HOUSING ALLOCATION TO FORCED MIGRANTS IN MEXICO

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ABSTRACT

Socioeconomic instability in various regions of the world has significantly increased the number of applications for refugee and asylum status in Mexico over the past decade. These applications come from individuals who migrate because their safety is at risk if they remain in their countries of origin. However, international organizations have pointed out that migrants in Mexico are exposed to organized crime due to a lack of coordination among institutions responsible for providing humanitarian aid, such as access to housing. From a market design perspective, this paper proposes a housing allocation mechanism for migrants, which involves humanitarian and governmental institutions. This mechanism considers the different types of protection offered by the Mexican government to forced migrants; it is fair and strategy-proof for migrants. Furthermore, it is not Pareto-dominated by any other fair mechanism, a desirable property for the design of effective public policies for migrant support.

Keywords: forced migration, market design, fairness, nested deferred acceptance.
JEL Classification: O15, D47, C78.

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RESUMEN

La inestabilidad socioeconómica en algunas regiones del mundo ha incrementado las solicitudes de refugio y asilo en México en la última década. Estas provienen de quienes migran porque su integridad corre el riesgo de ser vulnerada al permanecer en sus países de origen. Sin embargo, organismos internacionales han señalado que los migrantes se encuentran expuestos al crimen organizado en México debido a la falta de coordinación entre instituciones para proporcionar ayuda humanitaria, como el acceso a vivienda. Desde el enfoque del diseño de mercados, se propone un mecanismo de asignación de vivienda a migrantes que involucra a instituciones humanitarias y gubernamentales. El mecanismo considera los diferentes tipos de protección que el gobierno mexicano proporciona a migrantes desplazados y se demuestra que es justo y no manipulable por parte de los migrantes. Además, no es dominado por ningún otro mecanismo, lo cual es una propiedad deseable para el diseño de políticas públicas de atención a migrantes.

Palabras clave: migración forzada, diseño de mercados, justicia, aceptación diferida anidada.

Clasificación JEL: O15, D47, C78.

1. INTRODUCTION

In Mexico, the Law on Refugees, Complementary Protection and Asylum (LRPCA, *Ley sobre Refugiados, Protección Complementaria y Asilo Político*) identifies displaced people as those whose physical integrity is at risk in their countries. Depending on the characteristics of each migrant, the law provides different types of protection, including asylum and humanitarian protection, when migrants suffer from political persecution or need humanitarian protection, respectively. In addition, the LRPCA extends the refugee or asylum status to the close relatives of those who get it (Secretaría de Gobernación, 2020). Various organizations, however, have pointed out that the Mexican government has failed to provide humanitarian support to migrants (Torre, París, and Gutiérrez, 2021), although the LRPCA is based on the Cartagena Declaration, signed by Mexico in 1984.

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Criticisms of the Mexican government's actions denounce the indigence and insecurity experienced by those who request support from the LRPCA (Solano and Massey, 2022). The first refers to the concentration of displaced people in inhuman conditions in Tijuana and Tapachula (Brewer, Tejada, and Meyer, 2022; Ruíz Lagier and Varela Huerta, 2020), without access to health services or education. The second criticism points out that the displaced are victims of organized crime while waiting for support from official authorities in the Mexican territory (Sánchez, 2020). Specifically, they cannot get access to housing facilities due to the absence of coordination between public organizations and humanitarian associations (Chelius and Querales, 2024).

Thus, the Mexican government lacks a mechanism to assign housing to migrants, even though humanitarian and government organizations have legal access to the existing facilities (Castillo, 2020; REDODEM, 2023). This work proposes a matching mechanism that involves displaced families, migrant support institutions, and housing spaces.

This problem is similar to the matching through institutions (MTI) problem (Bloch, Cantala and Gibaja, 2020) since displaced people require housing that can only be assigned through an institution with the capacity to do so. That is, migrants, institutions, and housing spaces play roles similar to those of families, institutions, and departments, respectively, in the MTI. The problems, however, differ in how displaced people can get a housing space. Specifically, migrants can receive support from different institutions depending on: 1) the protection they get from the LRPCA (Ferris and Donato, 2023) and 2) the legal attributions and features of institutions prioritizing those migrants that each institution can support (Escobar and Luna, 2023).

Our modeling approach captures the fact that different institutions intervene to help and support displaced people in Mexico. The Instituto Nacional de Migración (INM) coordinates 32 migration offices where displaced people may follow up on their application for protection under the LRPCA (INM, 2023). Furthermore, displaced people can receive humanitarian support from shelters and other institutions; around 120 organizations provided housing, dining rooms, and health care for more than 120,000 displaced people in 2023 (ACNUR, 2024; REDODEM, 2023). Such humanitarian institutions generally differ in terms of resources and location in Mexico; some may own or rent housing, while others oper-

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ate shelters. So, institutions act as linking offices between migrants and affordable housing, which is the case of public assistance offices in every Mexican state (de la Rosa Rodriguez and Maia, 2020; REDODEM, 2020). Thus, our assignment mechanism considers housing as a common pool of resources that all institutions can assign. Institutions have priorities in allocating housing, given the housing they can provide and the refugee status they can support. For example, some institutions can provide only a single space in a shelter, meaning they prefer to support single migrants rather than families. Some institutions can assign apartments or houses to those whose refugee permits allow them to search for jobs. Other institutions pursuing specific humanitarian objectives prioritize families with some form of disability or illness (REDODEM, 2023).

The importance of establishing a mechanism for assigning housing to displaced persons lies in the fact that protection requests have increased from 1,300 in 2013 to 122,000 in 2022 in Mexico (Hernández López, 2023). The surge in migration is due to sociopolitical instability in Central America and the recent restrictions the United States has imposed on granting asylum or refugee status (Massey, 2020; Hatton, 2022). For example, Trump's Migrant Protection Protocols and Biden's Title 42 have led to displaced people remaining in Mexico indefinitely (Damon-Feng, 2021; Scarciglia, 2023). Thus, Mexico is becoming a country that receives displaced people without having mechanisms to mitigate a humanitarian crisis that is not new (Carte, 2014; Brewer, Tejada, and Meyer, 2022). The present work proposes an allocation mechanism that satisfies desirable properties, such as fairness and the non-wasteful use of resources, for allocating housing to displaced people through public and humanitarian institutions.

Providing support to displaced people is not exclusively a North American phenomenon. In general, the developed economies of Europe and South Asia are destinations for those who forcibly migrate from Africa and the Middle East (Hatton, 2020). Since this phenomenon continues to grow, the international community has been concerned about establishing mechanisms to appropriately allocate resources to displaced people. In particular, refugees may benefit from systems that match them with communities where their integration into the new country would be easier (Jones and Teytelboym, 2018). In this sense, Delacrétaz, Kominers, and Teytelboym (2023) introduce a matching framework to

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address refugees' resettlement in localities that offer different services and face constraints on the number of displaced people they can accept. They show that assignment mechanisms based on refugees' preferences and localities' priorities improve the match efficiency and fairness. Similarly, Bansak and Paulson (2024) propose a dynamic assignment mechanism that balances employment allocation in a dynamic setting. This approach has been successfully applied in the optimal allocation of refugees in the United States (Ahani *et al.*, 2021). Our main contribution relies on introducing a Nested Deferred Acceptance with Types (NDAT) algorithm, an assignment procedure under which displaced people in Mexico can get housing from humanitarian organizations. By showing that the NDAT can be described as the Nested Deferred Acceptance (NDA), we establish conditions under which it outputs a fair assignment, in the sense that migrants who receive housing have the highest priority. Also, migrants do not benefit from misrepresenting their preferences, which are desirable for addressing issues in Tapachula and Tijuana by relocating migrants to other parts of Mexico (Brewer, Tejada and Meyer, 2022).

The paper is organized as follows. Section 2 presents the model for analyzing the housing allocation problem involving migrants and institutions. Section 3 introduces the NDAT algorithm and describes how it works. Section 4 presents the relationship between the housing allocation problem for migrants and the matching through multiple institutions; also, this section presents the properties that the NDAT satisfies. The last section presents the conclusions.

2. MODEL

The placement of displaced people in Mexican territory involves public organizations and humanitarian associations acting according to the protection that migrants receive. So, we consider:

i) $F = \{f_1, f_2, \ldots, f_F\}$, the set of migrant families recognized by the LRPCA. Let f be a generic family, and $|f| \in N$ the number of its members.

ii) $I = \{1, 2, \ldots, I\}$, the set of organizations that can support and monitor families. We use i to represent a generic institution.

iii) $V = \{v_1, v_2, \ldots, v_V\}$, the set of housing spaces that can be provided to displaced people. We denote by v a generic housing space or simply housing.

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The LRPCA provides different types of protection to families entering the Mexican territory. Let $R = \{r_1, r_2, \ldots, r_R\}$ be the set of all types of protection that can be granted. Each family f can receive one and only one recognition $r \in R$. Therefore, we consider a protection function $\rho : F \to R$ where $\rho(f)$ is the protection the Mexican government provides to family f.

Housing spaces differ in location and capacity; some are houses, and others are rooms in a shelter. Let $L = \{l_1, .., l_K\}$ be the set of cities where housing spaces are located; a generic location is denoted by l. The type of a housing space $v \in V$ is a vector $(v_l, v_S) \in L \times \mathbb{N}$ where v_L is its location and v_S the number of people v can accommodate.

Each institution $i \in I$ has a quota $e_i \in \mathbb{N}$ that represents the number of housing spaces that institution i can assign. Let $e = (e_1, e_2, \ldots, e_I) \in \mathbb{N}^I$ be the vector of institutions' capacities.

Refugees have preferences over the set $V \cup \{\varnothing\}$, where $\varnothing$ represents continuing in transit. We denote by P_f the strict preference of family f, and W_f is the weak preference. A housing space $v \in V$ is acceptable for f when v is strictly preferred over continuing in transit, *i.e.*, $vP_f\varnothing$. Let $P = (P_{f_1}, P_{f_2}, \ldots, P_{f_F})$ be the preference profile of all families. As usual, P_{-f} denotes the preference profile of all families different from f.

Since the housing spaces have limited capacity, they cannot necessarily accommodate large families. When this happens, housing is not acceptable.

Assumption 1. Let $f \in F$ and $v \in V$. If $|f| > v_S$, then $\varnothing P_f v$.

The institutions' priorities are defined over pairs composed of a family and housing. So, the priority of an institution i is an order $\succ^i$ defined on the power set of $F \times V$, denoted by $2^{F \times V}$. We say that (f, v) is acceptable for i when $\{(f, v)\} \succ^i \varnothing$; this means that i is interested in assigning housing v to family f. The priority profile of the institutions is $\succ = (\succ^1, \succ^2, \ldots, \succ^I)$, where $\succ^{-i}$ is the priority profile of all institutions different from i.

We assume that institutions' priorities are responsive. An institution improves by assigning an additional (f, v) pair when said pair is acceptable or has higher priority over another.

Assumption 2. For all $i \in I$, the priority $\succ^i$ is responsive. That is, for any subset $U \in 2^{F \times V}$ and pairs $(f, v), (f', v') \in (F \times V) \setminus U$, the preference $\succ^i$ satisfies:

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i) $U \cup \{(f,v)\} \succ^i U$ if and only if $\{(f,v)\} \succ^i \varnothing$, and
ii) $U \cup \{(f,v)\} \succ^i U \cup \{(f',v')\}$ if and only if $\{(f,v)\} \succ^i \{(f',v')\}$.

Institutions cannot attend all types of protection due to their legal characteristics. Let $\eta : I \rightrightarrows 2^R$ be the correspondence that maps to each institution a set of protection types; that is, $\eta(i) \subset R$ for all $i \in I$. Thus, $F_i = \{f \in F : \rho(f) \in \eta(i)\}$ is the set of families whose protection can be attended by *i*. If a family *f* does not belong to F_i, *f* is unacceptable for *i* since the institution cannot support it.

Assumption 3. Let $i \in I$ and $f \in F$. If $\rho(f) \notin \eta(i)$ then $\varnothing \succ^i (f,v)$ for all $v \in V$.

Some resources in *V* are common, others are not. So, each $v \in V$ has a priority π_v, defined over *I*, which prioritizes the institutions that can manage it. Thus, *i* has priority over *j* to allocate *v* when $i\pi_v j$. An institution *i* is unacceptable to allocate housing *v* whenever it cannot manage it, which we denote as $\varnothing\pi_v i$. Let $\pi = (\pi_{v_1}, \pi_{v_2}, \ldots, \pi_{v_V})$ be the profile of all the priorities of the housing where π_{-v} is the profile of housing priorities different from *v*.

Therefore, a housing-displaced people matching problem (HDPMP) is a tuple $E = (F, I, V, R, e, \rho, P, \succ, \eta, \pi)$.

In an HDPMP problem, families obtain housing through the support of an institution. Therefore, an assignment is a pair of functions $\mu = (\theta, \varphi)$ such that:

i) $\theta : I \cup V \to 2^V \cup I \cup \{\varnothing\}$, where
  a) $\theta(v) \in I \cup \{\varnothing\}$,
  b) $\theta(i) \in 2^V$,
  c) $v \in \theta(i)$ if and only if $\theta(v) = i$;

ii) $\varphi : F \cup V \to F \cup V \cup \{\varnothing\}$,
  d) $\varphi(f) \in V \cup \{\varnothing\}$,
  e) $\varphi(v) \in F \cup \{\varnothing\}$,
  f) $\varphi(f) = v$ if and only if $\varphi(v) = f$;

iii) $\varphi(v) = f$ if and only if $v \in \theta(i)$.

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In other words, an assignment μ is made up of two assignments. The first, θ, assigns each institution a subset of housing spaces, which cannot be assigned to more than one institution (*i. a*, *b*, and *c*). The second, φ, matches each family with at most one housing, and a housing can be assigned to at most one family (*ii. a*, *b*, and *c*). Condition *iii.* links previous assignments: a family receives housing if and only if such housing is assigned to an institution.

Let μ be an allocation in an HDPMP market *E*. The allocation of a family f is $\mu(f)=\varphi(f)$, while the set $\mu(i)=\{(f,v)\in F\times V:\varphi(v)=f,\ \text{and}\ \theta(v)=i\}$ denotes the allocation of an institution *i*. Finally, the assignment of housing v is $\mu(v)=(f,i)$ if and only if $\mu(f)=\varphi(f)$ and $v\in\theta(i)$.

Before defining the desirable properties of an allocation, we first introduce the decision rule of institutions. Let $M_i=\{M\subseteq F_i\times V:(f,v)\in M$ then $(f,v')\notin M$ and $(f',v)\notin M$ for $f\neq f',v\neq v'\}$. That is, M_i is the set of pairs (f,v) in whose assignment the institution i can intervene and where each family or housing appears at most once. For any pair $(M,e_i)\in M_i\times\mathbb{N}$, the decision rule for *i* is to choose the subset of acceptable family-housing pairs with the highest priority whose cardinality does not exceed the institution's quota. So, the decision of institution *i* is $Ch_i(M,e_i)=\max_{\subset}\{m\subset M:|m|\leq e_i \text{ and } m\in M_i\}$.

As usual, an assignment μ is individually rational (IR) if each agent $a\in F\cup I$ receives an acceptable match. That is, an assignment μ is IR if:

i) For all $i\in I$, we have that $\mu(i)=Ch_i(\mu(i),e_i)$, and
ii) For all $f\in F$, we have that $\mu(f)W_f\varnothing$, or $\mu(f)=\varnothing$.

On the other hand, we say that an assignment μ is *non-wasteful* when there is no family-institution pair (f,i) that can claim an acceptable unassigned housing *v*. That is, there are no *f*, *v* and *i* such that:

i) $vP_f\,\mu(f)$,
ii) $(f,v)\in Ch_i(\mu(i)\cup\{(f,v)\},e_i)$, and
iii) $\mu(v)=\varnothing$.

To define a fair allocation, we start from the concept of justified envy since the housing must be assigned to those who need it most. A pair (f,i) has *justified envy over* (f',i') when:

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i) $\mu(f')P_f\mu(f)$,
ii) $(f,\mu(f'))\in Ch_i\left(\mu\cup\{(f,\mu(f'))\},e_i\right)$, and
iii) $i\pi_{\mu(f')}i'$.

We say that an allocation μ is *fair* when it is IR, non-wasteful, and no family-institution pair has justified envy over any other pair.

A particular case of justified envy is when we only consider families whose housing is assigned by the same institution. That is, in an assignment μ, there is *justified envy in the same institution* when there is a pair (f,i) that has justified envy over a pair (f',i). Thus, an allocation μ is *fair for institutions* when it is IR, non-wasteful, and there is no justified envy in the same institution.

The assignment μ is Pareto efficient when there exists no other assignment μ' such that $\mu'(f)P_f\mu(f)$ for all $f\in F$, where at least one family f' strictly prefers $\mu'(f')$ over $\mu(f)$. Thus, μ is Pareto efficient when no family can improve its allocation without harming another. In this sense, the assignment μ' Pareto dominates μ when $\mu'(f)W_f\mu(f)$ for any family *f*, and $\mu'(f')P_f\mu(f')$ for at least one family $f'\in F$.

Finally, the allocation mechanism should be non-manipulable. That is, no family can improve its allocation by lying about the list of preferences it reports to the government or central institutions. An allocation mechanism is a function *M* that maps a preference profile *P* into a mapping $M[P_f,P_{-f}]=\mu[P_f,P_{-f}]$. The mechanism *M* is not manipulable by families when $\mu[P_f,P_{-f}](f)\bar{P}_f\,\mu[P'_f,P_{-f}](f)$ where P'_f represents a deviation from the true preference P_f, for all P'_f and all P_{-f}.

3. THE ASSIGNMENT OF HOUSING AMONG DISPLACED PEOPLE

Housing allocation to displaced people has similarities with MTI (Bloch, Cantala, and Gibaja, 2020). Families, migrant support institutions, and housing play a similar role to families, institutions, and apartments. However, in an HDPMP, different institutions can support families according to their protection type. This does not occur in the MTI problem, where only a single institution supports each family.

Since money is not an acceptable allocation mechanism in the HDPMP problem, we propose the NDAT mechanism, given the similarities between MTI and HDPMP. The NDAT mechanism adapts the NDA (Bloch,

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Cantala, and Gibaja, 2020) to the HDPMP problem. This mechanism links two deferred assignments without separating them into distinct stages. We begin a deferred acceptance where families demand housing. The institutions observe the demand and initiate deferred acceptance, which determines the housing assigned by each institution. When the nested mechanism ends, the institutions assign their housing to the families with the highest priority. Next, we formally describe the NDAT mechanism.

Step 0. We initialize with the empty assignment $\mu^0 = \varnothing$; so, $\mu^0(f) = \mu^0(i) = \mu^0(v) = \varnothing$. This means that no element in $r \in F \cup I \cup V$ has been assigned to some element in the market.

Step t. The NDAT procedure considers the following phases:

Phase A.t. Families demand housing

Each family *f* demands its favorite housing space, according to P_f, among those that have not previously rejected it. Let D^t be the set of all pairs (f,v) such that a family *f* demands housing *v*. Institutions observe D^t; particularly, each institution *i* observes:

$$D_i^t = \left\{(f,v) \in D^t : \rho(f) \in \eta(i)\right\}$$

which represents the set of pairs that can be handled by institution *i*.

Phase B.t. Institutions get housing

The nested deferred acceptance starts. So, institutions compete to obtain their favorite housing spaces. We rename the demand of the institutions as $D_i^0 = D_i^t$.

Nested deferred acceptance starts with $\Delta_i^0 = Ch_i\left(\overline{D_i^0}, e_i\right)$. Each institution *i* demands the housing set $V_i^0 = \left\{v \in V : (f,v) \in \Delta_i^0 \text{ for some } f \in F\right\}$ for some. Each housing space $v \in V_i^0$ is tentatively assigned to the institution with the highest priority in π_v, and rejects requests from other institutions.

Let $D_i^s = D_i^{s-1} \setminus \left\{(f,v) \in \Delta_i^{s-1} : i \text{ is rejected by } v\right\}$. During this phase, we run a deferred acceptance procedure that ends when each institution has been rejected by all its acceptable partners or can no longer obtain

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more housing spaces. Let $\underline{\Sigma}$ be the final of the previous deferred acceptance; and consider $D_i^t = D_i^{\underline{\Sigma}}$ for each $i \in I$. Thus, the set of housing spaces that institution i tentatively assigns is $\theta^t(i) = \{v \in V : (f,v) \in D_i^t$ for some $f \in F\}$.

Phase C.t. Tentative allocation

At the end of Phase B, the algorithm returns to the assignment between housing spaces and families. Each institution i tentatively assigns a housing $v \in \theta^1(i)$ to a family f if and only if $(f,v) \in Ch_i(D_i^t, e_i)$. Otherwise, we say that families are rejected.

The NDA algorithm finishes when all families are assigned to some housing space or have been rejected by all their acceptable housing space. Given a market E, $\mu^{NDAT}[E]$ denotes the assignment produced by the NDAT algorithm. So, $\mu^{NDAT}(r)$ is the assignment of r for all $r \in F \cup I \cup V$.

It is worth noting that the NDAT differs from the NDA in how it defines institutions' demands. Specifically, since families and institutions have concerns about the protection provided by the LRPCA, institutions' demand is not derived from those attached to it, as in the NDA. In the NDAT, the institutions' demand is given by those migrants who request housing and have a type for which institutions can provide support.

The following example illustrates how the NDA algorithm works in a market $(F,W,I,V,R,e,\rho,P,\succ,\eta,\pi)$.

Example 1. Consider a market with a set of families $F = \{f_1, f_2, f_3\}$, institutions $I = \{1,2\}$ and housing $V = \{v_1, v_2, v_3\}$. The structure of preferences and priorities is the following:

$$P = \begin{pmatrix} P_{f_1} & P_{f_2} & P_{f_3} \\ v_1 & v_1 & v_3 \\ v_3 & v_3 & v_2 \\ v_2 & v_2 & v_1 \end{pmatrix}, \quad \succ = \begin{pmatrix} \succ_1 & \succ_2 \\ (f_3,v_1) & (f_1,v_1) \\ (f_2,v_2) & (f_2,v_1) \\ (f_1,v_1) & (f_2,v_3) \\ (f_1,v_2) & (f_2,v_2) \end{pmatrix}, \quad \pi = \begin{pmatrix} \pi_{v_1} & \pi_{v_2} & \pi_{v_3} \\ 1 & 2 & 1 \\ 2 & 1 & 2 \end{pmatrix}$$

The families' type function is given by $\rho^{-1}(\{f_1,f_3\}) = t_1$ and $\rho^{-1}(\{f_2\}) = t_2$. In other words, the Mexican government only provides

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two types of protection to displaced people. Since institutions have different attributions, we consider that the correspondence type of institutions η is given by $\eta(1)=\{t_1\}$, and $\eta(2)=\{t_1,t_2\}$. The capacities of institutions are $e_1=1$ and $e_2=2$.

Step 1

Phase A.1. At this phase, all families ask for their most preferred housing space, $D^1=\{(f_1,v_1),(f_2,v_1),(f_3,v_3)\}$. By considering each type of protection, the corresponding demand is $D_1^1=\{(f_1,v_1),(f_3,v_3)\}$ and $D_2^1=\{(f_1,v_1),(f_2,v_1),(f_3,v_3)\}$.

Then, the NDAT goes to Phase B1.

Phase B.1. Now, we consider that $\overline{D_i^0}=D_i^t$ for all $i\in I$. Thus, the choice of each institution is given by:

$$\Delta_1^0=Ch_1\left(\overline{D_1^0},e_1\right)=\{(f_1,v_1)\} \text{ and } \Delta_2^0=Ch_2\left(\overline{D_2^0},e_2\right)=\{(f_1,v_1),(f_2,v_1)\}$$

Then, the institutions' demand for housing spaces is $V_1^0=\{v_1\}=V_2^0$.

Note that v_1 is tentatively assigned to 1 because $1\pi_{v_1}2$. So, the institution 2 is rejected from the apartment v_1. The nested DA goes to its second step, where $D_1^1=\{(f_1,v_1)\}$ and $D_2^0=\varnothing$; then, the nested DA ends with $\theta^1(1)=\{v_1\}$ and $\theta^1(2)=\varnothing$.

Phase C.1. By the previous phase, we have that f_2 is rejected from v_1, f_3 is rejected from v_3, while the institution 1 tentatively allocates housing v_1 to family f_1.

Step 1 ends with the following tentative assignment:

$$\mu^{NDAT^1}=\begin{pmatrix} f_1 & f_2 & f_3 \\ v_1 & \varnothing & \varnothing \\ 1 & \varnothing & \varnothing \end{pmatrix}$$

Step 2

Phase A.2. The family f_1 retains housing space v_1, while families f_2 and f_3 ask for housing spaces v_3 and v_2, respectively. In other words, we have

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that $D^2 = \{(f_1, v_1), (f_2, v_3), (f_3, v_2)\}$. So, we have that $D_1^2 = \{(f_1, v_1)\}$ and $D_2^2 = \{(f_1, v_1), (f_2, v_3), (f_3, v_2)\}$.

Then, the NDAT goes to Phase B2.

Phase B.2. At the beginning of this phase, each institution observes $\overline{D_i^0} = D_i^2$ for all $i \in I$. Thus, we have that:

$$\Delta_1^0 = Ch_1\left(\overline{D_1^0}, e_1\right) = \{(f_1, v_1)\} \text{ and } \Delta_2^0 = Ch_2\left(\overline{D_2^0}, e_2\right) = \{(f_1, v_1), (f_2, v_3)\}$$

Then, the institutions' demand for housing spaces is $V_1^1 = \{v_1\}$ and $V_2^2 = \{v_1, v_3\}$. Note that $1\pi_{v_1} 2$ and $2\pi_{v_3} \varnothing$. So, v_1 remains under the management of institution 1, and v_3 is assigned to institution 2. The nested DA moves to the next step, where $V_1^2 = \{v_1\}$ and $V_2^2 = \{v_3\}$; so, the Phase B finishes with the tentative assignment $\theta^2(1) = \{v_1\}$ and $\theta^2(2) = \{v_3\}$.

Phase C.2. By the previous phase, we have that f_3 is rejected from v_2, while institution 1 tentatively allocates housing v_1 to family f_1, and institution 2 tentatively allocates housing v_3 to family f_2.

Step 2 ends with the following tentative assignment:

$$\mu^{NDAT^2} = \begin{pmatrix} f_1 & f_2 & f_3 \\ v_1 & v_3 & \varnothing \\ 1 & 2 & \varnothing \end{pmatrix}$$

Step 3

Phase A.3. Families f_1 and f_2 retain housing v_1 and v_3, respectively. Since the family f_3 was rejected from the housing v_2, she requests her last acceptable housing space v_1. So, we have that $D^3 = \{(f_1, v_1), (f_2, v_3), (f_3, v_1)\}$, $D_1^3 = \{(f_1, v_1), (f_3, v_1)\}$ and $D_2^2 = \{(f_1, v_1), (f_2, v_3)\}$.

Phase B.3. Consider that $\overline{D_i^0} = D_i^3$ for all $i \in I$. Then, each institution pursues to support the following pairs:

$$\Delta_1^0 = Ch_1\left(\overline{D_1^0}, e_1\right) = \{(f_3, v_1)\} \text{ and } \Delta_2^0 = Ch_2\left(\overline{D_2^0}, e_2\right) = \{(f_1, v_1), (f_2, v_3)\}$$

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Then, the institutions' demand for housing spaces is $V_1^1 = \{v_1\}$ and $V_2^2 = \{v_1, v_3\}$. Note that $1\pi_{v_1} 2$ and $2\pi_{v_3} \varnothing$. Analogously to Phase B.2, Phase B.3 finishes with the tentative assignment $\theta^3(1) = \{v_1\}$ and $\theta^3(2) = \{v_3\}$.

Phase C.3. Although institution 1 retains housing v_1, now, it assigns this housing space to f_3, and f_1 is rejected. Institution 2 assigns housing v_3 to family f_2.

Step 3 ends with the following tentative assignment:

$$\mu^{NDAT^3} = \begin{pmatrix} f_1 & f_2 & f_3 \\ \varnothing & v_3 & v_1 \\ \varnothing & 2 & 1 \end{pmatrix}$$

Step 4

Phase A.4. Families f_2 and f_3 retain housing v_3 and v_1, respectively. Now, family f_1 ask for housing v_3. Thus, each institution observes the set of pairs that they can handle, which are $D^3 = \{(f_1, v_1), (f_2, v_3), (f_3, v_1)\}$, $D_1^3 = \{(f_3, v_1)\}$ and $D_2^2 = \{(f_1, v_3), (f_2, v_3)\}$.

Phase B.4. The nested DA starts with $\overline{D_i^0} = D_i^3$ for all $i \in I$. Then, the choice of each institution is given by:

$$\Delta_1^0 = Ch_1\left(\overline{D_1^0}, e_1\right) = \{(f_3, v_1)\} \text{ and } \Delta_2^0 = Ch_2\left(\overline{D_2^0}, e_2\right) = \{(f_2, v_3)\}$$

Since (f_1, v_3) is not acceptable for any institution. This phase with $\theta^4(1) = \{v_1\}$ and $\theta^4(2) = \{v_3\}$.

Phase C.4. Given the result of Phase B.4, Step 4 outputs the tentative assignment:

$$\mu^{NDAT^3} = \begin{pmatrix} f_1 & f_2 & f_3 \\ \varnothing & v_3 & v_1 \\ \varnothing & 2 & 1 \end{pmatrix}$$

In other words, f_1 is rejected from v_3.

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Step 5

Now, f_1 asks for her last acceptable housing v_2. However, (f_1, v_2) is not demanded by any institution since institution 1 has fulfilled its quota, while (f_1, v_2) is not acceptable for institution 2. So, this step is analogous to Step 4, and the final assignment is:

$$\mu^{NDAT} = \begin{pmatrix} f_1 & f_2 & f_3 \\ \varnothing & v_3 & v_1 \\ \varnothing & 2 & 1 \end{pmatrix}$$

4. PROPERTIES OF THE NESTED DEFERRED ACCEPTANCE WITH TYPES

Housing allocation between families of displaced migrants is closely related to the Matching through Institutions problem (Bloch, Cantala, and Gibaja, 2020). Families, institutions, and housing play a similar role to households, institutions, and apartments. At first glance, the difference between the two problems lies in the institutions' intervention in allocating housing. In the MTI problem, institutions can assign housing spaces to any family attached to them, whereas in the HDPMP, families are not directly connected to institutions. The protection provided by the LRPCA links families with some institutions, since not all institutions have the infrastructure to support all protection types. In this sense, we can say that many institutions can support the same family, which implies that the HDPMP can be seen as a matching problem across multiple institutions; that is, a matching problem in which types are determined by correspondences from families to institutions. The following proposition formalizes the fact that the HDPMP induces a matching-through-multiple-institutions problem.

Proposition 1. The housing-displaced people matching problem induces a matching through multiple institutions.

Proof

In the HDPMP problem, the type of a family *f* is the protection $\rho(f)$ provided by the LRPCA, while the type of an institution *i* is a subset $\eta(i)$ of

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all the possible protections in R that the institution can support. Thus, we can define the set $\gamma(f) = \{i \in I : \rho(f) \in \eta(i)\}$ that is not empty and has a cardinality greater or equal to 1. Thus, γ is a correspondence from F to I that links each family i with those institutions that can assign it housing. In other words, γ is a type correspondence in the sense of matching through multiple institutions.

Finally, the preference/priority structure is identical in the HDPMP and the MTI with multiple institutions. In other words, we have that families/households have preferences over housing/apartments, institutions priorities are defined over sets of family-housing/household-apartment pairs, and housing/apartments prioritize institutions. Therefore, the HDPMP and the correspondence γ induces a matching through multiple institutions.

Proposition 1 says that the HDPMP induces a matching through multiple institutions market. Thus, the NDAT can be rewritten as the NDA mechanism for matching through multiple institutions.

Proposition 2. Consider a housing-displaced people matching problem $(F, I, V, R, e, \rho, P, \succ, \eta, \pi)$. The NDAT can be rewritten as the NDA for multiple institutions.

Proof

To prove that the NDAT can be rewritten as the NDA algorithm, it is important to recall that both algorithms have three phases. The first phase starts a deferred acceptance algorithm under which families ask for housing. In the second phase, a nested deferred acceptance tentatively allocates housing spaces between institutions by considering the families' demand of the previous phase. Finally, in the third phase, institutions tentatively assign housing to the families with the highest priority.

The main difference between the previous mechanisms relies on how institutions determine the pairs (f, v) they can match before running the nested DA in the second phase. In the NDA, an institution can match all pairs (f, v) such that family f is attached to it through the type correspondence; mathematically, we have the set $\tilde{D}_i^t = \{(f, v) \in D^t : i \in \rho(f) \text{ and } v = D_f^t\}$, where ρ is the protection correspondence and D_f is the demand of family f at step t. Concerning the NDAT, institutions can match all pairs (f, v)

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(f,v) only if f has a protection type that the institution can attend; that is to say, $D_i^t = \{(f,v) \in D^t : \rho(f) \in \eta(i) \text{ and } v = D_f^t\}$.

By Proposition 1, the HDPMP induces a correspondence $\gamma : F \rightrightarrows I$ where $\gamma(f) = \{i \in I : \rho(f) \in \eta(i)\}$. Hence, we have that $D_i^t = \{(f,v) \in D^t : i \in \gamma(f) \text{ and } v = D_f^t\}$. So, we conclude that the NDAT can be rewritten as the NDA with multiple types.

Proposition 2 shows that the NDAT is the NDA when it is applied in a matching through multiple institutions problems. So, the housing allocation between families of displaced migrants inherits the issues that arise when multiple institutions intervene in allocating an indivisible object. In the problem of matching through multiple institutions we have that i. a fair assignment that copes with exact capacities may not exist, and ii. the NDA assignment is not always fair because of the existence of interrupters (Bloch, Cantala, and Gibaja, 2020).

Concerning the first issue, we introduce an over-demand condition to guarantee the existence of assignments under which institutions cope with their capacities.

Assumption 4. (Over-demand condition). For all individually rational assignments $\mu = (\theta, \varphi)$, for all institutions i and housing v, there exists a family f such that it remains unassigned at μ, and $(f,v) \succ^i \varnothing$, $vP_f\varnothing$ and $i\pi_v\varnothing$.

Although the intervention of multiple institutions facilitates housing allocation without wasting resources, fairness may be compromised in the HDPMP, since rejected families cannot request an apartment that has been dropped by institutions that do not prioritize its allocation (see Example 3 in the Appendix). In other words, during some steps of the procedure, there are institutions that interrupt other institutions for assigning housing they do not assign at the end.

Definition 1

Consider a housing-displaced people matching problem in which the NDA is applied to the induced matching market with multiple institutions. An institution i is an *interrupter for housing* v if there exists:

i) Steps t to $t+n$ such that $v \in \theta^{t'}(i)$ for all $t' \in \{t, t+1, \ldots, t+n\}$ but $v \notin \theta^{t'}$ for all $t' > t+n$, and

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ii) An institution $j \neq i$ and a family f such that $(f,v) \in Ch_i\left(D_i^{t'}, e_i\right)$ but $(f,v) \notin \mu^{t'}(j)$ for some $t' \in \{t, t+1, \ldots, t+n\}$.

Now, we proceed as Bloch, Cantala, and Gibaja (2020) to avoid the appearance of interrupters and the generation of justified envy. Specifically, we consider the Nested Deferred Acceptance with Interrupters (NDAI), which consists of two stages: the first stage runs the NDA, and the second stage deletes pairs from the institutions' priorities that cause interruptions (Appendix B provides a complete description of the deletion operation and the NDAI). The NDAI proceeds as follows.

Step 0. This step unfolds in the following two stages:

Stage 0.1. The NDA phase. Let $\succ_0$ the profile of initial priorities. Run the NDA by considering institutions' priorities $\succ_0$, families' preferences P, and housing priorities π.
*Stage 0.2. Priorities adjustment***.** If there are no interrupter institutions, the algorithm terminates at Stage 0.1 and outputs the assignment μ^{NDAT}. Otherwise, find the last step where an interrupter drops a housing from which it is an interrupter. Based on the priorities of all interrupter institutions, we delete the acceptable pairs that cause the interruption. Let $\succ_s$ the updated profile of priorities.

Step s. The stages of this step are the following:

Stage s.1. The NDAT phase. Run the NDA by considering institutions' priorities $\succ_s$, families' preferences P, and housing priorities π.
*Stage s.2. Priorities adjustment***.** If there are no interrupter institutions, the algorithm terminates at Stage s.1, and outputs the assignment μ^{NDAT}. Otherwise, find the last step, where an interrupter drops a housing from which it is an interrupter. From the priorities of all interrupter institutions, we delete those acceptable pairs (f,v) where they cause the interruption. Let $\succ_{s+1}$ the updated profile of priorities.

We denote the output of the previous assignment mechanism as μ^{NDAT}.

The following theorem establishes the properties that the NDAI satisfies.

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Theorem 1. Consider a market $(F,I,V,R,e,\rho,P,\succ,\eta,\pi)$. When we apply the NDAI mechanism to allocate housing among families of displaced migrants, by considering the induced matching through a multiple institutions market, the μ^{NDAI} is fair for institutions, Pareto undominated by fair for institutions assignments and strategy-proof for migrants.

Proof

By Proposition 1, the HDPMP is a particular case of the Matching through Institutions problem when families are attached to multiple institutions. Moreover, Proposition 2 shows that we can apply the NDA to the HDMPM. So, the proof of this theorem summarizes Theorem 5.1 in Bloch, Cantala, and Gibaja (2020) by considering the notation of the HDPMP. Below, we provide the general ideas about it.

Individual rationality. We know that the NDAI stops when all unassigned families have been rejected from all their acceptable apartments. Otherwise, families are assigned to some acceptable apartments. So, we have that $\mu^{NDAI}(f)P_f\varnothing$ for all $f \in F$.

Concerning each institution *i*, note that $\mu^{NDAI}(i) \subset Ch_i\left(D_i^{\Sigma}, e_i\right)$, where Σ is the step where the last NDAI stops. Thus, $\mu^{FNDAT}(i) \succ^i \varnothing$.

Non-wastefulness. We proceed by contradiction. Consider a family-institution pair (f,i) that claims an empty housing space *v*; that is to say, we have that:

i) $vP_f\varphi(f)$,
ii) $(f,v) \in Ch_i\left(\mu^{NDAI}(i) \cup \{(f,v)\}, e_i\right)$, and
iii) $\theta(v) = \varnothing$.

By condition *i*), family *f* demands housing *v* at some step *t* in the last NDAI run by the FNDAT mechanism. Moreover, condition *ii*) means that the pair (f,v) is acceptable for institution *i*. Thus, institution *i* demands housing *v* at step *t*. The apartment must then be assigned to *i* at step *t*. Since there are no interrupters and $\theta(v) = \varnothing$, there is a pair $(f',v') \in \mu^{NDAI}(i)$, with $v' \neq v$, such that *i* rejects (f,v) in some step $t' > t$ because $(f',v') \succ^i (f,v)$. So, we have that $(f,v) \notin Ch_i\left(\mu^{NDAI}(i) \cup \{(f,v)\}, e_i\right)$, which contradicts *ii*).

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There is no justified envy in the same institution. Let s^* be the last iteration of the NDAI. By contradiction, we consider the existence of a pair (f,i) that has justified envy over a pair (f',i), where $\rho(f)\cap\rho(f')\subset\eta(i)$.

Then, there exists housing v such that $\varphi^{NDAI}(f')=v$, $v\in\theta^{NDAI}(i)$, $vP_f\mu^{NDAI}(f)$ and $(f,v)\in Ch_i\left(\mu^{NDAI}(i)\cup\{(f,v)\},e_i\right)$.

Since $vP_f\mu^{NDAI}(f)$ and $(f,v)\in Ch_i\left(\mu^{NDAI}(i)\cup\{(f,v)\},e_i\right)$, housing v was demanded by i at some step t of the last NDAT. However, $(f,v)\notin\mu^{NDAI}(i)$. Since priorities are responsive, (f,v) was rejected from the allocation of i at some step $t'>t$ since there exists some pair $(f'',v'')\in Ch_i\left(D_i^{t'}\cup\{(f,v)\},e_i\right)$; in other words, we have that $(f'',v'')\succ^i(f,v)$. However, $(f,v)\in Ch_i\left(\mu^{NDAI}(i)\cup\{(f,v)\},e_i\right)$. By transitivity and the fact that institutions' demand is finite, we can conclude that $(f,v)\succ^i(f'',v'')\succ^i(f,v)$, which is a contradiction.

Pareto undominated by fair for institutions assignments. To show that no fair for institutions assignment μ Pareto dominates μ^{NDAI}, we show that in any other fair for institutions assignment, each family f gets the same housing or a housing less preferred than $\varphi^{NDAI}(f)$.

Let s^* be the last step of the NDAI. We proceed by induction over the steps of the NDAI at stage $s^*.1$ to show that families are not rejected by housing that can be assigned in any other fair for institutions assignment; as in Gale and Shapley (1962), such housing is referred as *achievable housing*. The inductive base is straightforward since no family has been rejected.

To prove the inductive step, we assume the opposite. There is a family f that has been rejected by some achievable housing v at some fair for institutions assignment μ. By construction of the NDAT stage, rejection happens within the same institution i because such an institution prioritizes the pair (f',v) over the pair (f,v). Thus, f' gets a less preferred housing at μ. Consequently, (f',i) has justified envy over (f,v) at assignment μ, which is contradictory because μ is fair for institutions.

Therefore, no fair for institutions assignment μ Pareto dominates μ^{NDAI}.

Strategy proofness for families. In this case, as in Roth (1984), we show that no family can successfully misrepresent their preferences to get better housing. By Proposition 1, there exists a type correspondence γ from F to I that links families to the institutions that can attend them. Consider

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a family f that wants to misrepresent its true preference P_f; we have the following cases:

Case I. All institutions in $\gamma(f)$ are interrupters. By construction of the NDAI, we note that all pairs (f,v) have been deleted from $\succ^i$ for all $i \in \gamma(f)$. So, even if f misrepresents their true preferences, such a family does not get better housing since no pair (f,v) is acceptable for any institution during the last NDAI.

Case II. There is an institution $i \in \gamma(i)$ such that it is not an interrupter. Hence, such an institution can assign housing to f. So, we proceed by contradiction. If f successfully misrepresents P_f by submitting P'_f to the last NDAI phase, this means that f was rejected in $\mu^{NDAT}[P]$ because there is some institution j, family f' and housing v such that (f,i) cannot justifiably claim v to (f',j).

Case II.1. $j = i$, the fact that $(f,v) \in \mu^{FNDAT}[P'_f, P_{-f}](i)$ implies that $\{(f,v)\} \succ^i \{(f',v)\}$. However, f was rejected from v at some step of the NDAI phase under preferences P, *i.e.*, we have that $(f,v) \notin \mu^{NDAI}[P](i)$. So, we can show that $\{(f',v)\} \succ^i \{(f,v)\}$, which is a contradiction.

Case II.2. $j \neq i$. Notice that both institutions demand v at some stages in the NDAI when we consider preferences (P'_f, P_{-f}) and P. Since $(f,v) \notin \mu^{NDAI}[P](i)$ and i is not an interrupter, and we can conclude that $j \pi_v i$. However, $(f,v) \in \mu^{NDAI}[P'_f, P_{-f}](i)$ and j still demands v. Then, we have that $i \pi_v j$, which is not possible.

In any case, we get a contradiction by considering that f can misrepresent its preferences to get something better.

5. CONCLUSIONS

In this paper, we propose a housing allocation mechanism that considers families of displaced migrants, institutions that support forced migration, and housing in different cities. Since the Mexican Law on Refugees, Complementary Protection and Asylum provides different forms of recognition for displaced families, housing allocation is con-

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sidered a crucial feature for guaranteeing humanitarian assistance. So, the allocation problem is closely related to a matching problem through multiple institutions since not all institutions have the same features to support displaced people with different forms of recognition to stay in Mexico. Particularly, we provide an assignment procedure that is fair for institutions, a feature that deals with the criticisms around the actions implemented by Mexican institutions that deal with migration.

Our theoretical solution, however, is not readily implementable. It requires, first, the existence of a centralizer with a deep understanding of a mechanism design approach and the social benefits of organizing a centralized mechanism such as the HDPMP. Second, leadership must convince national institutions to participate in the mechanism and, together with humanitarian institutions, discuss and specify their respective needs. ◄

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APPENDIX

Appendix A. Examples

Example 2. (No fair assignments that cope with exact capacities). Let $F=\{f_1,f_2\}, I=\{1,2\}$ and $V=\{v_1,v_2\}$. Consider that $\rho(f)\in\eta(1)\cap\eta(2)$ for all $f\in F$. The structure of priorities and preferences is the following:

$$P=\begin{pmatrix} P_{f_1} & P_{f_2} \\ v_1 & v_1 \\ v_2 & \end{pmatrix},\ \succ=\begin{pmatrix} \succ^1 & \succ^2 \\ (f_1,v_1) & (f_1,v_2) \\ (f_2,v_1) & \end{pmatrix},\ \pi=\begin{pmatrix} \pi_{v_1} & \pi_{v_2} \\ 1 & 2 \\ 2 & 1 \end{pmatrix}$$

The vector of capacities is $e=(1,1)$. Note that there is only one assignment that satisfies the exact capacities:

$$\mu=\begin{pmatrix} f_1 & f_2 \\ v_2 & v_1 \\ 2 & 1 \end{pmatrix}$$

where $v_1 P_{f_1} v_2$, $\{(f_1,v_1)\}\succ^1\{(f_2,v_1)\}$ and $1\pi_{v_1}2$. So, the pair $(f_1,1)$ has justified envy over the pair (f_2,v_1).

Example 3. (Justified Envy within Institutions). Consider a market with a set of families $F=\{f_1,f_2,f_3,f_4\}$, institutions $I=\{1,2\}$ and housing $V=\{v_1,v_2\}$. The structure of preferences and priorities is the following:

$$P=\begin{pmatrix} P_{f_1} & P_{f_2} & P_{f_3} & P_{f_4} \\ v_1 & v_1 & v_1 & v_2 \\ v_2 & v_2 & v_2 & v_1 \end{pmatrix},\ \succ=\begin{pmatrix} \succ_1 & \succ_2 \\ (f_3,v_2) & (f_2,v_1) \\ (f_1,v_1) & (f_4,v_2) \\ (f_1,v_2) & (f_4,v_1) \\ (f_3,v_1) & (f_2,v_2) \end{pmatrix},\ \pi=\begin{pmatrix} \pi_{v_1} & \pi_{v_2} \\ 1 & 1 \\ 2 & 2 \end{pmatrix}$$

The families type function is given by $\rho^{-1}(\{f_1,f_3\})=t_1$ and $\rho^{-1}(\{f_2,f_4\})=t_2$, and the institutions' correspondence type is given by $\eta(1)=\{t_1\}$, and $\eta(2)=\{t_1,t_2\}$. Finally, the vector of capacities is $e=(1,1)$.

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Step 1

Phase A.1. All families ask for their most preferred housing. We have that $D_1^1 = \{(f_1, v_1), (f_3, v_1)\}$ and $D_2^1 = \{(f_1, v_1), (f_2, v_1), (f_3, v_1), (f_4, v_2)\}$.

Then, the NDAT goes to Phase B1.

Phase B.1. Let $\overline{D_i^0} = D_i^t$ for all $i \in I$. The nested deferred acceptance starts; each institution demands the following sets:

$$\Delta_1^0 = Ch_1\left(\overline{D_1^0}, e_1\right) = \{(f_1, v_1)\} \text{ and } \Delta_2^0 = Ch_2\left(\overline{D_2^0}, e_2\right) = \{(f_2, v_1)\}$$

during Step 1 of the inner loop. The institutions' demand for housing is $V_1^0 = \{v_1\} = V_2^0$, where $1\pi_{v_1}2$. So, housing v_1 is tentatively assigned to 1, and the institution 2 is rejected from the apartment v_1.

The nested deferred acceptance moves to Step 2, where $D_1^1 = \{(f_1, v_1), (f_3, v_1)\}$ and $D_2^2 = \{(f_4, v_2)\}$. So, the demand of each institution is given by:

$$\Delta_1^1 = Ch_1\left(\overline{D_1^1}, e_1\right) = \{(f_1, v_1)\} \text{ and } \Delta_2^1 = Ch_2\left(\overline{D_2^1}, e_2\right) = \{(f_4, v_2)\}$$

The nested DA goes to its third step, where $\overline{D_1^2} = \overline{D_1^1}$ and $\overline{D_2^2} = \overline{D_2^2}$; then, the nested DA ends with $\theta^1(1) = \{v_1\}$ and $\theta^1(2) = \{v_2\}$.

Phase C.1. By the previous phase, we have that f_2 and f_3 are rejected from v_1, while the institution 1 tentatively allocates housing v_1 to family f_1 and institution 2 tentatively assigns v_2 to family f_4.

Step 1 ends with the following tentative assignment:

$$\mu^{NDAT^1} = \begin{pmatrix} f_1 & f_2 & f_3 & f_4 \\ v_1 & \varnothing & \varnothing & v_2 \\ 1 & \varnothing & \varnothing & 2 \end{pmatrix}$$

Step 2

Phase A.2. The families f_1 and f_4 retain housing v_1 and v_2, respectively, and families families f_2 and f_3 ask for housing v_2. So, we have that $D_1^2 = \{(f_1, v_1), (f_3, v_2)\}$ and $D_2^2 = \{(f_1, v_1), (f_2, v_2), (f_3, v_2), (f_4, v_2)\}$.

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Then, the NDAT goes to Phase B2.

Phase B.2. Each institution observes $\overline{D_i^0} = D_i^2$ for all $i \in I$. Thus, we have that:

$$\Delta_1^0 = Ch_1\left(\overline{D_1^0}, e_1\right) = \left\{\left(f_3, v_2\right)\right\} \text{ and } \Delta_2^0 = Ch_2\left(\overline{D_2^0}, e_2\right) = \left\{\left(f_4, v_2\right)\right\}$$

Then, the institutions' demand for housing is $V_1^1 = \left\{v_2\right\} = V_2^1$. Note that $1\pi_{v_2}2$. Then, v_2 is now tentatively assigned by institution 1, and institution 2 is rejected from housing v_2. The nested DA moves to the next step, where $V_1^2 = \left\{v_2\right\}$ and $V_2^2 = \left\{\varnothing\right\}$; so, the Phase B finishes with the tentative assignment $\theta^2(1) = \left\{v_2\right\}$ and $\theta^2(2) = \varnothing$.

Phase C.2. By the previous phase, we have that f_1 and f_4 are rejected from v_1 and v_2, respectively. Also, institution 1 tentatively allocates housing v_2 to family f_3, and institution 2 does not allocate housing.

Step 2 ends with the following tentative assignment:

$$\mu^{NDAT^2} = \begin{pmatrix} f_1 & f_2 & f_3 & f_4 \\ \varnothing & \varnothing & v_2 & \varnothing \\ \varnothing & \varnothing & 1 & \varnothing \end{pmatrix}$$

Step 3

Phase A.3. Family f_3 retains housing v_2. Since f_1 and f_4 were rejected from v_1 and v_2, both families ask for their last acceptable housing spaces v_2 and v_1, respectively. Since f_2 has been rejected from all her acceptable housing, we have that $D_1^3 = \left\{\left(f_1, v_2\right), \left(f_3, v_2\right)\right\}$ and $D_2^2 = \left\{\left(f_1, v_2\right), \left(f_3, v_2\right), \left(f_4, v_1\right)\right\}$.

Phase B.3. Let $\overline{D_i^0} = D_i^3$ for all $i \in I$. Then, the institutions' demand is given by:

$$\Delta_1^0 = Ch_1\left(\overline{D_1^0}, e_1\right) = \left\{\left(f_3, v_2\right)\right\} \text{ and } \Delta_2^0 = Ch_2\left(\overline{D_2^0}, e_2\right) = \left\{\left(f_4, v_1\right)\right\}$$

Then, the institutions' demand for housing is $V_1^1 = \left\{v_2\right\}$ and $V_2^1 = \left\{v_1\right\}$, where institutions 1 and 2 are acceptable for allocating housing speces

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v_2 and v_1, respectively. Thus, the nested deferred acceptance goes to the following step: each institution reiterates its housing demand. Consequently, Phase B.3 finishes with the tentative assignment $\theta^3(1)=\{v_2\}$ and $\theta^3(2)=\{v_1\}$.

Phase C.3. Institution 1 retains housing space v_2 and assigns it to family f_3, while institution 2 assigns hpusing space v_1 to family f_4.

Step 3 ends with the following tentative assignment:c

$$\mu^{NDAT^3}=\begin{pmatrix} f_1 & f_2 & f_3 & f_4 \\ \varnothing & \varnothing & v_2 & v_1 \\ \varnothing & \varnothing & 1 & 2 \end{pmatrix}$$

Since f_1 and f_2 have been rejected from all their acceptable housing, the NDAT finishes at this step. Thus, the final assignment is:

$$\mu^{NDAT}=\begin{pmatrix} f_1 & f_2 & f_3 & f_4 \\ \varnothing & \varnothing & v_2 & v_1 \\ \varnothing & \varnothing & 1 & 2 \end{pmatrix}$$

In the previous assignment, note that $v_1 P_{f_2} \varnothing$ and $\{(f_2,v_1)\} \succ^2 \{(f_4,v_1)\}$, where $\rho(f_2)\in\eta(2)$. Thus, $(f_2,2)$ has justified envy over $(f_4,2)$.

Example 4. (Running the NDAI). We consider the same market as in Example 3. Not that such an example shows stage 0.1 of the NDAI mechanism. At the end of stage 0.1, we note that institution 1 is an interrupter of housing v_1. Thus, we delete all acceptable pairs (f,v_1) from the priority $\succ^1$.

Thus, the FNDAT goes to Step 1 with:

$$\succ_1=\begin{pmatrix} \succ_1^1 & \succ_1^2 \\ (f_3,v_2) & (f_2,v_1) \\ (f_1,v_2) & (f_4,v_2) \\ & (f_4,v_1) \\ & (f_2,v_2) \end{pmatrix}$$

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So, stage 1.1 runs an NDAT with institutions' priorities $\succ_1$, families' preferences P, and housing priorities π. This stage ends with the following assignment:

$$\mu^{FNDAT} = \begin{pmatrix} f_1 & f_2 & f_3 & f_4 \\ \varnothing & v_1 & v_2 & \varnothing \\ \varnothing & 2 & 1 & \varnothing \end{pmatrix}$$

The previous assignment does not have interrupters. So, the FNDAT finishes.

Appendix B. Deletion of Interrupters

Example 3 points out that the NDAT is not fair for institutions. However, such an example allows us to understand why justified envy in institution 2 arises. Note that institution 1. tentatively assigns housing v_1 at Step 1 of the NDAT, which implies the rejection of f_2 from such housing. However, in the next step, institution 1 drops v_1 because it prioritizes the pair (f_3, v_2) over (f_1, v_1). Since f_2 is no longer asking for housing at Step 3, institution 2 assigns v_1 to f_4, which causes justified envy in the same institution. As in Kesten (2010) and Bloch, Cantala, and Gibaja (2020), we say that institution 1 is an interrupter for housing v_1.

Given that institutions' tentative assignments may cause justified envy, we add a stage in the NDA that deletes all family-housing pairs from the priorities of interrupter institutions. Below, we formally define the deletion operation.

Definition 2

Let $\mathcal{I}$ be the set of all possible priorities $\succ^i$ for all institutions $i \in I$. The *delete operation* is the map $\mathbb{D}: \mathcal{I} \times V \to \mathcal{I}$. such that $\mathbb{D}(\succ^i, v) = \succ^i - v$ is the priority where $\varnothing (\succ^i - v) \{(f, v)\}$ if and only if $\{(f, v)\} \succ^i \varnothing$.

In words, the priority $\succ^i - v$ keeps the same order in $\succ^i$ and declares unacceptable all those acceptable pairs (f, v) where institution i is an interrupter of housing v.

Initialization. The counter is set at $s = 0$.

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Step 0. This step unfolds in the following two stages:

Stage 0.1. The NDA phase. Let $\succ_0 = \left(\succ_0^i\right)_{i \in I}$ the profile of initial priorities. Run the NDA by considering institutions' priorities $\succ_0$, families' preferences P and housing priorities π.
Stage 0.2. Priorities adjustment. If there are no interrupter institutions, the algorithm finishes at Stage 0.1 and outputs the assignment μ^{NDAT}. Otherwise, find the last step where an interrupter drops a housing from which it is an interrupter. Update the institutions' priorities as follows:

$$\succ_1^i = \begin{cases} \succ_0^i - v & \text{if } i \text{ is an interrupter of } v \\ \succ_0^i & \text{otherwise} \end{cases}$$

Step s. The stages of this step are the following:

Stage s.1. The NDAT phase. Run the NDAT by considering institutions' priorities $\succ_s$, families' preferences P, and housing priorities π.
*Stage s.2. Priorities adjusment***.** If there are no interrupter institutions, the algorithm terminates at Stage s.1 and outputs the assignment μ^{NDAT}. Otherwise, find the last step where an interrupter drops a housing from which it is an interrupter. Update the institutions' priorities as follows:

$$\succ_{s+1}^i = \begin{cases} \succ_s^i - v & \text{if } i \text{ is an interrupter of } v \\ \succ_s^i & \text{otherwise} \end{cases}$$

We denote the output of the previous assignment mechanism as μ^{FNDAT}.

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