Solving Shortage in a Priceless Market: Insights from Blood Donation

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Preliminary, comments welcome!

Abstract

Blood shortage is common in many countries but it cannot be solved by price adjustment given the WHO recommendation for 100% unpaid voluntary donation. In this paper, we evaluate two non-price methods that blood banks often use to address shortage. The first method is informing existing donors of the current shortage via mobile message and encouraging them to donate voluntarily. The second method is asking the patient's family or friends to donate in a family replacement program. Using 472,342 individual donation records from a large Chinese blood bank, we show that both methods are effective in addressing blood shortage in the short run but the two methods target different audiences and therefore have different implications for total blood supply.

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1. Introduction

When market supply is short of market demand, economists often recommend price adjustment to clear the market. However, due to safety and ethical concerns, many markets prohibit price adjustments or do not allow a market price to exist at all (Roth et.al. 2007). Organ, tissue and blood donations are prominent examples. A stream of research has examined how matching mechanisms can increase the number of kidney transplants conditional on a pool of people who have already expressed an intent to donate (Roth et.al. 2006, Roth, Sonmez Unver 2004,2005). However, the number of donors is still low relative to the increasing demand, which motivates a recent call for recruiting new donors (Kessler and Roth 2012, 2014). Economic incentive (Lacetera et.al. 2011,2013) and alternative allocation policy (Kessler and Roth 2012) have been proposed to increase donation. While effective, much uncertainty and many restrictions still remain in implementing these proposals.

In this paper, we adopt a new angle and evaluate two non-price methods that practitioners have considered in the field. Both methods utilize "shortage" as a tool to increase the "warm glow" from donation and therefore stimulate market supply. They have different implications and can be used under different scenarios to alleviate shortage. We study these two methods in a classic priceless market -- blood donation -- but our findings can be generalized to other priceless markets with shortage.

Mostly driven by quality concerns, the World Health Organization (WHO) advocates for 100% unpaid voluntary donation for all medical use of human blood.[1] But this goal is hard to reach in many countries. As of 2012, 73 countries collect over 90% of their blood supply from voluntary unpaid blood donors; however, 72 countries collect more than 50% of their blood supply from family replacement or paid donors (WHO 2014). Figure 1 presents a WHO map of donation rate as of 2007. Countries that have low donation rate per capita are often poor and suffer from chronic blood shortage. In comparison, mid-to-high countries have relatively high donation rates and are more likely to experience occasional shortage due to unexpected attritions or emergency events.

Facing shortage, blood banks often resort to two methods. First, they strive to recruit more unpaid voluntary donors by conveying the shortage information in a blood drive in order to induce a warm glow feeling of donation.[2] However, if shortage is too severe or too frequent, donor recruitment from shortage message alone may not be sufficient to close the gap. Another method is family replacement (FR). In time of shortage, FR donors donate blood so that their sick family or friends can use the blood immediately without reducing the total blood supply in a blood bank. In practice, because not all blood types can be transfused safely between individuals, the blood bank usually swaps FR donation with the same amount of blood from the bank for the dedicated patient. Compared with shortage message, FR clarifies the immediate recipient of donation, and

[1] WHO (2009) stated that "more than 30 years after the first World Health Assembly resolution (WHA28.72) …. family replacement and paid donation continue in many countries even though there is convincing evidence that they are both less safe and that their use can inhibit progress to a safer system based on 100% VNRBD." VNRBD stands for 100% voluntary non–remunerated blood donation.

[2] In the economics literature, altruistic individuals are assumed to gain utility from increasing the welfare of others, while individuals motivated by warm glow receive utility from their own contributions directly (Andreoni, 1989; 1990). Studies in the lab and the field have confirmed the importance of warm glow (Crumper and Grossman 2008, DellaVigna, List and Malmendier 2012), and find that donations connected with a greater sense of need or deservingness also create more warm feelings (Konow 2010). In our context, it is difficult to distinguish altruism from warm glow, so we refer to both of them as warm glow.

therefore could generate even more warm glow from a patient's close social connections. In addition, FR shifts the burden of donor recruitment from the blood bank to individual patients, which could cut the cost of recruitment by 75 to 87 percent.[3]

However, neither shortage message nor FR donation are immune from downside risks. Theoretical and empirically, economists have shown that some individuals are conditional cooperators who are more willing to contribute to a public good when they learn that others do so as well.[4] In our context, both shortage message and FR donation convey credible information about others' (insufficient) donation and therefore could reduce the incentive of donation among those who value conditional cooperation. We refer to this effect as "distrust". Moreover, FR program allows blood donation to be shared within family/friends rather than with the general public. While this could reduce one's incentive to free ride, it may also create an incentive to save the blood for one's small social circle and crowd out the incentive to donate for the society. We refer to this effect as "crowd-out".

In practice, FR also raises a concern of blood quality. FR could encourage desperate patients to hire professional donors as a "friend" of the patient and jeopardize blood quality. For this reason, the WHO recommends phasing out FR donation and eliminating paid donation. Nevertheless, researchers have found mixed evidence on the blood quality of FR donors: on the one hand, Abdel Messih et al. (2014) use Egyptian data to show that the prevalence of transfusion-transmissible infections is much higher among FR donors than among voluntary donors; on the other hand, Allain et al. (2010) compare FR donors with first-time voluntary donors in West Africa and find their blood quality to be similar. From a policy maker's point of view, it is essential to understand the tradeoff between these downside risks and the positive incentives from shortage message and FR program before they decide when to pursue which method to alleviate shortage.

Our data come from a large blood bank located in a major southeast city of China with over 8 million population as of 2012. Since 2010, the city faced an increase in blood shortage, partly due to increased demand for blood, partly due to a rising concern on non-profit service which in turn discourages voluntary donation. The bank has used two methods to address blood shortage: one is sending mobile phone messages to the donors that have donated to the bank before; the other is requesting the patients' families to find FR donors.

For both methods, it is not easy to quantify the tradeoffs facing blood banks because individual incentives are unobservable. Fortunately, our data contain over 300,000 individual donors and their donation history from 2005 to 2013, which allows us to find control individuals that are closely matched with the individuals who either received shortage message or donated via FR. As detailed below, the effect of shortage message is cleanly identified because sometimes blood supply is only short for certain blood type(s), which gives us exogeneity in who received a shortage message specific to the shorted blood type. The variation on FR and non-FR donation is

[3] As shown in Bates et al. (2007), the cost of getting blood from voluntary donors recruited and screened at transfusion centers is four to eight times as much as the cost of obtaining blood from hospital-based FR donation. It is usually the bank's responsibility to find voluntary donors, whereas the burden of finding FR donors falls on the patient's family.

[4] See Andreoni (1988), Fischbacher et al. (2001) and Sugden (1984) for theoretical models on conditional cooperation and reciprocy. See Fischbacher, Gachter and Fehr (2001), Potters, Sefton and Vesterlund (2005), Frey and Meier (2004) and Kessler and Roth (2014) for lab evidence, and Shang and Croson (2008, 2009), Martin and Randal (2008), Allcott (2011), and Croson and Shang (2008) for evidence from field experiments.

less clean, because we only observe who donated FR rather than who received a request of FR donation, which introduces selection even if the chance of having family or friends being sick is completely random. We articulate the implication of such selection and find a way to separate the causal effect of FR program from potential selection.

Comparing treated and control individuals, we find that a shortage message leads to more donations among existing donors within the first six months but not afterwards. This effect is stronger for donors who have donated more times before receiving the shortage message, suggesting a greater warm glow effect for frequent donors. In comparison, FR donation has a small positive effect in encouraging existing donors (who have donated before the FR) to donate more blood voluntarily after their FR donation, but discourages no-history donors (whose first donation is FR) from donating in the future. This suggests that warm glow dominates the crowd-out and distrust effects for existing donors, while crowd-out and distrust effects are more prevalent for no-history donors.

Because neither treatment generates worse blood quality, the efficiency comparison between the two methods is largely dependent on level of control, targeted audience, and the effects of treatment in short and long runs. Back of envelope calculation suggests that shortage message can be used in places where the donor population is large and the shortage is minor, while FR could be more useful when the donor population is small and the shortage is severe. That being said, in a society with a low donation rate (which could be the reason for severe shortage to begin with), most FR donors will be no-history FR donors and the FR treatment may discourage voluntary donation in the long run by generating either distrust or crowd-out. Although a widespread introduction of FR can bring significant blood supply in the short run, it may exacerbate the shortage problem in the long run.

The rest of the paper is organized as follows. Section 2 presents econometric models to identify the potential pros and cons of mobile message and FR donation. Section 3 describes and summarizes the data. Section 4 presents our empirical results. Section 5 discusses policy implications of our findings.

2. Potential Effects and Econometric Identification

While shortage message and FR program are two commonly used methods to alleviate blood shortage, their exact implementation can vary by the targeted audience. By donation history (measured by the number of donations N before the intervention time), the potential audience can be grouped into no-history donors (N=0), infrequent donors (N=1), and frequent donors (N>=2). In principle, both shortage message and FR program can target all three types. In practice, the local blood bank in our data targets the shortage message on existing donors (including both infrequent and frequent ones), and implements the FR group quietly for all three groups conditional on their families or friends need blood in a hospital and there is blood shortage at that time.

2.1 Effects of shortage message

For existing donors, the shortage message can have a mixed effect on their willingness to donate. On the positive side, shortage implies that the donated blood can be used immediately on someone that need blood, which increases the donor's perceived benefits from unpaid voluntary donation. The perceived benefits may come from pure altruism or warm glow. With no information to tell the two apart, we simply refer to the sum of the two as "warm glow". Note that the extra warm glow from donating in response to a shortage message is tied to that specific shortage and therefore is a short run effect. The warm glow effect may also differ by the donation history of message recipients: if frequent donors donate more frequently because they derive more warm glow from donation, the shortage message may generate more warm glow for them than for infrequent donors.

On the negative side, shortage may change an existing donor's belief on how the rest of the community has contributed to the public good. If the donor believes that the shortage occurs because the rest of the community contributes too little, she may become less motivated for future donation. This negative effect on conditional cooperation – referred to as distrust – can occur in both short and long runs.

Above all, assuming the data offer an exogenous variation in shortage message and we can find control donor(s) for every treated donor that receives this exogenous message, the sign of the aggregate effect should be positive if warm glow dominates distrust or negative vice versa. Moreover, if the aggregate effect is positive, we expect it to be positive only in the short run; if the aggregate effect is negative, it can be negative in both short and long runs.

The econometric model is straightforward. We first match a treated individual i with individual(s) that have the same demographics and donation history as i but do not receive the message, call the pair group g. We then run a typical differences-in-differences regression, where y_{it} denotes whether i donates voluntarily at time t, $1_{msg,i}$ is a dummy for the treated individuals, and $1_{aft,t}$ is a set of dummies equal to one if t is in a specific half year at or after the time of the message.

$$y_{it} = \alpha_i + \alpha_t + \beta_{msg} \cdot \sum_{t=T}^{T\in\{0,>0\}} 1_{msg,i} \cdot 1_{aft,t} \quad + \varepsilon_{it}.$$

2.2 Effects of FR

FR is more complicated than shortage message. In addition to conveying shortage, a record of FR donation implies another two pieces of information. First, the donor knows that her FR donation benefits a family or friend, rather than an unknown stranger. Assuming individuals are typically more altruistic towards family and friends or derive greater warm glow from social ties, the warm glow effect of FR can be greater and more long lasting than shortage message alone. However, the same reason could generate a crowd-out effect in the future. If one knows that she can dedicate her blood to her family and friends when they need them, she may have an incentive to save the blood for her own social circle in the future instead of donating it to the general public. In this sense, the FR program may introduce a danger of reducing the pool of risk sharing and undermining the efficiency of risk pooling.

The second piece of information conveyed by a FR donation record is selection. In principle, the treatment we are interested in is being aware of the FR program. In reality, the FR program is implemented quietly, which implies that the real treatment is whether an individual has received a FR request at a hospital. However, what is observed in the data is FR donation, not FR request. Because FR donation will not occur unless the FR donor has agreed to donate upon request, FR donation is subject to unobserved selection. The magnitude of selection is crucial for the overall evaluation of an FR program. At one extreme, if FR donors are so altruistic that they would have donated voluntarily to the blood bank even if they have not received the FR request, the FR program does not increase the blood supply at all. At the other extreme, if all FR donors are those that will not donate to the blood bank but will donate for their own family and friends, these FR donations will sustain the demand from their family and friends and free up same amount of blood for the rest of the community.

The econometric challenge is how to distinguish the selection effect from the warm glow, distrust, and crowd-out effects.

For an FR donor that has donated via FR at time t (denoted as $FR_t = 1$), let us assume she carried demographics X_i and a donation history (H_i) before t. There are M_i number of FR donors that have exactly the same $\{X_i, H_i, FR_t\}$. In our donation records, we find N_i individuals that had the same X_i and H_i before t but did not donate FR. Among these M_i+N_i individuals, should the FR not exist, a fraction (λ_i) would have donated voluntarily at t while the rest (1- λ_i) will not donate at t. The first type (referred to as V type) might be more altruistic than the second (referred to as N type). These two types of donors, if unaware of FR, will donate in the future with probabilities p_V and p_N respectively. For simplicity, let Δp denote $p_V - p_N$:

$$y_V = p_V = \Delta p + p_N$$
$$y_N = p_N$$

Suppose the risk of having a family or friend in need of blood (π) is the same for every one, but the likelihood of agreeing to donate FR is θ_V for V type and θ_N for N type. Thus, by selection, the ratio of FR donors that have the same $\{X_i, H_i\}$ by t is

$$\frac{M_i}{M_i + N_i} = \pi \cdot \theta_V \cdot \lambda_i + \pi \cdot \theta_N \cdot (1 - \lambda_i).$$

Conditional on being a FR donor, the probability of donating in the future is the sum of the selection effect and a combination of warm glow, distrust and crowd-out effects (ω):

$$\begin{aligned} y_{FR} &= \frac{\theta_V \cdot \lambda_i \cdot p_V + \theta_N \cdot (1 - \lambda_i) \cdot p_N}{\theta_V \cdot \lambda_i + \theta_N \cdot (1 - \lambda_i)} + \omega \\ &= p_N + \omega + \frac{\theta_V \cdot \lambda_i \cdot \Delta p}{\theta_V \cdot \lambda_i + \theta_N \cdot (1 - \lambda_i)} \\ &= p_N + \omega + \Delta p \cdot \left(1 - \frac{\theta_N \cdot (1 - \lambda_i)}{\theta_V \cdot \lambda_i + \theta_N \cdot (1 - \lambda_i)}\right) \\ &= p_N + \omega + \Delta p \cdot \left(1 - \frac{1}{1 + \frac{\theta_V}{\theta_N} \cdot \frac{\lambda_i}{1 - \lambda_i}}\right) \\ &= p_N + \omega + \Delta p \cdot \left\{\frac{\theta_V}{\theta_N} \cdot \frac{\lambda_i}{1 - \lambda_i} - \left(\frac{\theta_V}{\theta_N}\right)^2 \cdot \left(\frac{\lambda_i}{1 - \lambda_i}\right)^2 + \left(\frac{\theta_V}{\theta_N}\right)^3 \cdot \left(\frac{\lambda_i}{1 - \lambda_i}\right)^3 - \cdots\right\} \\ &\approx p_N + \omega + \Delta p \cdot \left\{\frac{\theta_V}{\theta_N} \cdot \frac{\lambda_i}{1 - \lambda_i}\right\}. \end{aligned}$$

Denote $\Delta\theta = \frac{\theta_V}{\theta_N}$, add an i.i.d error term and rewrite the above in vectors, we have:

$$y = \begin{pmatrix} y_V \\ y_N \\ y_{FR} \end{pmatrix} \approx p_N \cdot \begin{pmatrix} 1 \\ 1 \\ 1 \end{pmatrix} + \Delta p \cdot \begin{pmatrix} 1 \\ 0 \\ 0 \end{pmatrix} + \omega \cdot \begin{pmatrix} 0 \\ 0 \\ 1 \end{pmatrix} + \Delta p \cdot \Delta\theta \cdot \begin{pmatrix} 0 \\ 0 \\ \frac{\lambda_i}{1 - \lambda_i} \end{pmatrix} + \begin{pmatrix} \varepsilon_V \\ \varepsilon_N \\ \varepsilon_{FR} \end{pmatrix}.$$

In this equation, the ω term is the warm glow/distrust/crowd-out effect that applies to each FR donor equally. The last non-error term is the selection effect, which is identifiable from the warm glow/distrust/crowd-out effect of FR because the selection effect depends on λ_i, the proportion of type V in the $\{X_i, H_i\}$ population. If we can have a good proxy for $\frac{\lambda_i}{1-\lambda_i}$, this equation can be run in linear specifications. The ratio of the fourth and second coefficients tell us $\Delta\theta$, which denotes the extent to which type V donors are likely to donate relative to type N and should be bigger than one.

One rough proxy for $\frac{\lambda_i}{1-\lambda_i}$ is the ratio of type V to type N in non-FR donors, which in theory follows:

$$\frac{N_{V,FR=0}}{N_{N,FR=0}} = \frac{\lambda_i \cdot (1 - \pi \cdot \theta_V)}{(1-\lambda_i) \cdot (1 - \pi \cdot \theta_N)}.$$

It is not perfect because the non-FR population is already a result of selection, although the selection is arguably small if π is very small. Another possibility is computing this ratio *before* FR is introduced. Empirically, we can calculate the hazard ratio of donating voluntarily at a certain time condition on $\{X_i, H_i\}$, this ratio will be a proxy of λ_i from which we can easily calculate $\frac{\lambda_i}{1-\lambda_i}$.

Once we identify $\Delta p, \Delta\theta$, and $\frac{\lambda_i}{1-\lambda_i}$, the total selection effect of FR (relative to type N) can be computed as:

$$selection\ effect = \Delta p \cdot \left(1 - \frac{1}{1 + \Delta\theta \cdot \frac{\lambda_i}{1-\lambda_i}}\right).$$

In the case of no FR, the average voluntary donation per capita will be:

$$Supply_{noFR,t} = \lambda_i \cdot 1 + (1-\lambda_i) \cdot 0 = \lambda_i;$$

$$Supply_{noFR,after\ t} = \lambda_i \cdot p_V + (1-\lambda_i) \cdot p_N.$$

By definition, type V will donate voluntarily at t for sure and type N will not donate voluntarily at t. This explains why $Supply_{noFR,t}$ is just the proportion of type V, which is λ_i.

If FR is introduced for all donors with $\{X_i, H_i\}$ at t conditional on their family or friends are in need of blood (the probability of this event is π), the average supply per capita at t and after t will be:

$$Supply_{FR,t} = (1-\pi) \cdot Supply_{noFR,t} + \pi \cdot \theta_V \cdot \lambda_i + \pi \cdot \theta_N \cdot (1-\lambda_i);$$

$$Supply_{FR,after\ t} = (1-\pi) \cdot Supply_{noFR,after\ t}$$
$$+\pi \cdot (1 - \theta_V) \cdot \lambda_i \cdot p_V + \pi \cdot (1-\theta_N) \cdot (1-\lambda_i) \cdot p_N$$

$$+\pi\cdot[\theta_V\cdot\lambda_i+\theta_N\cdot(1-\lambda_i)]\cdot\left\{p_N+\ \omega+\Delta p\cdot\left(1-\frac{1}{1+\Delta\theta\cdot\frac{\lambda_i}{1-\lambda_i}}\right)\right\}.$$

Because type V will denote voluntarily without FR anyway, we will assume type V will always donate upon an FR request, i.e. θ_V=1. Under this assumption, the extra supply due to FR can be written as:

$$\Delta Supply_t=\pi\cdot[(\theta_V-1)\lambda_i+\theta_N(1-\lambda_i)]=\pi\cdot\theta_N\cdot(1-\lambda_i);$$

$$\Delta Supply_{after\ t}=\pi\cdot\omega.$$

In words, the ability for FR to raise blood supply at t depends on the extent to which FR can hit on type N donors and the rate of converting this hit into donation. After the FR treatment, the extra supply due to FR is solely dependent on the warm glow/distrust/crowd-out effect (ω) because selection alone changes no behavior.

In sum, if we just compare the future donation behavior of an FR donor with the donation behavior of the seemingly identical donors that do not donated FR at t, the empirical effect will capture both the true warm glow/distrust/crowd-out effect (ω) and a selection effect. It is important to distinguish the two, not only because the former is the true effect of FR on future donation behavior, but also because the selection effect affects the causal effect of FR on blood supply at t.

The sign of the warm glow/distrust/crowd-out effect (ω) can tell us whether the positive warm glow effect dominates the negative distrust and crowd-out effect. It is helpful to know whether ω persists in the long run, as warm glow towards family/friends is likely not applicable to voluntary donations in the future but distrust and crowd-out may last.

In summary, we present econometric models to estimate the causal effect of shortage message and FR program. Two items are worth highlighting: first, receiving shortage message is not bundled with whether one responds to the message or not, which makes the econometrics clean and simple. But FR donation bundles the receipt of FR request and a positive response to that request, which is why we need to consider selection in FR donation. Second, shortage message was sent to existing donors, while FR could hit both existing and no-history donors. Consequently, the effectiveness of FR depends not only on the effect of FR on future donation behavior, but also on the extent to which the FR hits no-history donors at the time of FR request. This is because no-history donors are by definition more likely to be a free rider on the society, and FR serves as a way to motivate these free-riders to contribute. We will come back to the magnitude of this effect after we present our data and coefficient estimates.

3. Data

3.1 Data Description

Our data come from a centralized blood bank (hereafter ‘blood center’ or ‘BC’) at a provincial capital city with more than 8 million population. The blood center is responsible for supplying blood to 18 hospitals in the city and is encouraged to equalize demand and supply of whole blood on their own.[5]

The data covers two forms of whole blood donation: (1) voluntary donation collected by 17 permanent street mobiles spread across the city and by group drives at specific universities, companies and government agencies; and (2) directed FR donation for family and friends. The blood center's administrative database includes every donation record from 2005/1/1 to 2013/8/10, tracking the exact time, location, form (voluntary or FR), amount (200ml, 300ml, or 400ml) and quality ("pass" or "fail") of donation, as well as the donor's age, gender, education and marriage status at the time of donation. The blood center has carefully removed all identity-related information and identifies each donor by a unique, scrambled donor ID, allowing us to follow the donation behavior of each donor over time.

After deleting individuals who only have donated placelet[6], the resulting dataset consists of 472,342 episodes of whole blood donation by 358,489 unique donors. Taking donor age as of 2013, Table 1 shows that 27.14% of the donors were aged below 20, 54.14% aged between 20 and 30, 12.58% aged between 30 and 40, and the rest 6.14% are above 40. Majority of the donors (60.71%) are male. As for other demographics, 77.81% do not have college degree, 68.79% are single, 18.66% have residential permit (hukou) from the city, 37.56% have hukou from elsewhere of the same province, 29.87% have hukou from other provinces, and the rest 13.91% have unknown hukou status. The donor concentration in younger, male population is consistent with the medical literature. The dispersed distribution of hukou status is driven by the fact that this is a capital city of a province with dense population, and one is allowed to study, work, and carry out military duties in the city even if his/her hukou is from elsewhere.

Table 2 summarizes the data by donation episodes instead of donor identity. Of the total 472,342 donation episodes, 56.15% are voluntary donation at street mobiles, 39.79% are voluntary donation at group drives, and the rest 4.06% are FR donations. Figure 2 shows the over time variation between voluntary and FR donations. Perceived as the last resort, FR donation was not used until the second quarter of 2010, when a few idiosyncratic events shook public trust on the health effect of blood donation, the disposal of donated blood, and government-owned non-profit service in general. In comparison, mobile message calling for existing donors to donate whole blood at time of shortage has been used four times throughout our data period, dating back to as early as September 3, 2010.[7] Of the four whole blood shortage messages, one was specific to type B (2012/10/8), one was specific for blood types A and B (2010/9/3), and the remaining two did not specify demand for blood type (2012/1/13, 2012/1/18). In order to construct control individuals who were omitted from some messages but have the same demographics as those receiving these messages, we define our treatment messages as the two messages specific to blood type(s).

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[5] In the rare cases of emergency blood shortage, the blood center may request extra supply from nearby blood banks, but at extremely high transportation and administration cost. Such situation is reported to be very rare in our interview with the blood center.

[6] The blood bank handles both platelet and whole blood donations. The two types of donations differ greatly in procedures, locations, and donor population. Platelet donation usually takes place at the centralized location of the blood bank, rather than a street mobile.

[7] There was one message that did not indicate whether the needed donation is for whole blood or platelet but it instructed donors to donate at a specific location in the headquarter of the blood bank. Because most donations at the bank headquarter are platelet donations, we treat this message as for platelet shortage.

The bottom of Table 2 shows the distribution of donation amount and blood quality: donation amount is dispersedly distributed between 200 and 400ml, with more density for 301-400ml (41.68%) and 201-300ml (33.64%) than at or below 200ml (24.67%). Blood quality is generally good, 95.82% passed a battery of blood tests for HIV, hepatitis, syphilis and other diseases.

The rest of Table 1 and Table 2 summarize the data according to whether a donor has received any treatment message and whether a donor has made any FR donation. By headcount, 11,600 donors have received at least one of the two shortage messages specific to blood type and have never donated FR throughout. Compared to the full sample of donors, they are more likely to be young, female, single, local and without a college degree. By definition, shortage messages were only sent to existing donors. Among the 11,600, message recipients, 8,042 have donated once before getting the message, 1,937 have donated twice, and 1,621 have donated three or more times.

Turning to 19,072 donors that have ever made FR donation, majority of them (17,996) never donated anything before their FR donations, we refer to them as no-history FR donors. The rest FR donors (1,076) are all existing donors, among which 680 have donated once before making the FR donation, 201 have donated twice, and 195 have donated three or more times. Compared to all donors or those receiving shortage message, FR donors, especially the no-history FR donors, are older and more likely to be local and married. This suggests that FR attracts very different types of population as compared to shortage message or voluntary donation in general.

Inconsistent with the WHO concern, blood quality is comparable between FR and voluntary donors (96.19% vs 95.82%), although the quality of no-history FR donations (95.87%) is slightly lower than that of existing FR donations (98%). Those who received shortage message also donate blood of similar quality (97.68%), as compared to other donors. Both FR donors and the treatment message recipients donate a greater amount per episode than the rest of the sample, probably because they know some of their donations target immediate shortage. It is not often to observe the same individual receiving two treatment messages (501), making more than one FR donations (87), or receiving any of the two treatment messages and donating FR anytime throughout the sample (89). We delete these donors from analysis.

3.2 Matching

3.2.1 Matching for message recipients

Because donor incentive is hard to observe and some unobserved donation incentives may not be highly correlated with age, gender, or other observable attributes, we match treated and control individuals by both demographics and donation history. By donation history, we mean the timing and channel of past donations, where timing is defined by a calendar half year, and donation channel is defined by whether a voluntary donation took place at a street mobile (so called individual donation) or at a dedicated blood drive at the donor's work place (so called group donation).

For shortage message, we define treated and control individuals as follows. The two shortage messages we focus on are specific to types A and B (2010/9) and type B (2012/10), hence we define the treated as those that received one of the messages. We exclude those receiving both messages from the analysis, to ensure that we identify the effect of receiving one message. For clean comparison, we only search for controls in the pool of donors whose blood type is either AB or O. To avoid any cross effect between shortage message and FR donation, both treated and controls are conditional on not making any FR donation throughout our sample period. We treat the recipient of the two treatment messages as exogenous conditional on observables, because the blood bank uses an automated marketing software to choose message recipients and the software only allows selection on a few observable variables including blood type, total number of past donations, the timing of last donation as well as previous test result.

More specifically, to search for all controls that have the same demographics and donation history as a treated donor, we perform the matching algorithm in two steps. First, for individual i in a calendar half year t, we define a variable d_{it} equal to 1 if he/she made an individual donation at t, 2 if he/she made a group donation, and 0 if he/she did not donate. Then for an individual j in the pool of potential controls, we define the Euclidean distance between i and j as

$$\mathrm{ED}_{\mathrm{ij}} = \left[\sum_{\mathrm{t=p}}^{\mathrm{r-1}} \left(d_{it} - d_{jt}\right)^2\right]^{1/2}$$

where p is the start of our sample period and r is the half year that the treated individual received a treatment message. To be conservative, we focus on the pool of controls with zero distance to the treated ($\mathrm{ED}_{\mathrm{ij}} = 0$). In the second step, among those with zero distance, we search for donors that share the same gender, age (<20, 20-30, 30-40, and 40+), education (bachelor degree or not), marital status (married or not) and hukou location (in the city, elsewhere in the same province, other province, or unknown) with the treated donor.

For the second treatment message (specific to type B), it is possible that a treated donor has received other non-blood-type-specific shortage message(s) in January 2010 before this treatment. Therefore, for donors subject to this treatment, we also match the controls by whether they have received the same non-treatment shortage message(s) in January 2010. It turns out that any treated donors that have also received non-treatment message(s) in January 2010 cannot find a zero-distance match at all, which implies that they are excluded from the message-analysis sample.

The first two rows of Table 3 summarizes the count of treated and control donors for the two message treatments. Specifically, 3,103 donors received the message specific to blood types A and B, and we can find at least one zero-distance controls for 1,738 of them. Another 8,497 donors received the B-specific message, of which 6,883 have zero-distance controls. On average, each treated donor in shortage message has 4 to 5 control donors.

3.2.2 Matching for FR donors

Similar matching algorithm applies to the FR treatment. Any individual that has made one FR donation throughout our sample period is defined as a treated donor. Those who donated FR more than once, or have donated FR once and received any of the two shortage messages are excluded from the analysis. A treated donor may be an existing FR donor or a no-history FR donor.

For an existing FR donor who has donated voluntarily before the FR donation, we search in our database of donors for those who have exactly the same donation history and demographics before the treatment half year. The matching algorithm is the same as above.

For a no-history FR donor i, there are two types of controls. The first type includes those who did not donate before the half year of the FR event but donated voluntarily at or after the event time. We can find them in our donor database by the above matching algorithm. Let us refer to them as type-1 control and denote their count as N_{1i}. The second type of control includes those who never donated to the blood bank throughout our sample period. By definition, they do not appear in our database of donors. To locate them, we resort to the demographic summary from the 2005 census of the city, which tells us the percentage of city residents (S_{2i}) that have the same age, gender, education, marital status and hukou location as i.[8] Assuming the composition of demographics is stable over time, we calculate the number of city residents in that i's demographic cell at time t as $N_{2it} = Pop_t * S_{2i}$. Within N_{2it}, some may have donated to the blood bank before the treated FR time (regardless of whether their donation is FR or not), let us denote their count as N_{0i}. Then the count of type-2 control for i can be expressed as $N_{2it} - N_{0i} - N_{1i}$. Though these people do not appear in our database of donors, we add them back to the database by imputing their donation dummy at each half year as zero.

Of the 17,996 no-history FR donors, the majority (16,777) have valid type-1 control donors, with on average 7 type-1 controls per treated donor. The number of type-2 controls is on average 175,341 per treated donor at the event half year (the median is 62,283). Compared to no-history FR donors, the matching rate is lower for existing FR donors, especially if they had already donated multiple times before the FR donation. This is not surprising because in total only 4.5% of the 8+ million population of the city have ever donated to the blood bank. In total, out of 1,076 existing FR donors, we are able to find controls for 866 of them, with an average of 103 controls per treated donor.

In terms of demographics, no-history FR donors are different from both message recipients and existing FR donors. In particular, no-history FR donors are more likely to be middle-aged, married, and male. People with different donation history before the message or FR treatment are also different in demographics: typically, those who had a longer donation history before treatment are younger and more likely male, college-educated and with hukou within the same province. Given these differences in observable demographics, we believe donors with different donation history may differ in unobservable attributes as well, some of which (e.g. the warm feeling from donation) could trigger different responses to our message or FR treatment.

4. Estimation Results

In this section, we present the regression results on the effects of the two treatments. The first two subsections focus on donation rate and donation amount in response to shortage message and FR donations separately. Given WHO concern on blood quality, results on blood quality are presented at the end of this section.

4.1 Effects of shortage messages on donation rate and donation amount

Figure 3 contrasts the donation rate of message recipients and their controls, by every half calendar year. Time 0 is defined as the half year that the message was sent out. Because different message recipients may end up having a different number of controls in our analysis sample, we weight each control equally within each treatment-control pair and make sure that the total weight is one for the controls as a whole (as opposed to one for the treated donor). By definition, treated and control donors follow an identical path of donation before time 0, which declines before time 0 partly because of natural attrition of donors (e.g. some donors may have left the city permanently), partly because one is not eligible to donate until the last donation time is at least six months ago. At time 0, treated donors have a slightly higher donation rate than the controls but the two become identical since time 1. This suggests that some treated donors responded to the shortage message almost immediately, and this positive effect drops to zero soon after the message.

[8] We are grateful to Chong Liu at Tsinghua University for providing us the count of population by demographics.

Table 4 delivers the same finding in a regression form. Starting with our matched sample of treated and controls, we collapse the controls of each donor into one observation every half-year so that the final regression sample is grouped by one treated and one (average) control per pair per half-year.[9] The unit of observation is donor by half-year, the dependent variables are the dummy of donating or not in Columns 1-3 and the amount of donation (zero if not donate) in Columns 4-6. Both regressions are OLS with donor fixed effects and half-year fixed effects. Throughout the whole matched sample, shortage message motivates a 1.6 percentage point increase in donation rate at t=0 and nothing afterwards. This amounts to 5.2ml more blood per treated donor at t=0 and insignificant change of donation rate at t>0. If we split the sample by whether the treated donor has donated once (infrequent) or more than once (frequent) before receiving the shortage message, the message has a much bigger effect on frequent donors (3.9% increase in donation rate, roughly 13.75ml) than on infrequent donors (1.2%, 3.57ml). One explanation is that frequent donors were more motivated to donate even before the message because they experience more warm glow from donation, and the shortage information from the message generates more warm glow for frequent donors.

4.2 Effects of FR on donation rate and donation amount

As articulated in Section 2, it is more challenging to evaluate the causal effect of FR donation on an FR donor's future donation incentives and the blood bank's total blood supply. In particular, because we only observe who made the FR donation rather than who received an FR request, FR donors might be a selected group even if the risk of family or friends being sick is completely random and the incurrence of blood shortage is out of the control of any individual.

Figure 4 compares the donation rate of FR donors and their controls in the raw data. Like Figure 3, controls are weighted so that we give the same weight to each treated donor and all of his/her controls combined. Time zero denotes the time of each FR donation, and the unit of time is defined as half calendar year. At time zero, the FR donation rate is one by definition, but the donation rate of the control donors is typically much lower. Given the demographic difference between no-history and existing donors, we present Figure 4 for no-history and existing FR donors separately. The donation rate of no-history donors jumps back to nearly zero right after the FR donation, which is below the donation rate of their corresponding controls at t=1 but comparable to the controls at t>=2. One possible explanation is that the experience of FR donation has triggered distrust or crowd-out effects among no-history FR donors.

The picture for the existing FR donors is quite a contrast. By construction, these FR donors and their controls have the same donation history before time 0. Both groups had a dip at t=-1, because donors are not allowed to donate again until six months after the last donation. At time 0, the FR donors donated 100% (by definition), while less than 10% of their controls donated voluntarily. After time 0, the FR donors continue to have a slightly higher donate rate than their controls and this difference seems to persist from t=1 to t=5. One potential explanation is selection: the existing donors that agree to donate FR may donate anyway even without the FR program, if this is the case, FR from these donors have little effect on the bank's current and future blood supply. Another explanation is that the warm glow generated by the FR experience dominates the potential negative effects (distrust and crowd-out), encouraging the existing FR

[9] We take average during the collapse operation. Results are identical if we weight individual controls rather than collapse the controls. In particular, in that weighted regression, if a treated donor has M controls, each control donor receives 1/M weight so that each treatment-control pair receives the same weight in the regression.

donors to donate even more in the future. This could have a beneficial effect on future blood supply, even if the FR donors are a selected group.

Regression results are presented in Tables 5, 6 and 7. As a start, Table 5 Column 1 shows an OLS regression of *all* donors in our database (FR or not) *without matching*. The dependent variable is whether a donor donates in a particular half calendar year. Although we include donor fixed effects and half-year dummies, the regression results can be biased because FR and non-FR donors can differ in many observable and unobservable dimensions, carry different donation histories, and appear in our data at different times. If we ignore potential bias from these differences, the regression suggests that FR generates a spike of positive effect at time zero (which is by definition) and a negative effect on donation rate (-5.8%) afterwards. Note that this result is mostly driven by no-history donors, as they account for 94% of all FR donors in our data.

The other three columns of Table 5 rerun the regression after we construct control donors for each no-history FR donor. Recall that we have two types of controls for no-history FR donors: type-1 control donors did not donate before t=0, but have donated at or after t=0; type-2 control donors are the part of the city population that have the same demographics as a no-history FR donor but never donated whole blood throughout our data period. Including both types of controls, we first collapse controls per treated donor into one observation per half-year and then run the OLS regression with donor fixed effects and half-year fixed effects. Column 2 shows that FR has generated close to one donation at t=0 (0.815, driven by definition of FR donors) and 0.038 fewer donations per half year after t=0. Column 3 further breaks down the post-FR period into t=1, t=2 and t>=3. The negative effect at t=1 is bigger than the other two periods (-4.7% versus -3.1% and -3.4%), which is understandable as there is a natural attribution after a donation and even regular donors may prefer to donate once a year rather than twice a year. Translating the effect on donation rate into donation amount, Column 4 shows that the FR treatment generates 270.7ml more blood supply per donor at t=0, and 11.7ml less per donor per half-year after t=0.

Table 6 reports the parallel regression results for existing FR donors. Column 1 shows the OLS results without matching, which we argue can be biased due to observable and unobservable differences between our existing FR donors and all the other non-FR donors. This regression has fewer observations than Column 1 of Table 5 because we exclude no-history FR donors. Like that regression, this OLS regression without matching shows a positive coefficient on FR donors at t=0 (by definition) and a negative coefficient on FR donors after t=0.

Narrowing down to the matching sample, the OLS results presented in Column 2 of Table 6 still shows a large positive coefficient for FR donors at t=0 (0.96, driven by definition), but the coefficient for FR donors after t=0 becomes positive (2.9%). Column 3 decomposes the post-event period into t=1, t=2 and t>=3. It shows that the positive effect on FR donors is 2.3% at t=1, becomes stronger at t=2 (4.7%) and then comes back to 2.1% at t>=3. The stronger effect at t=2 than t=1 can be explained by the fact that many repeat donors donate once a year and therefore there is a natural attrition half a year after last donation. The positive effect at t>=3 suggests a long lasting effect of FR encouraging the existing FR donors to donate more in the future. This is possible if FR creates extra warm glow and it dominates distrust and crowd-out. Table 6 column 4 shows that the positive effect of FR after t=0 is robust if we use a duration model to characterize the time lapse since last donation.[10] The last two columns of Table 7 show that the positive effect of FR on the existing FR donors creates 332.4ml blood supply per donor at t=0 and 10.5ml extra blood supply per half-year per donor after t=0.

[10] In the duration model, we randomly pick a control from the matched control group for each treated donor and control the random coefficient of each donor in the hazard model.

To distinguish selection from the true FR effect on future blood supply, Table 7 follows the econometric structure presented in Section 2. The first four columns look at donate rate and donation amount for no-history FR donors, and the last two columns look at the same dependent variables for existing FR donors. As we expect, there is a significant selection effect among the existing FR donors, while the selection effect for no-history FR donors is close to non-existence. This is probably because we have more variations in the fraction of donating voluntarily at time zero (λ) among the controls of existing FR donors than among the controls of no-history FR donors. In particular, the selection coefficient ($\Delta\theta = \frac{\theta_V}{\theta_N}$), which is defined as the ratio between the likelihood of type V donors accepting the FR request versus the likelihood of type N accepting, turns out to be 3.2 for the existing FR donors. If we assume $\theta_V = 1$ (because type V donors are defined to be willing to donate at time 0 even without an FR request), this number implies type N donors will donate with a likelihood $\theta_N = 31.2\%$ upon an FR request. We will use this number to conduct a back-of-envelope calculation for the effect of FR on the total blood supply.

After isolating the selection effect, the rest of Table 7 shows that the causal effect of FR on future donation rate, or ω, is negative for no-history FR donors (-0.034) but positive for existing FR donors (0.025), which translates into -10.26ml less per half-year per no-history FR donor and 8.96ml more per half-year per existing FR donor.

4.3 Effect of shortage message and FR donation on blood quality

Defining a quality dummy equal to one if the donated blood passes the standard battery of blood test, Table 8 regresses this dummy on the treatment status by t=0 and t>0 separately for each treatment group (message treatment, no-history FR donors, and existing FR donors). We choose to run the regression for t=0 and t>0 separately because blood quality is not available until a blood donation exists hence any regression on blood quality must be conditional on sub-sample of donation dummy equal to one. This sub-sample could differ by time, which makes the across-time comparison hard to interpret. In light of this, for each particular time period (t=0 or t>0), the regression tells us a straightforward quality comparison between the treated and control donors, conditional on both donating at the time. Again, we collapse the controls so that each treated and control pair gets the same weight. Every column of Table 8 is against the WHO concern on blood quality: for message treatment or no-history FR donors, there is no significant quality difference between treated and control donors at both t=0 and t>0. For existing FR donors, the quality of treated donors is even significantly higher than that of control donors at t>0 by 1.2 percentage point. All these results suggest that the WHO concern of quality is not confirmed in our data.

One caveat is that our analysis excludes repeated FR donors, who are more likely to be professional donors and may drive down blood quality. There are only 87 such donors in our sample. While the sample size is too small for any rigorous analysis, the small sample size itself suggests that the potential problem of professional donors is not serious in our data.

4.4 Robustness checks
blood type
different messages
random one control per treated

4.5 Heterogeneous effects
by marriage, age, edu, hukou

5. Discussion

So far we have shown that both shortage message and FR program can mitigate blood shortage in the short run with little compromise on blood quality. But they target different audiences, have different effects in the long run, and affect different donors differently.

From a policy maker's point of view, what are the key tradeoffs between shortage message and family replacement? We believe one tradeoff lies in the extent of control. A blood bank can fully control who receives a shortage message and how many receive it, but the recruitment of FR donors is outsourced to patients. This implies that shortage message may be more effective if the bank is short of a specific type of blood and the bank has a large pool of existing donors to choose from. That being said, direct message has less control on timing, as the blood bank cannot force donors to donate at a specific time. In contrast, FR may be more helpful in mitigating the shortage facing a particular patient at a particular time.

The second tradeoff between shortage message and FR program is related to their targeted audiences and their particular effects in the short and long runs. While mobile message can easily reach existing donors, it is difficult to reach those who have not donated to the bank. In theory, the bank could broadcasting blood shortage on TV, radio, newspaper, or the Internet, but such broadcasting is less targeted and may be crowded out by other information, which introduces more uncertainty and is likely less effective than mobile messages to individual donors. In comparison, FR program relies on individual patients to reach out to her own social connections, which could bring in a large number of donors who may otherwise never donate voluntarily. These no-history individuals may be more willing to donate to their friends or family than donate to a stranger. As shown in our data, the FR approach brings an additional source of blood supply, which could be more effective in increasing blood supply quickly when the population of voluntary donors is small and decreasing.

Table 9 summarizes these considerations in a back-of envelope calculation. In particular, following our data, consider a city with one million population, of which 4.5% are existing donors; each one has a 3% chance in need of one donation in a random half year. If the bank sends out a shortage message to all existing donors, our estimates suggest that the blood supply can be boosted by 720 extra donations within six months of the message delivery but zero effect afterwards. In comparison, if the bank requires half of the sick patients to find one FR donation by themselves, the FR program will affect 14,325 individuals who have no donation history at the bank, and 675 individuals who have a donation history at the bank. For existing FR donors, our data suggest $\lambda = 0.04$. If we are willing to assume $\theta_V = 1$, our estimates suggest $\theta_N = 31.2\%$. For no-history FR donors, let us assume $\lambda = 0$ and $\theta_N = 31.2\%$.

Under these assumptions, the FR program at t=0 can generate 4469.4 FR donations from no-history donors and 202.17 donations from existing donors. However, based on our estimates of ω in Table 7, the no-history donors will reduce 151.95 donations per half-year after FR and the existing FR donors will bring 5.05 more donations per half-year after FR. Summing over the effect for five years (from t=0 to t=9), introducing FR to half of the patients is much more effective in increasing blood supply than sending out a shortage messages to all existing donors (3,202.5 vs 720 donations). In other words, in order to generate the same effect on the overall blood supply within the next five years, sending out shortage messages to all existing donors is equivalent to introducing FR to 10.7% of the sick patients. If the goal is to generate the same blood supply in the short run (t=0 only), then sending out shortage messages to all existing donors is equivalent to introducing FR to 7.7% of the sick patients. In Panel B of Table 9, we change the percent of donating population to 15%, it reduces the gap of the two methods. If we increase it further to 30%, shortage message becomes more effective than the FR program in increasing blood supply over five years (Panel C).

Overall, the back-of-envelope calculation suggests that shortage message can be used in places where the donor population is large and the shortage is small. In comparison, FR could be more useful when the donor population is small and the shortage is severe. In this sense, our data suggests a more optimistic picture for FR than the WHO recommendation. However, in a society with a low donation rate (which could be the reason for severe shortage to begin with), most FR donors will be no-history FR donors and the FR treatment may discourage voluntary donation in the long run by generating either distrust or crowd-out. Although a broader introduction of FR can bring more blood supply in the short run, it may exacerbate shortage problem in the long run. Like the WHO, we reach a cautionary conclusion for the FR program but for a reason different from quality concerns.

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Figure 1: World map of donation rate

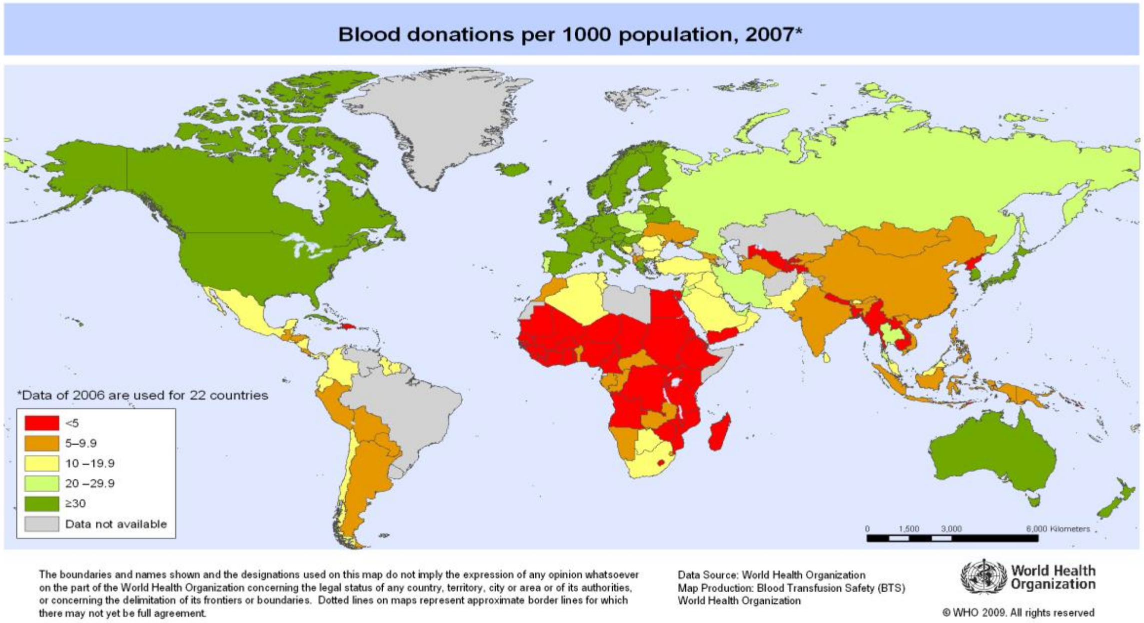

Figure 2:

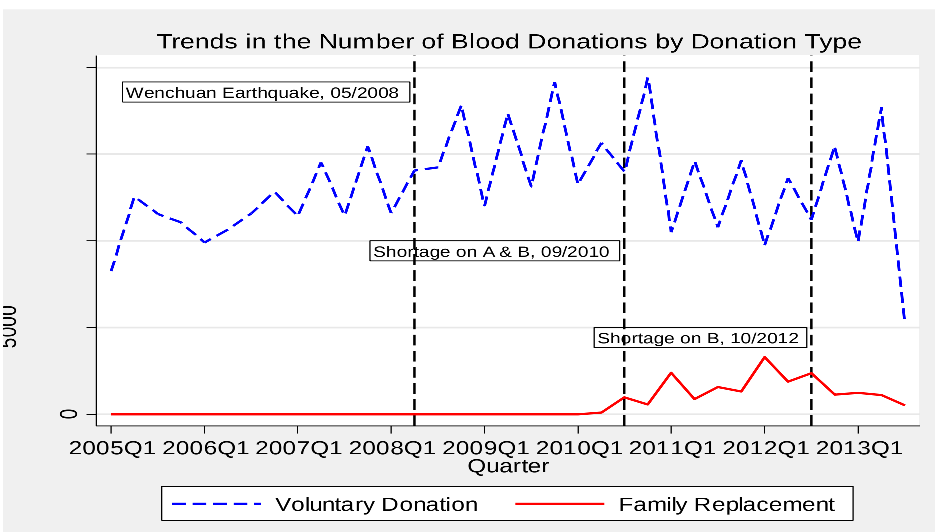

Figure 3: Donation rate by treated and control donors, upon receiving a shortage message (t=0 refers to the time of receiving a treatment message.)

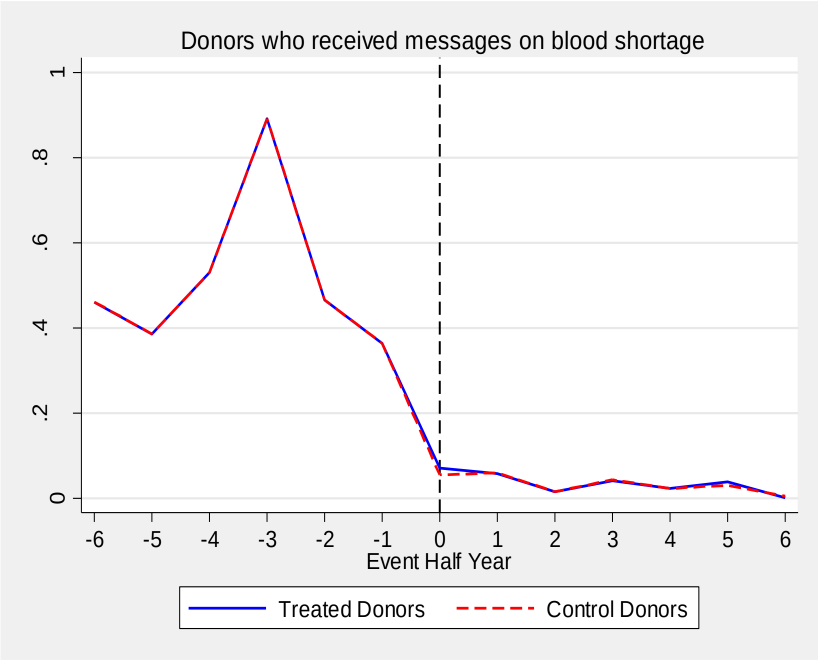

Figure 4: Donation rate by treated and control donors, upon FR donation (t=0 refers to the timing of making an FR donation.)

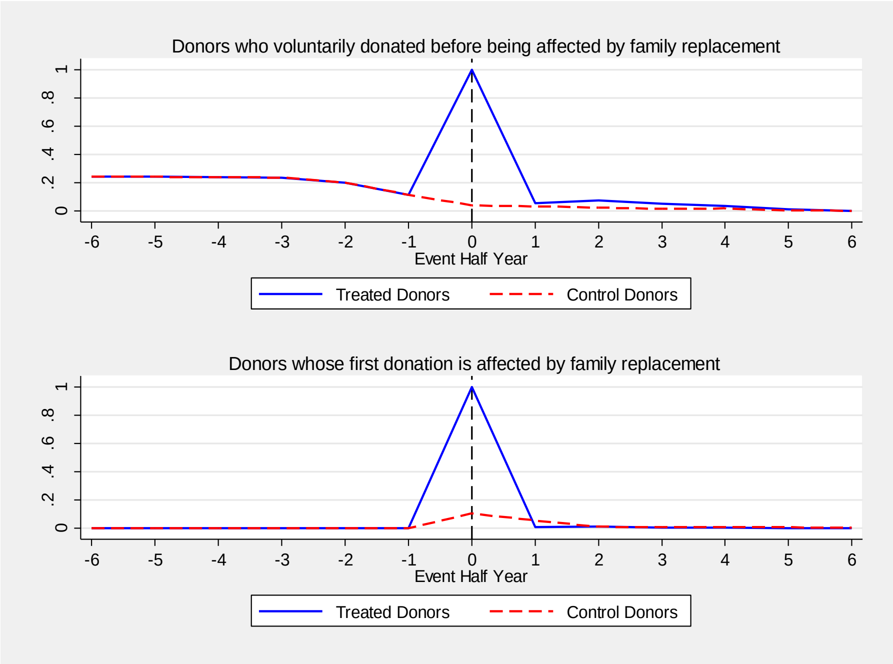

Table 1: Headcount

	Total Counts of Donors			Received a shortage message & never FR		Have ever donated FR			
						Have donated before FR		Never donated before FR	
	Count	% in sample	% in population	Count	% in sample	Count	% in sample	Count	% in sample
Total	358,489			11,600		1,076		17,996	
Not Married	246,589	68.79%	31.30%	7,370	63.53%	658	61.20%	5,284	29.36%
Married	111,900	31.21%	68.70%	4,230	36.47%	418	38.80%	12,712	70.64%
Male	217,617	60.71%	49.30%	6,597	56.87%	675	62.70%	12,118	67.30%
Female	140,812	39.29%	50.80%	5,003	43.13%	401	37.30%	5,878	32.70%
College Degree	79,534	22.19%	19.00%	1,683	14.51%	211	19.60%	2,161	12.00%
No College Degree	278,955	77.81%	81.00%	9,917	85.49%	865	80.40%	15,835	88.00%
Local Hukou	66,888	18.66%	79.30%	2,786	24.02%	434	40.30%	5,097	28.32%
Same-province Hukou	134,657	37.56%	12.80%	4,142	35.71%	348	32.30%	5,781	32.12%
Other-Province Hukou	107,083	29.87%	7.90%	4,541	39.15%	284	26.40%	4,332	24.07%
Unknown	49,861	13.91%	0.00%	131	1.13%	10	0.90%	2,768	15.48%
Below 20 years old	97,287	27.14%	21.90%	3,631	31.30%	247	23.00%	2,838	15.82%
(20, 30]	194,053	54.14%	17.90%	5,094	43.91%	511	47.50%	6,063	33.80%
(30, 40]	45,074	12.58%	20.60%	1,948	16.79%	192	17.80%	5,381	30.00%
40+	22,015	6.14%	40.30%	927	7.99%	126	11.70%	3,654	20.37%

Table 2: Summary of donation episodes

	Total		Received a treatment message & never FR		Have ever donated FR			
					Have donated before FR		Never donate before FR	
Count of donation episodes	472,342	100(%)	21,315	100(%)	3,203	100(%)	18,318	100(%)
Blood donation type								
Voluntary	453,152	95.94	21,325	100	2,127	66.41	382	2.09
FR	19,190	4.06	0	0.00	1,076	33.59	17,936	97.91
Donation amount								
<=200ml	116,544	24.67	1,688	7.92	400	12.49	3,179	17.36
>200ml and <=300ml	158,899	33.64	5,744	26.94	934	29.16	5,584	30.48
>300ml and <=400ml	196,893	41.68	13,892	65.15	1,869	58.35	9,555	52.16
Blood Quality								
Passed quality test	452,611	95.82	20,830	97.68	3,138	98.00	17,561	95.87

Table 3: Summary of treated and control

	Before Matching	After Matching									
	Treated	Treated	Control	Married	Male	College	Age	Local	Same Prov	Other Prov
Shortage on A and B	3,103	1,738	8,399	0.28	0.55	0.20	25.00	0.24	0.38	0.36
Shortage on B	8,497	6,883	30,676	0.35	0.58	0.11	25.00	0.19	0.36	0.44
First Donation as FR*	17,996	16,777	121,860	0.71	0.67	0.12	31.33	0.30	0.34	0.25
Second Donation as FR	680	680	87,818	0.34	0.63	0.21	26.51	0.38	0.33	0.28
Third Donation as FR	201	160	1,493	0.34	0.62	0.15	26.64	0.34	0.38	0.28
Fourth Donation as FR	97	24	44	0.38	0.71	0.21	27.83	0.25	0.54	0.21
4+ Donation as FR	98	2	2	0.50	1.00	0.00	24.50	0.50	0.00	0.50
Total of Ever Donated as FR	19,072	18,794	211,217	0.69	0.67	0.12	31.00	0.29	0.32	0.24

Note: * For those whose first donation is FR, the number of controls refer to type 1 control. The average type 2 control is 175,341 at the time of FR, the median is 62283.

Table 4: Effects of shortage message on donation rate and donation amount

Dependent Variable	Donors who received messages					
	Donate or not			Donate Volume (0 if not donate)		
	All Donors	Infrequent Donors	Repeated Donors	All Donors	Infrequent Donors	Repeated Donors
	(1)	(2)	(3)	(4)	(5)	(6)
Treated*Post (t=0)	0.016***	0.012***	0.039***	5.160***	3.571***	13.750***
	(0.003)	(0.002)	(0.011)	(1.067)	(0.974)	(4.158)
Treated*Post (t>=1)	0.001	0.001	-0.003	-0.586	0.518	-1.759
	(0.002)	(0.001)	(0.006)	(0.713)	(0.670)	(2.385)
Donor Fixed Effects	Y	Y	Y	Y	Y	Y
Half Year Dummies	Y	Y	Y	Y	Y	Y
Observations	106,078	86,466	19,612	106,078	86,466	19,612
R-squared	0.526	0.580	0.389	0.519	0.568	0.394

Note: Robust standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1.

Table 5: Effects of FR donation on no-history FR donors

	All FR Donors	FR Donors without prior donation history		
	OLS with raw data	OLS with matching		Donate Volume (0 if not donate)
	(1)	(2)	(3)	(4)
Treated*Post (t=0)	0.861***	0.815***	0.816***	270.694***
	(0.008)	(0.002)	(0.003)	(1.323)
Treated*Post (t>=1)	-0.058***	-0.038***		-11.673***
	(0.008)	(0.001)		(0.307)
Treated*Post (t=1)			-0.047***	
			(0.001)	
Treated*Post (t=2)			-0.031***	
			(0.001)	
Treated*Post (t>=3)			-0.034***	
			(0.001)	
Donor Fixed Effects	Y	Y	Y	Y
Group Fixed Effects	N	N	N	N
Half Year Dummies	Y	Y	Y	Y
Observations	3,504,259	300,739	300,739	300,524
R-squared	0.306	0.863	0.863	0.821

Note: Robust standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1.

Table 6: Effects of FR on existing FR donors

	FP donors with prior donation history				
Dependent Variable	Donate=1 if a donor contributes his/her blood				Donate Volume (0 if not donate)
Model	OLS with raw data	Duration model	OLS with matching		
	(1)	(2)	(3)	(4)	(5)
Treated*Post (t=0)	0.823***		0.960***	0.960***	332.405***
	(0.008)		(0.004)	(0.004)	(2.771)
Treated*Post (t>=1)	-0.045***	0.515**	0.029***		10.468***
	(0.008)	(0.237)	(0.005)		(1.917)
Treated*Post (t=1)				0.023***	
				(0.008)	
Treated*Post (t=2)				0.047***	
				(0.010)	
Treated*Post (t>=3)				0.021***	
				(0.006)	
Donor Fixed Effects	Y	N	Y	Y	Y
Half Year Dummies	Y	Y	Y	Y	Y
Donor Random Effects	N	Y	N	N	N
Donor Time-invariant Characteristics	N	Y	N	N	N
Observations	3,427,287	1,732	17,104	17,104	17,104
R-squared	0.281		0.348	0.349	0.441

Note: Robust standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1.

Table 7: Effect of FR, accounting for selection

Dependent Variable	FP Donors without prior donation history		FP donors with prior donation history	
	Donate or Not	Donate Volume (0 if not donate)	Donate or Not	Donate Volume (0 if not donate)
	(1)	(2)	(3)	(4)
P_b	0.066***	22.932***	0.019	6.973
	(0.005)	(1.835)	(0.013)	(5.109)
ΔP	0.022***	9.885***	0.064***	23.568***
	(0.001)	(0.384)	(0.005)	(1.820)
ω	–0.034***	–10.260***	0.025***	8.956***
	(0.001)	(0.325)	(0.005)	(1.821)
$\Delta P*\Delta\theta$	0.00003***	0.010***	0.205***	82.787***
	(0.000003)	(0.001)	(0.076)	(29.775)
$\Delta\theta$	0.003***	0.001***	3.203	3.496***
	(0.0001)	(0.00001)	(18.555)	(0.054)
Group Fixed Effects	Y	Y	Y	Y
Half Year Dummies	Y	Y	Y	Y
Observations	160,375	162,960	7,160	7,160
R-squared	0.335	0.395	0.223	0.226

Note: Robust standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1.

Table 8: Effect of shortage message and FR donation on blood quality

Dependent Variable	Blood Quality (pass or not)					
	Donors who received a shortage message		FR Donors without prior donation history		FR donors with prior donation history	
	(1)	(2)	(3)	(4)	(5)	(6)
Treated*Post (t=0)	-0.010		0.003		-0.001	
	(0.023)		(0.002)		(0.013)	
Treated*Post (t>=1)		-0.005		0.011		0.012**
		(0.010)		(0.008)		(0.005)
Donor Fixed Effects	Y	Y	Y	Y	Y	Y
Half Year Dummies	Y	Y	Y	Y	Y	Y
Observations	4,814	9,803	32,697	56,231	1,024	946
R-squared	0.765	0.365	0.509	0.482	0.513	0.627

Note: Robust standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1.

Table 9: Back of Envelope Calculation

Unit of time = half year
Population = 1,000,000
% ever donated before treatment time = 4.5%, 15% or 30%
% of population that needs blood at a specific t = 3%
λ (existing donors) = % of existing donors that will donate voluntarily at a specific t = 4%
θ_V (existing donors) = % of type-V existing donors that will donate upon FR request = 1
θ_N (existing donors) = % of type-N existing donors that will donate upon FR request =31.2%
λ (no-history) = % of no-history donors that will donate voluntarily at a specific t = 0
θ_N (no history) = % of no-history donors that will donate upon FR request =31.2%

		Shortage message to all existing donors	FR to half patients			Difference between message and FR
			No-history FR	Existing FR	Total FR	
Scenario 1: % of ever donated = 4.5%	# of individuals affected	45000	14,325	675	15,000	30,000
	Extra donations					
	T=0	720	4469.4	202.2	4,671.6	-3,951.6
	T>0	0	-152.0	5.1	-146.9	
	From t=0 to t=9	720	3101.8	247.7	3,349.4	-2,629.4
Scenario 2: % of ever donated = 15%	# of individuals affected	150000	12,750	2,250	15,000	135,000
	Extra donations					
	T=0	2400	3978.0	673.9	4,651.9	-2,251.9
	T>0	0	-135.3	16.8	-118.4	
	From t=0 to t=9	2400	2760.7	825.6	3,586.3	-1,186.3
Scenario 3: % of ever donated = 30%	# of individuals affected	300000	10,500	4,500	15,000	285,000
	Extra donations					
	T=0	4800	3276.0	1347.8	4623.8	176.2
	T>0	0	-111.4	33.7	-77.7	
	From t=0 to t=9	4800	2273.5	1651.1	3924.6	875.4