mechanisms.

The second broader debate our work contributes to is about the importance of details in market design. Some authors, most notably Klemperer (2002), have argued that most of auction theory is of second-order importance for practical auction design. The auction models he describes are often stylized representations of the actual market clearing rules. In contrast, our model of the H-1B allocation scheme closely approximates the scheme used by the USCIS and we have illustrated the importance of particular institutional details. These situations - where the model most closely matches the real-world institution – seem likely to be the ones in which the details matter the most.

the incentives for adoption of new market designs.

A Appendix: Proofs

A.1 Proof of Theorem 1

Proof. Let μ be any matching that complies with the statute. That is, μ is any non-wasteful matching that accommodates reservation policy and respects priorities.

For any $k \leq q$, let $J_G(k)$ denote the set of general-category applicants and $J_R(k)$ denote the set of reserved-category applicants among k highest π-priority applicants. Hence, $|J_G(k)|$ denotes the number of general-category applicants, and $|J_R(k)|$ denotes the number of reserved-category applicants among k highest π-priority applicants. By definition, for any $k \leq q$,

$$|J_G(k)| + |J_R(k)| = k.$$

Consider the q_u highest π-priority applicants. Of these applicants, $|J_G(q_u)|$ are from the general-category and $|J_R(q_u)|$ are from the reserved-category.

We first relate the set of applicants $\mu^{oa}(I_G)$ and $\mu(I_G)$. Since μ is non-wasteful and respects priorities,

$$|\mu(I_G)| \geq |J_G(q_u)|. \tag{1}$$

Since general-category applicants receive $|J_G(q_u)|$ unreserved and 0 reserved slots under μ^{oa},

$$|\mu^{oa}(I_G)| = |J_G(q_u)|. \tag{2}$$

Equation (1) and equation (2) imply $|\mu^{oa}(I_G)| \leq |\mu(I_G)|$, which in turn implies

$$\mu^{oa}(I_G) \subseteq \mu(I_G), \tag{3}$$

since both matching μ and matching μ^{oa} respect priorities.

We next relate the set of applicants $\mu(I_R)$ and $\mu^{oa}(I_R)$. Equation (1) implies

$$|\mu(I_R)| \leq q - |J_G(q_u)| = q - (q_u - |J_R(q_u)|) = q_r + |J_R(q_u)|. \tag{4}$$

Since reserved-category applicants receive $|J_R(q_u)|$ unreserved slots and q_r reserved slots under matching μ^{oa},

$$|\mu^{oa}(I_R)| = q_r + |J_R(q_u)|. \tag{5}$$

Equation (4) and equation (5) imply $|\mu(I_R)| \leq |\mu^{oa}(I_R)|$, which in turn implies

$$\mu(I_R) \subseteq \mu^{oa}(I_R), \tag{6}$$

since both matching μ and matching μ^{oa} respect priorities.

Next consider the q highest π-priority applicants. Of these applicants, $|J_G(q)|$ are from the general-category and $|J_R(q)|$ are from the reserved-category.

***Claim*:** $|\mu(I_R)| \geq \max\{q_r, |J_R(q)|\}$.

Proof of the Claim: Since matching μ is non-wasteful and it accommodates reservation policy,

$$|\mu(I_R)| \geq q_r. \tag{7}$$

Consider an applicant $i \in I_R$ who is one of the q highest π-priority applicants. Towards a contradiction, suppose $\mu(i) = \emptyset$. Since matching μ is non-wasteful, it accommodates reservation policy and respects priorities, all q_r reserved slots must be awarded to reserved-category applicants who have higher π-priority than applicant i. But since all q_u unreserved slots are also exhausted by non-wastefulness, at least one of the applicants who receive an unreserved slot must have lower π-priority than applicant i, for otherwise applicant i would not be one of the q highest π-priority applicants. This contradicts matching μ respecting priorities (for unreserved slots), yielding the desired contradiction.

Hence, $\mu(i) \neq \emptyset$, and thus

$$|\mu(I_R)| \geq |J_R(q)|. \tag{8}$$

Equations (7) and (8) imply

$$|\mu(I_R)| \geq \max\{q_r, |J_R(q)|\},$$

completing the proof of the Claim. $\diamondsuit$

Observe that

$$|\mu^{ef}(I_R)| = \max\{q_r, |J_R(q)|\} \text{ and } |\mu^{ef}(I_G)| = q - \max\{q_r, |J_R(q)|\}. \tag{9}$$

Therefore, the first part of equation (9) and the Claim imply $|\mu^{ef}(I_R)| \leq |\mu(I_R)|$, which in turn implies

$$\mu^{ef}(I_R) \subseteq \mu(I_R), \tag{10}$$

since both matching μ and matching μ^{ef} respect priorities.

Finally, observe that the Claim further establishes

$$|\mu(I_G)| \leq q - \max\{q_r, |J_R(q)|\}. \tag{11}$$

Equation (11) and the second part of equation (9) imply $|\mu(I_G)| \leq |\mu^{ef}(I_G)|$, which in turn implies

$$\mu(I_G) \subseteq \mu^{ef}(I_G), \tag{12}$$

since both matching μ and matching μ^{ef} respect priorities.

Together, relations (3), (6), (10), and (12) complete the proof of the theorem. ■

A.2 Proof of Theorem 2

Proof. Let J_R^* be the set of q_r highest π^*-priority reserved-category applicants, and J_R be the set of q_r highest π-priority reserved-category applicants. We have

$$\mu_r^{ru}(I) = J_R^* \text{ and } \mu_r^{ef}(I) = J_R.$$

Let S^* be the set of q_u highest π-priority applicants in $I \setminus J_R^*$ and S be the set of q_u highest π-priority applicants in $I \setminus J_R$. Define

$$\begin{aligned} S_R^* &= S^* \cap I_R, \qquad & S_G^* &= S^* \cap I_G, \text{ and} \\ S_R &= S \cap I_R, \qquad & S_G &= S \cap I_G. \end{aligned}$$

Observe that

$$\begin{aligned} \mu^{ru}(I_R) &= J_R^* \cup S_R^*, \qquad & \mu^{ru}(I_G) &= S_G^*, \\ \mu^{ef}(I_R) &= J_R \cup S_R, \qquad & \mu^{ef}(I_G) &= S_G. \end{aligned}$$

Let $g \in S_G^*$. That is, applicant g is one of the general-category recipients of an unreserved slot under matching μ^{ru}. By construction of the set S_G^*,

$$|\{i \in I \setminus J_R^* : \, i \,\pi\, g\}| < q_u,$$

for otherwise applicant g would not be assigned one of the unreserved slots in μ^{ru}.

Since $|J_R \setminus J_R^*| = |J_R^* \setminus J_R|$ and

$$j \,\pi\, j^* \qquad \text{for all } j \in J_R \setminus J_R^* \text{ and } j^* \in J_R^* \setminus J_R,$$

we must have

$$|\{i \in I \setminus J_R : \, i \,\pi\, g\}| < q_u,$$

which in turn implies $g \in S_G$. Therefore, $S_G^* \subseteq S_G$, and hence

$$\mu^{ru}(I_G) \subseteq \mu^{ef}(I_G), \tag{13}$$

showing the second desired relation.

Recall that we have $|J_R^*| = |J_R| = q_r$. Therefore the relation (13), together with the non-wastefulness of matchings μ^{ru} and μ^{M-G} imply

$$|\mu^{ef}(I_R)| \leq |\mu^{ru}(I_R)|, \tag{14}$$

showing the first desired relation and completing the proof. ■

A.3 Proof of Theorem 3

Proof. Let μ be any matching that complies with the statute. That is, μ is any non-wasteful matching that accommodates reservation policy and respects priorities. Let J_G denote the set of general-category applicants and J_R denote the set of reserved-category applicants among q_u highest π-priority applicants. By definition,

$$|J_G| + |J_R| = q_u. \tag{15}$$

We first relate the set of applicants $\mu^{ur}(I_G)$ and $\mu(I_G)$. Since μ is non-wasteful and it respects priorities,

$$|\mu(I_G)| \geq |J_G|. \tag{16}$$

Since general-category applicants receive $|J_G|$ unreserved and 0 reserved slots under μ^{ur},

$$|\mu^{ur}(I_G)| = |J_G|. \tag{17}$$

Equation (16) and equation (17) imply $|\mu^{ur}(I_G)| \leq |\mu(I_G)|$, which in turn implies

$$\mu^{ur}(I_G) \subseteq \mu(I_G), \tag{18}$$

since both matching μ and matching μ^{ur} respect priorities.

We next relate the set of applicants $\mu(I_R)$ and $\mu^{ur}(I_R)$. Equation (16) and equation (15) imply

$$|\mu(I_R)| \leq q - |J_G| = q - (q_u - |J_R|) = q_r + |J_R|. \tag{19}$$

Since reserved-category applicants receive $|J_R|$ unreserved slots and q_r reserved slots under matching μ^{ur},

$$|\mu^{ur}(I_R)| = q_r + |J_R|. \tag{20}$$

Equation (19) and equation (20) imply

$$|\mu(I_R)| \leq |\mu^{ur}(I_R)|. \tag{21}$$

We finally show that

$$\mu(I_G) \subseteq \mu^{ru}(I_G) \quad \text{and} \quad |\mu^{ru}(I_R)| \leq |\mu(I_R).|$$

Let J_R^* be the set of q_r highest π^*-priority reserved category applicants. Ny construction

$$|J_R^*| = q_r \tag{22}$$

and

$$\mu^{ru}(i) = r \quad \text{for any } i \in J_R^*. \tag{23}$$

Let S^* be the set of q_u highest π-priority applicants in $I \backslash J_R^*$. By construction,

$$|S^*| = q_u. \tag{24}$$

Define $S_R^* = S^* \cap I_R$ and $S_G^* = S^* \cap I_G$. Observe that $\mu^{ru}(I) = J_R^* \cup S^*$. Here,

$$\mu^{ru}(I_R) = J_R^* \cup S_R^* \quad \text{and} \quad \mu^{ru}(I_G) = S_G^*. \tag{25}$$

***Claim*:** $\mu(I_G) \backslash S_G^* = \emptyset$.
Proof of the Claim: Suppose that there exists an applicant $g \in \mu(G) \backslash S_G^*$. Since $g \notin \mu^{ru}(I_G)$ by relation (25), we must have

$$i \, \pi \, g \qquad \text{for any } i \in S^*,$$

for otherwise matching μ^{ru} would fail to respect priorities. Therefore,

$$S^* \subset \mu(I), \tag{26}$$

since matching μ respects priorities as well. Moreover, since matching μ respects priorities and accommodates reserve policy,

$$J_R^* \subset \mu(I)$$

by construction of the set of applicants J_R^*. Hence,

$$S^* \cup J_R^* \cup \{g\} \subset \mu(I).$$

But since $|S^*| = q_u$ by equation (24) and $|J_R^*| = q_r$ by equation (22),

$$S^* \cap J_R^* = \emptyset \text{ and } g \notin (S^* \cup J_R^*) \implies |S^* \cup J_R^* \cup \{g\}| = q_u + q_r + 1.$$

Hence, we have a contradiction as

$$|\mu(I)| \geq q_u + q_r + 1 = q + 1.$$

This proves the claim. ◇

As a result,

$$\mu(I_G) \subseteq S_G^* = \mu^{ru}(I_G). \tag{27}$$

Since μ is non-wasteful,

$$|\mu(I_R)| = \min\{q - |\mu(I_G)|, |I_R|\}.$$

If $|\mu(I_R)| = |I_R|$, then all reserve-category applicants in μ are matched under μ and

$$|\mu^{ru}(I_R)| \leq |\mu(I_R)|.$$

Otherwise,

$$|\mu(I_R)| = q - |\mu(I_G)| \geq q - |\mu^{ru}(I_G)| = |\mu^{ru}(I_R)|,$$

where the inequality follows from relation (27). In either case,

$$|\mu^{ru}(I_R)| \leq |\mu(I_R)|. \tag{28}$$

Equations (18), (21), (27), and (28) complete the proof. ■

B Appendix: Documentation of Visa Allocation Rules

This appendix contains excerpts from the Federal Register, the official journal of the federal government of the United States, related to H-1B allocation.

B.1 2005 Federal Register, Vol. 70, No. 86, May 5

"The H-1B Visa Reform Act of 2004 was enacted after the start of FY 2005 and after the receipt of all petitions necessary to reach the existing 65,000 H-1B cap for FY 2005. The amendment [...] authorizing the cap exemption of 20,000 H-1B nonimmigrant aliens with U.S. master's or higher degrees, did not become effective until March 8, 2005. 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. Congress specifically did not require USCIS to 'reopen' its review of the H-1B petitions already received and re-characterize the petitions that would have qualified for the next exemption had it been in effect at the time the petitions were received. Thus, in order to give full effect to the newly created exemption, it is reasonable to do so only going forward only, applying the exemption to up to 20,000 petitions seeking work start dates during FY 2005." (Page 23777).

"[...], 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." (Page 23777).

"For FY 2006 and future fiscal years, USCIS will accept and adjudicate properly filled H-1B petitions on a first-in, first-out basis and will track those H-1B petitions that qualify for the U.S. master's or higher degree exemption under the H-1B Visa Reform Act of 2004 as cases are received and adjudicated. [...] Similarly, H-1B nonimmigrant aliens that are exempt under the H-1B Visa Reform Act of 2004 will not be counted towards the fiscal year numerical limit of 65,000. USCIS will continue to exempt such aliens until USCIS has allocated all 20,000 H-1B exemption numbers authorized [...] Thereafter, any H-1B petition granted for an H-1B nonimmigrant alien who has earned a U.S. master's or higher degree, unless otherwise exempt, will be counted against the fiscal year numerical limitations." (Page 23777)

B.2 2008 Federal Register, Vol. 73, No. 57, March 24

"In order to ensure that the 65,000 and 20,000 caps are not exceeded, USCIS monitors the number of H-1B petitions it receives. The first day on which petitions may file H-1B petitions can be as early as six month ahead of the employment start date. Therefore, a petition requesting an employment start date of October 1, the first day of the next

fiscal year, may file the H-1B petition as early as April 1 of the current fiscal year. When the USCIS determines, based on the number of H-1B petitions it has received, that the applicable cap will be reached, it announces to the public the final day on which it will accept such petitions for adjudication in that fiscal year. USCIS refers to this day as the "final receipt date." USCIS then randomly selects the number of petitions necessary to reach the cap from the petitions received on the final receipt date." (Page 15390)

"However, because demand for other H categories has not been as great as for the H-1B classification, USCIS has only had to apply the random selection procedures to H-1B petitions subject to the overall 65,000 cap or the 20,000 cap on master's degree exemption." (Page 15391)

"On Monday, April 2, 2007, the first available filing day for fiscal year (FY) 2008, USCIS received H-1B petitions totaling nearly twice the 65,000 cap. This was the first time since the random selection process regulations were promulgated that USCIS received more petitions than available cap numbers on the first available filing day. [. . .] The high volume of filings scheduled for delivery on April 2 caused logistical problems for overnight couriers and on the two USCIS service centers where filings could be made. Using the petitions received on April 2, and April 3, USCIS conducted the random selection process and thereafter rejected all petitions that were not randomly selected." (Page 15391)

"Just as with the 65,000 cap, the 20,000 cap on the master's degree exemptions has been exhausted earlier and earlier for each fiscal year since the cap exemption was added to the law. For FY 2006, the 20,000 cap was reached on January 17, 2006. For FY 2007, the cap was reached on July 26, 2006, less than four months after petition filings began on April 1, 2006. For FY 2008, the cap was reached on May 4, 2007, just over one month after petition filings began on April 2, 2007. For each of these fiscal years, USCIS announced a final receipt date and conducted the random selection process." (Page 15391)

"USCIS believes that the trend of exhausting the 20,000 cap on master's degree exemptions at an earlier date will continue. Should both 20,000 and 65,000 caps be reached on the same day that numbers become available (e.g., April 1 of the preceding fiscal year) no regulatory mechanism is in place to facilitate administration of the 20,000 cap in relation to the 65,000 cap." (Page 15391)

"This problem would be exacerbated were the 20,000 cap to be reached prior to or at the same time as the 65,000 cap, since all petitions not selected random selection process for the 20,000 cap would be considered twice—at the time of the random selection for the 20,000 cap and, thereafter, for the 65,000 cap." (Page 15391)

"This rule provides that USCIS will include petitions filed on all of those first five business days in the random selection process if USCIS receives a sufficient number of petitions to reach the applicable numerical limit (including limits on exemptions) on any one of the five business days on which USCIS may accept petitions. [. . .] This rule also

provides that, if both the 65,000 and 20,000 caps are reached within the first five business days available for filing H-1B petitions for a given fiscal year, USCIS must first conduct the random selection process for petitions subject to the 20,000 cap on master's degree exemptions before it may begin the random selection process of petitions to be counted towards the 65,000 cap. After conducting the random selection for petitions subject to the 20,000 cap, USCIS then must add any non-selected petitions to the pool of petitions subject to the 65,000 cap and conduct the random selection process for this combined group of petitions. Therefore, those petitions that otherwise would be eligible for the master's degree exemption that are not selected in the first random selection will have another opportsloty to be selected for an H-1B number in the second random selection process. This rule also clarifies that those petitions not selected in either random selection will be rejected." (Page 15392)

B.3 2019 Federal Register, Vol. 84, No. 2, Thursday, January 31

"The statute is ambiguous as to the precise manner by which beneficiaries with a master's or higher degree from a U.S. institution of higher education must be counted toward the numerical allocations. The statue states that the 65,000 numerical limitation does not apply until 20,000 qualifying beneficiaries are exempted, but is otherwise silent as to whether they must be exempted prior to, concurrently with, or subsequent to the 65,000 numerical limitation being counted and/or reached, or some combination therefor. This ambiguity was recognized by DHS when it initially determined how the exemption should be administered." (Page 895)

"DHS believes this approach is most consistent with the overall statutory framework as it counts all petitions filed by cap-subject petitioners until the numerical limitation is reached, and otherwise precludes additional petitions, allows for an additional 20,000 petitions." (Page 895)

"DHS believes that administering the numerically limited cap exemption in a way that does not reduce the odds of selection for beneficiaries with a U.S. advanced degree under the regular cap is most appropriate and maximizes the overall odds of selection for such beneficiaries under the numerical allocations." (Page 895)

"DHS also disagrees that the statue requires that initial H-1B visas be allocated to petitions in the order received." (Page 896)

"While DHS agrees that Congress has not limited the H-1B classification to the 'best and brightest" foreign nationals, nothing in the statute or legislative history precludes DHS from administering the cap allocation in a way that increases the odds of selection for beneficiaries with a master's or higher degree from a U.S. institution of higher education." (Page 896)

"Rather, this final rule simply creates a registration process to streamline the existing H-1B cap selection process, and reverses the order in which submissions are counted toward the H-1B numerical allocations, but does not change the overall number of foreign workers that may be hired under existing statutory authority." (Page 897)

"Reversing the cap selection order is expected to result in a greater number of beneficiaries with master's or higher degrees from U.S. institutions of higher education being selected under the numerical allocations and is in line with the executive order's directive to 'help ensure that H-1B visas are awarded to the most-skilled or highest-paid petition beneficiaries." Furthermore, master's or higher degree holders still maintain their own selection pool." (Page 912)

"It was clearly Congress's intent to prioritize such workers by creating a 20,000 cap exemption only for them." (Page 912)

"DHS is not able to increase the H-1B cap allocations, as the cap allocations are statutory and set by Congress." (Page 913)

"Under the current process, when the number of cap-subject petitions filed with USCIS during the first five days that such petitions may be filed exceeds the numerical limits, a certain number of petitions projected as needed to meet the 20,000 advanced degree exemption are randomly selected first from the 55,900 advanced degree petitions eligible for the advanced degree exemption. Of the remaining 172,918 petitions, 35,900 (21 percent) of H-1B beneficiaries with master's degree or higher from a U.S. institution of higher education remain in the pool to be selected in the 65,000 regular cap limit. Then, USCIS randomly selects a certain number of petitions projected as needed to meet the 65,000 regular cap limit from the remaining pool, which includes H-1B beneficiaries with bachelor's degrees and beneficiaries with a master's or higher degree from a U.S. institution of higher education no selected under the advanced degree exemption. DHS estimates than an additional 13,495 petitions otherwise eligible for the advanced degree exemption but not selected under the advanced degree exemption would be randomly selected in the regular cap. Therefore, USCIS currently selects an estimated total of 33,495 petitions filed for beneficiaries with a master's or higher degree from a U.S. institution of higher education, which accounts for 17 percent of 192,918 Form I-129 petitions." (Page 928)

"Under the new change to the H-1B cap-subject selection process, those seeking to file an H-1B cap-subject petition will have to submit an electronic registration for each beneficiary, unless the registration requirement is suspended. Only those with selected registrations will be eligible to file an H-1B cap-subject petition during an associated filing period for that fiscal year. As previously stated, DHS continues to assume 192,918 registration will be received annually. Under the new selection process, when registration is required, USCIS would first select a certain number of registrations projected as needed to meet the 65,000 regular cap limit from the 192,918 registrations. All 55,900 H-1B

beneficiaries with a master's or higher degree from a U.S. institution of higher education (29 percent) will therefore be included in the pool for selection. DHS estimates that up to 18,825 advanced degree registrations that could be selected during the selection for the regular cap." (Page 928)

"Next, USCIS will select a certain number of registrations projected to meet the 20,000 advanced degree exemption from the remaining pool of 37,065 advanced degree registrations. In total, USCIS is likely to select an estimated 38,835 registrations for petitioners seeking to file H-1B petitions under the advanced degree exemption. These registrations account for 20 percent of the 192,918 registrations. Therefore, DHS estimates USCIS could accept up to 5,340 (or 16 percent) more H-1B cap-subject petitions annually for beneficiaries with a master's or higher degree from a U.S. institution of higher education." (Page 929)

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