A Survival Analysis on the Waiting Lists for Kidney Transplants in the United States: Who Waits the Most?

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I. Introduction

Chronic Kidney Disease, also known as CKD, has been identified as a "leading public health problem worldwide" (Lv, Zhang 2019). In 2019, researchers estimated that over five million individuals required a kidney transplant. Individuals who are in need of a kidney transplant suffer from End-Stage Renal Disease, ESRD, a severe diagnosis of CKD, most commonly known as kidney failure (Lv, Zhang 2019). It has been hypothesized that the magnitude of this demand stems from the global adoption of a "western lifestyle," which includes fast food — which is high in fat and sugar — stress, and alcohol (Major 2020). Such indulgences leave individuals more prone to both hypertension and diabetes, causing kidney disease and renal failure.

Historically, kidney transplants were viewed as the last line of defense following dialysis when combatting ESRD. The use of transplants as a primary course of action against ESRD, however, has been on the rise since the late 1990's. This treatment plan has proven to be associated with a longer lifespan and a higher quality of life than dialysis treatments. Subsequently, more doctors are prioritizing this course of action and more patients are demanding it.

It appears — at first glance — as though this rise in demand for a kidney on behalf of the patients is being met by an equal rise in those willing to supply a kidney for transplant, however that is not the case. There is a shortage of kidneys. The occurrence of a transplant relies on the availability of an organ. The United States relies on altruism, "the belief in or practice of disinterested and selfless concern [for] the well-being of others," to supply their market (Oxford Dictionary 2016). This reliance, however, does not guarantee an equality between the supply of and demand for organs needed for transplant. In the United States, the demand for organs within the market is not able to be met by the supply and thus doctors are unable to bring the demanded transplants — at a given point in time — to fruition.

When such a shortage persists, there are various mechanisms through which one is able to receive a kidney transplant. The most common pathway is through a voluntary donation by a known individual. An example of such would be a mother donating a kidney to her child or a friend-to-friend transaction. However, this avenue is not a viable option for all individuals. If no such networks exist for the individual or if their family and friends do not produce a medically viable match, then the individual would seek matching through the United Network for Organ Sharing.

Since its founding in 1984, the United Network for Organ Sharing, UNOS, has sought to unite donors and recipients within the transplant community in an effort to address the shortage of available transplants. Serving as the main governing body of organ donations within the United States, UNOS produces transplant matching lists for readily available kidneys and individuals in need. These lists are then maintained by the Organ Procurement and Transplant Network, OPTN, and then further filtered for matching donor-recipient characteristics by individual hospitals (*Cleveland Clinic* 2020).

If a donor-recipient match is found by a patient themselves, UNOS and OPTN play a minimal role. Otherwise, UNOS begins the process of matching the individual in need of a kidney with a donor by putting them on a transplant waiting list. When OPTN is made aware that an organ is available for transplant, the medical organization in possession of the organ — typically a hospital — sends additional data to OPTN needed for matching. This data includes metrics such as “medical, social, and genetic” information (*Cleveland Clinic* 2020). Matches are then determined based on comparing the compatibility between the recipient and donor’s patient profiles which includes such information along with blood type, tissue type, organ size, medical urgency of their illness, and duration of the time they have been on the waiting list (*Cleveland Clinic* 2020). This donation may either come from an individual who is alive, willing, and able to donate a kidney, or from a deceased individual who has been registered as an organ donor.

If one has found a donor outside of UNOS and OPTN, their wait time varies between two to three months. This delay is associated with the specific tests that are required to ensure the identified donor and recipient are a match. If one joins the UNOS waitlist, however, the median wait time is 3.6 years (*National Kidney Foundation* 2016*)*. Wait times continue to grow in the United States since the supply of kidneys remains relatively low, while the demand continues to exponentially rise. In 2017, the prevalence of ESRD in the United States was 746,577, a 2.6% increase from 727,912 in 2016 (*U.S. Renal Data System Annual Data Report* 2019*)*. Although the increase in demand was accompanied by an increase of deceased donor transplants from 13,501in 2016 to 14,077 in 2017, this uptick was still not enough to bridge the gap between the quantity of kidneys demanded and the quantity supplied (*OPTN/SRTR Annual Data Report: Kidney* 2017*)*.

The National Organ Transplantation Act, passed in 1984, continues to be utilized in an effort to address the disparity between the quantity supplied and demanded of kidneys. The National Organ Transplantation Act declared organs to be a “scarce public resource,” and that such a resource should be distributed "by criteria based on need, effectiveness, and fairness that are publicly stated and publicly defended" (Gupta 2008). However, who dictates and enforces such criteria is not well defined nor regulated. Subsequently, as the average length of time one must wait to receive an organ increases, many wonder what characteristics, if any, makes an individual more inclined to be moved off the waitlist and to receive a kidney donation. Although the United States’ altruistic-driven kidney market is hypothetically structured in such a way that organs are “distributed fairly using a transparent system,” certain biases may persist as they would in any other setting (National Kidney Foundation 2021).

The following theoretical analysis will examine why certain characteristics are expected to influence the aforementioned ‘transparent’ matching process such that the system disproportionately benefits certain demographics. The theoretical analysis will be twofold. The first segment of the analysis will observe an individuals’ likelihood of being placed on the transplant list. The second will then consider an individual’s likelihood of receiving a transplant conditional they are on the waiting list.

II. Mechanisms in the Market

A. Kidneys and Recipients: Quality, Benefit, and Longevity

Every kidney that is available for donation is given a Kidney Donor Profile Index (KPID) score following the Organ Procurement and Transplant Networks (OPTN) guidelines. The KPID score is a percentage score that ranges from zero to one hundred and essentially provides information on the quality of a kidney available for transplant. This metric reflects the probability that the given kidney will outperform other possible transplants in terms of function. Transplants with a lower KDPI score are viewed as being of better quality. For example, a kidney transplant with a KDPI score of twenty percent will outperform eighty percent of the other kidneys available for transplant. On the other hand, a KDIP score of seventy percent indicates that the transplant will only outperform thirty percent of other possible transplants. According to OPTN the factors that affect a kidney's KPID score include the donor's age, height, weight, ethnicity, history of high blood pressure, history of diabetes, exposure to hepatitis C, cause of donor death along with the donor's level of heart and brain function, and the kidney's serum creatinine. Although the factors that are said to influence a donation's KPID score are readily available information, the magnitude — and hence relative importance — of these characteristics impact on a donation's KPID score is unknown since the formula and weight ascribed to each determinant is not public knowledge. Therefore, it is unclear which of these factors aid or damage one's chances at receiving a transplant. The empirical approach presented in this paper aims to address this shortcoming in the current literature.

Transplant recipients are also evaluated by the OPTN and receive a numerical score to reflect the "quality" of potential kidney recipients. Kidney transplant candidates are given an Estimated Post Transplant Survival (EPTS) score. Similar to the KPID, the EPTS score is a percentage score that ranges from zero to one hundred and reflects the length of time the given individual will likely utilize the transplant "compared with other candidates" (Kidney Allocation System 2020). An individual with an EPTS score of twenty percent is expected to use the kidney eighty percent longer than other transplant candidates. On the other hand, an individual with an EPTS score of seventy percent will most likely use the kidney thirty percent longer than other candidates. Therefore, a lower EPTS score indicates a better candidate. The OPTN asserts that a donation candidate's EPTS is based on the following factors: the recipient's age, their length of time spent on dialysis, whether or not they have received a previous transplant of any organ, and the status of their current diabetes diagnosis. If a patient is over 25, has a history of diabetes, and has previously undergone kidney transplantation, they are likely to receive a poor EPTS score in the higher range.

Following the Organ Procurement and Transplant Network's policy, an individual's EPTS score, formulated by the Scientific Registry of Transplant Recipients, is calculated in the following manner:

$$\begin{aligned}\text{Raw EPTS } &= 0.047 * max(\text{Age} - 25, 0) - 0.015 * \text{Diabetes} * max(\text{Age} - 25, 0)\\ &+ 0.398 * \text{Prior Solid Organ Transplant} - 0.237 * \text{Diabetes} * \text{Prior Organ Transplant}\\ &+ 0.315 * log(\text{Years on Dialysis} + 1) - 0.099 * \text{Diabetes} * log(\text{Years on Dialysis} + 1)\\ &+ 0.130 * (\text{Years on Dialysis} = 0) - 0.348 * \text{Diabetes} * (\text{Years on Dialysis} = 0) + 1.262 * \text{Diabetes}\end{aligned}$$

B. Matching Donated Kidneys and Recipients

A transplant's KPID score and a potential recipient's EPTS score are both taken into consideration when a donor and recipient match is being advised by UNOS for the associated hospital(s). Kidneys with a KDPI score of less than twenty and possible recipients with a comparable EPTS score are viewed as *strong* matches. These matches are desirable since they combine individuals who lead a sustainable life and therefore expect a long life remaining with kidneys that are likely to function well for a long duration of time. Thus, such matches will potentially allow the kidney to be utilized for a long period of time. This arrangement is expected to generate a high degree of benefits from the transplant, both for the individual and society.

According to UNOS, matching donors and recipients is a two-step process. First, kidneys with a KPID score of less than twenty are offered to individuals with an EPTS score of less than twenty. Subsequently, if a kidney with a KPID score of less than twenty is not accepted by its corresponding EPTS score match, it is then offered to any individual, regardless of their EPTS score. The efficiency of this matching process, however, is questionable as quality transplant candidates, those with an EPTS below twenty, continue to face donation wait times above four years. This raises an interesting question regarding the factors that are likely to motivate the administrators of the matching process, UNOS, individual hospitals, and doctors, to move a person — onto, and ultimately off — of the waitlist. The hypothesized factors that influence such allocations, will be brought to light in the following section.

III. Conceptual Framework

A. Analytical Framework

1. Overview

An individual with end-stage renal disease (ESRD) requires a kidney transplant. The average individual, however, is not well suited to secure an appropriate kidney because they lack the necessary skills and or training needed to find, obtain, or evaluate a kidney. In the organ procurement process, these capabilities ensure a transplant is not simply a successful medical procedure, but also of a sufficient quality to promote longevity of organ function and recipient survival. Individuals that want to become organ donors face a similar challenge because they lack the skills needed to identify and evaluate a suitable potential recipient. The basis on which to evaluate potential recipients such as willingness to pay, age, gender, or employment, to name a few, is unclear and requires a substantial amount of appropriate knowledge.

These entry barriers prevent a transaction from occurring without professional help. This situation is not unique to the organ market. In various markets, demanders (or suppliers) assume the responsibility of procuring the supply (or demand) of a good or service they are in search of. Lack of knowledge or experience in doing so hinders this from happening. Observing this disconnect, firms or other institutions — acting as intermediaries — attempt to bridge this gap. They have the skills and real-world experience to ensure these transactions occur, leading to efficiency in the market for kidneys, and charge a fee to the recipient for their services.

There are numerous well-known markets, such as the automobile and loanable funds, where similar challenges exist, and intermediaries have evolved so that transactions occur. Consider the automobile market. Individuals that need a car look to dealerships as a reliable institution to provide the good they need. In contrast, dealerships work with suppliers to offer a variety of vehicles including cars that are: new, used, small, large, luxury, and economic models. Dealerships, functioning as an intermediary, efficiently bring together buyers and sellers in the market to conduct a transaction. Furthermore, banks serve a similar purpose within the loanable funds market. Identifying individuals with complementary financial desires, they unite savers –

the suppliers of loanable funds – with those in need of funds – borrowers – to create a smoothly functioning market flow of funds.

Within the market for kidney donations non-profits, such as the United Network for Organ Sharing (UNOS) and the Organ Procurement Transport Network (OPTN), and various hospitals function as an intermediary, similar to automotive dealerships and banks. While UNOS and OPTN work to create quality donor-recipient matches, hospitals perform the technical labor of undergoing the transplant procedure – bringing the match to fruition. UNOS and OPTN are non-profit institutions, and thus seek to maximize the benefits they provide to society by acting to optimize the gains to each match they make. Hospitals, however, may either function as a non-profit or a profit-maximizing institution. Regardless of these differing intermediaries' motivations, they seek to efficiently distribute kidneys within a market by facilitating every match where the marginal benefits exceed the marginal costs. Intermediaries provide the optimal number of kidney matches by equating marginal costs and marginal benefits. This assumption and the marginal-cost marginal-benefit model will be employed in the following analysis to further understand the factors that influence an intermediaries' decisions of whether or not to provide a kidney donation.

B. Marginal Cost Curve

1. Acquiring a Kidney, the slope of the Marginal Cost Curve

When intermediaries enter the market, they are looking to acquire a kidney to use in a transplant procedure. Suppose that upon the intermediaries' initial entry an organ donor is readily available. Subsequently, the time, resource, and labor costs associated with an initial match is low. Time costs represent the opportunity cost the intermediaries face with regard to matching donors and recipients. Resource costs include the infrastructure and capital that must be in place to undergo these processes, while the labor costs include administrative staff that contact, engage, and document the donor along with medical professionals that receive, review, and evaluate potential donor's history.

The first donation the intermediaries acquire can be seen as Point A on Figure 1. Point A is associated with MC_1 and Q_1. If the intermediaries were to seek a second donor, they will need to acquire supplementary resources as additional donors are not readily available. Re-allocating resources away from their designated areas increases the opportunity cost faced by the intermediaries. Thus, if the intermediaries were to undergo the process of finding an additional donor, producing quantity Q_2, they will face a higher marginal cost as reflected by MC_2 and Point B.

As the intermediaries continue to seek out more kidneys — to produce more matches — they are forced to pull additional resources away from their allocated areas. This decreases the efficiency of the allocation process as these resources will be less well suited to the practice of acquiring kidneys. Thus, the opportunity cost faced by the intermediaries will continue to rise as they expand the stock of kidneys they have acquired, inflating cost. Therefore, the Marginal Cost Curve for acquiring a kidney to use in a transplant procedure will be upward sloping.

2. Shifting the Marginal Cost Curve

For any given quantity of the Number of Kidney Donors, there are additional factors that affect the overall costs the intermediaries must bear when acquiring another potential kidney donor. These external influences are held constant when deriving the marginal cost curve for kidney acquisition. However, these factors can be altered resulting in a *ceteris paribus* violation for the marginal cost curve.

a) Age

Individuals who are 18 years and older and in good physical and mental health may begin the process of donating a kidney (*National Kidney Foundation* 2021). Regardless of age, all possible donors must undergo match testing to establish their organ profile and a compatibility marker between themselves and a possible recipient. Individuals that are of advanced age, or over 65 years of age, however, must undergo additional testing as their body is more sensitive to external factors and they are more likely to possess underlying health conditions. Such testing not only requires additional time and labor from intermediaries but also imposes additional resource-based costs – shifting the marginal cost curve upward or to the left.

Despite extensive testing, there is still risk involved with undergoing a transplant. This risk increases for people of advanced age as they are more susceptible to infection and other medical complications. Subsequently, the likelihood a transplant will fail, meaning the transplant will not be accepted by the recipient's body, and the likelihood the donor will not survive the transplant increases with age. Such situations may also call for unprecedented decision-making, leaving the intermediaries susceptible to legal action. Furthermore, these factors leave the intermediaries at risk of performing an unsuccessful transplant, harming their public view and their likelihood of being a top candidate for future donations. Therefore, the explicit and reputational cost of undergoing a transplant on an individual of advanced age is high.

Observe Scenario One below. $Marginal\ Cost\ Curve_1$, also denoted MC_1 , represents the Marginal Cost Curve depicted in Figure 1. $MC_2(Advanced)$, on the other hand, reflects a *ceteris paribus* violation known as greater age. Being of an advanced age has a positive effect on marginal cost as it raises the overall costs the intermediaries must cover due to the increased risk associated with treating individuals of an advanced age. Thus, for a given quantity Q_{d_A}, say for the amount of two kidneys, the marginal cost for an older individual, shown by MC_B and Point B, will be higher than the *ceteris paribus* marginal cost, depicted by MC_A and Point A. Therefore, advanced age causes MC_2 to shift to the left or upwards.

$MC_3(Younger)$, on the other hand, depicts a *ceteris paribus* violation for younger age. Being younger has a negative effect on cost due to the fact that younger individuals are both less costly, as they require less testing, and less risky to treat. Therefore, for the given quantity Q_{d_A}, the marginal cost for a younger individual will be lower, as shown by MC_c and Point C, than the marginal cost for MC_1, displayed by MC_A and Point A. This difference presents itself as a negative and can be modeled by $MC_3(Young)$ shifting to the right or downard.

b) BMI

Intermediaries seek to allocate quality kidney donations with the individuals who will utilize them for the longest period of time. Factors such as an individual's health status are taken into consideration during the allocation process. Despite the average BMI in the United States being 25.55, the CDC defines individuals who have a BMI over 30 to obese, a BMI between 25 and 29 to be overweight, a BMI between 18.5 and 24.9 to be normal and a BMI of under 18.5 to be underweight. These BMI categories are not seen as conducive to a successful transplant as a result of the extreme conditions the transplant must function under.

The additional stress the body must carry in overweight individuals impedes normal organ function and can subsequently lead to transplant failure. Furthermore, obese individuals face a higher risk themselves when undergoing transplants. The added weight creates difficulties when breathing under anesthesia and often results in complications during surgery and potentially leads to death. Similarly, performing a transplant in an unusually underweight individual results in a higher rate of rejection as the transplant does not have the necessary supply of nutrients needed to survive. Thus, both of the two extreme BMI categories, overweight and underweight, place additional burdens on one's body which in turn increases the risk of the transplant being unsuccessful.

Undergoing an unsuccessful transplant is costly to an intermediaries' reputation. Their lack of success may result in a decline in their likelihood of receiving future donations, consequently harming their function and profit. Furthermore, the opportunity costs associated with undergoing such a transplant is high as the transplant could have been utilized successfully by an individual who did not face such risks. Therefore, individuals who are of a high or low BMI status are seen as increasing the cost of producing a transplant. Thus, these BMI ranges can be modeled in a similar manner to Scenario 1 using High BMI and Low BMI instead of Advanced Age.

c) Smoking

Although individuals' physical health is taken into consideration during the matching process through measures such as BMI, these metrics do not provide a holistic understanding of the health of an individual. These metrics do not consider actions, such as smoking, that individuals may undertake to leave themselves exposed to greater health risks. The decay that smoking imposes on one's body leaves them at a greater risk for complications under anesthesia, wound infection, and death during transplant. These associated consequences not only leave the intermediaries at a greater risk for legal consequences, but they also impose additional costs on the intermediaries as they are forced to divert additional labor and tools to address the complications when they arise. Therefore, individuals who smoke are seen as having a positive effect on cost. This positive effect on cost can be modeled akin to Scenario 1 while using Smoking instead of Advanced Age.

3. Marginal Cost Curve Summary

The factors discussed above are seen as increasing cost. On the other hand, classifying within a normal BMI range, not smoking, and a younger age group are characteristics that have a negative effect on cost. These factors and their impact on the marginal cost curve are summarized in Scenario 1 Summary.

C. The Marginal Benefit Curve

1. Receiving a Kidney, the Slope of the Marginal Benefit Curve

As previously mentioned, there are many individuals who are in need of a kidney. Thus, when the intermediaries first enter the market looking for a recipient, recipients are readily available. The intermediaries will then work to provide the first kidney to the recipient who receives the greatest value from it. These individuals have a recipient profile, lifestyle, and health that is conducive to the donation being efficient and productive for the longest period of time. In other words, they are young, healthy, and in good medical and social standing. These characteristics ensure that the maximum benefit can be reaped by society from any given donation.

The first kidney recipient chosen, depicted by Q_{r_A}, in Figure 2, is a high-quality recipient and thus provides a large magnitude of benefits to society as seen by MB_A and point A. If the intermediaries were to continue choosing recipients, and thus move to quantity Q_{r_B}, the associated recipient will be of a lesser quality than at Point A. Therefore, the marginal benefit provided to society by this recipient will be less than MB_B and Point B.

The marginal benefit curve, Figure 2, depicts the marginal benefits society receives for all levels of recipients *ceteris paribus*. As the quantity of recipients rises, the marginal benefit experienced by each additional recipient, while still remaining positive, declines. Therefore, the Marginal Benefit Curve is downward sloping, as demonstrated in Figure 2.

The marginal benefit curve is downward sloping due to the diminishing returns to the individual, the recipient of the transplant. However, when viewing the marginal benefit curve from the viewpoint of the intermediaries, three benefits will be taken into account. The first benefit will be that of the recipient, a private benefit, which we modeled in Figure 2. The second will be the social benefit provided by a kidney recipient, and the third will be the benefit to the function and reputation of the intermediary.

2. Shifting the Marginal Benefit Curve

a) Education

Once the individual receives the transplant, they will hopefully be capable of fulfilling a healthy and productive life by contributing to the economy and society. Intermediaries may observe an individual's educational attainment as a way of providing insight to the contribution individuals are capable of making. If the individual chosen for transplant has finished secondary school or college, they are capable of entering the workforce. This productive capacity produces benefits to society which will be reaped by the community in which the transplant occurs. This transfer of benefits to the community can be considered a positive externality.

The positive effect educational attainment has on marginal benefit can be modeled by Scenario 2. Individuals with high educational attainment — college or above — have a positive effect on social benefit. Therefore, for a given quantity Q_{r_A} the marginal benefit associated with these individuals, MB_B, will lie above the private marginal benefit, MB_A. Thus, the positive impact of additional educational attainment, created by a social benefit, entails a *ceteris paribus* violation which increases the private benefit of the transplant and thus results in an upward (i.e. rightward) shift in the marginal benefit curve.

If an individual has not completed secondary school, they are less likely to be employed or contributing to society in a productive capacity as their occupational opportunities are comparatively smaller. Subsequently, individuals who are of a low education status are seen as having a negative effect on benefit. For a given quantity Q_{r_A}, the marginal benefit associated with an individual who has a low educational attainment will fall below the *ceteris paribus* marginal benefit. Thus, having a low level of educational attainment can be seen as causing the marginal benefit curve to shift to the left.

b) Education, Proxy for Socioeconomic Status

When an individual receives and undergoes a successful transplant, they may express their gratitude by giving back to the intermediaries that aided their treatment. Most commonly, individuals may choose to host a fundraiser, charity event, or contribute a monetary donation. These actions provide benefits to the intermediaries as additional funding bolsters their reputations while enabling them to expand and continue ongoing operations with ease. Thus, individuals from a higher socioeconomic status have a positive effect on benefit. This impact can be shown by Scenario 2 using educational attainment as the input variable.

c) Age

The functionality and lifespan of a transplant not only depend on the transplant itself but also on the recipient. If an individual is younger, they will be able to contribute to the economy and society for a longer period than an individual of advanced age. The longer the transplant is functioning, the more society will benefit. Therefore, a younger recipient is seen as having a positive effect on benefit, so they can be modeled by Scenario 2 using age instead of education as the input.

3. Marginal Benefit Curve Summary

Please see Scenario 2 A.

D. Optimal Kidney Exchange: The Equilibrium

1. Finding the Equilibrium

The optimal amount of kidney transplants occurs where $MC = MB$. At a quantity of transplants Q_L, on Figure 3, the marginal benefit exceeds marginal cost, $MB_{Q_l} > MC_{Q_l}$. At such a point, the intermediaries see room for expansion to improve social benefits and will therefore continue to produce matches. As the intermediaries continue to produce matches, moving towards Q_*, the marginal benefit will begin to fall while the marginal cost will rise. Suppose the intermediaries moved to produce Q_H. At this point, the marginal cost greatly exceeds the marginal benefit, $MC_{Q_H} > MB_{Q_H}$. Thus, the intermediaries will observe the need for consolidation and decrease the number of matches being made. As the quantity begins to decrease, moving towards Q_*, the marginal cost begins to fall while the marginal benefit rises. When underproducing and overproducing, the market has a tendency to navigate towards Q_*. Therefore, the intermediaries by gravitating to an output of transplants Q_*, where marginal cost equals marginal benefit, facilitates the optimal quantity of matches which is the efficient level of kidney transplants.

2. Shifting the MC Curve and Equilibrium

Let the market begin at equilibrium at Point A in Scenario 3 A. Now, suppose there is a *ceteris paribus* violation that alters the position of the marginal cost curve such as a change in the age of the kidney recipient and or donor. This development will affect the market equilibrium for the number of transplants. Elderly individuals, as addressed in Section II, impose additional cost on the intermediaries and therefore shift the marginal cost curve to the left. Now, at quantity Q_{*_A} and Point B, marginal cost exceeds marginal benefit. Therefore, the intermediaries will begin to reduce the quantity of matches being made with elderly recipients. As this reduction occurs, there will be a simultaneous movement down the MC_2 , from Point B to Point C, along with a movement up the MB curve, from Point A to Point C. These movements along the curve will continue until Point C where equilibrium is achieved again as marginal cost is equal to marginal benefit. However, at the new equilibrium the composition of the recipients —the group of the recipients — has changed to include fewer elderly persons.

3. Shifting the MB Curve and Equilibrium

Now, observe Scenario 3 B, and consider the impact of a *ceteris paribus* violation for the marginal benefit curve such as an alteration in the age of the recipients. Let the market begin at equilibrium, Point A. Younger individuals, as addressed in Section III, provide additional benefits, and thus shift the marginal benefit curve upward — to the right. Now, at quantity Q_{*_A} and Point B, marginal benefit exceeds marginal cost thus the market is not at an optimal point nor equilibrium. The intermediaries will then begin to increase the quantity of matches being made, incentivized by their desire to provide society with the optimal level of transplant matches. As this increase occurs, there will be a simultaneous movement down the MB_2 , from Point B to Point C, along with a movement up the MC curve, from Point A to Point C. These movements along the marginal cost and marginal benefit curve naturally gravitate to Point C, where equilibrium is achieved again as marginal cost is equal to marginal benefit. The share of the matches made of young recipients will be greater at the new equilibrium relative to the original equilibrium (Point A).

IV. Literature Review

A. Waitlist Acceptance

The variables that affect an individual's ability to be placed on a transplant waiting list have not been thoroughly studied to date. Kasiske (1998) brought the importance of this topic to light. In their study using univariate and multivariate regression, they established that "patients who were young, better educated, white, working full time, and had better insurance coverage were more often listed before dialysis" meaning that they were more likely to be placed on the waitlist for a transplant. This outcome shows that the variables substantiated to impact transplant probability as shown by (Kasiske 2002) also play a role in transplant registration (i.e. getting off the waitlist). The authors, however, failed to control for the fact that individuals who are "better educated" are more likely to be working full time and therefore more likely to receive "better insurance coverage" from their employers which would lead to their direct placement on the transplant list. Nevertheless, the paper marked an important start to the study of the determinants of waitlist registration.

B. Transplant Acceptance

1. Donation Quality

Many papers analyzing the features associated with a transplant match (Gill (2013), Goldfarb-Rumyantzev (2010), Schaeffner et. al. (2008)) conduct survival analysis by solely observing whether or not a transplant was undergone. This approach neglects to consider the quality of the transplant match. A match whose organizers don't consider factors that influence quality will provide inaccurate information on the factors that influence a match. For example, many studies define the incidence rate to be the receipt of a kidney donation regardless of whether or not it was from a living donor or a deceased donor. Thus, the authors neglected to consider transplant quality. Deceased donor transplants are known to be less effective than living donor transplants. On average, a living donor transplant will last fifteen to twenty years while a deceased donor transplant will last ten to fifteen years (*American Kidney Fund).* Furthermore, Cecka (1992), drawing on data from UNOS Scientific Renal Transplant Registry, reported a 93% one-year and an 86% three-year graft survival rate for living donations. They also reported a 17-year half-life. Thus, one year after transplant, 93% of the grafts continue to function and three years after transplant 86% of the grafts continue to function. However, for deceased donor transplants, the authors found an 87% one-year and a 76% three-year graft survival rate with a 17-year half-life. Thus, after one year only 87% of graphs are functional and, after three years, only 76% continue to function.

2. Age

Another important variable to consider in evaluating the role of various features that contribute to a kidney match is age. Fabrizii et. al. (2004) offered no material differences in the five-year graft survival rates among different age groups[1]. This led the authors to assert that "discrimination against older candidates for kidney transplantation on age-related grounds alone is not warranted." Similarly, McAdams-DeMarco (2014) studied kidney recipients over the age of 65 from 1990 to 2011. The results showed that "mortality and graft loss have decreased" for their targeted patient population. Hence, the authors' claim that there is an "improving landscape for" kidney transplants in elderly individuals is warranted.

Veroux (2011), however, reports that "elderly recipients had a significantly lower graft and patient survival as well as a significantly higher risk of graft loss and patient death."[2] Their findings highlighted that both young, defined as less than 45 years of age, and old, defined as

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[1] Fabrizii (2004) used linear and logistic regression along with univariate and multivariate Cox Proportional Hazards Models to reach this conclusion.

[2] Kaplan Meier survival time estimates and Cox Proportional Hazard regressions, both univariate and multivariate, were used to assess the survival rates among individuals of differing ages.

over 65 years of age, recipients were at a “higher risk of graft” failure, as indicated by a hazard ratio of 5.65, if they received a transplant from an individual over the age of 65.

Furthermore, Veroux (2011) claimed that “kidney transplantation does not offer a significant survival benefit” to elderly recipients when compared to the waiting list. That is, elderly patients will have a longer life expectancy if they were to stay on the waiting list rather than receive a transplant. While age most certainly impacts transplant outcomes (Moers 2009), very few studies have supported this striking assertion as most concur that transplantation decreases the risk of mortality for all ages (Tonelli et. al. 2014, Panduranga et. al. 2007, Oniscu et. al. 2004). The authors of the study utilized data from their own institution and thus internal biases against performing such transplants may have influenced this finding.

Andreoni (2013) also touched upon age-related outcomes in kidney transplants by investigating the outcome of matches for very young recipients[3]. The authors concluded that “recipients who receive[d] their first kidney transplant at age 14 to 16 years were at the highest risk of graft loss.” These findings suggest that age, on both ends of the spectrum, should be considered.

3. Education

Using a nationally representative sample of 3,245 patients on dialysis in the United States, Schaeffner et. al. (2008) sought to understand the role that education played “as a determinant of access to and outcomes after kidney transplantation.” The study found that individuals who had completed a higher level of education, indicating secondary school, were three times more likely to be placed on the waitlist and to receive a kidney transplant once on the waitlist compared to patients who had not completed secondary education. The authors did not, however, find any notable differences in mortality rates among varying education groups.

When undergoing their analysis, the authors failed to limit their observations to individuals who were above the age of 18. Including individuals under 18 bias these findings as these individuals have not yet had the opportunity to attain secondary education. Therefore, it is not justified to conclude that education impacted their likelihood of receiving a transplant.

In situations in which data is limited, however, income can be used as a proxy for educational attainment, or vice versa, as higher educational attainment is known to be associated with a higher level of income. Utilizing data from UNOS between 1998 and 2010, Gill (2013) studied the correlation between median household income and transplant outcomes. Having undergone survival analysis, the authors found that individuals who were from “higher income quintiles” were more likely to receive a transplant from a living kidney donor. As Cecka (1992) aforementioned, living donor transplants are perceived as higher quality due to the better outcomes associated with these transplants. Thus, the results of the study suggest that individuals who are of a higher income bracket, and are therefore likely of a higher educational status, are more likely to undergo a successful kidney transplant. Nevertheless, the study did not take into

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[3] Utilizing data from 1987 to 2010, Andreoni (2013) used Cox Proportional Hazards models when undergoing his analysis.

account the status of the patients after their transplant was completed. Therefore, it is unclear if individuals of a higher income status were truly at an advantage.

Goldfarb-Rumyantzev (2010) used patient profiles from the USRD data system to directly observe the effect that educational attainment can have on racial disparities. The study observed outcomes in terms of the magnitude of individuals who were placed on the waiting list or received a transplant without listing and the individuals who received a transplant once on the waitlist. Within this study, African Americans were associated with "reduced access to transplantation" and waitlisting. However, within the data, less African Americans graduated from college than white individuals, 10% vs. 16.7%, and African Americans comprised a larger percentage of individuals who had never graduated high school, 38.6% vs. 30.8%. When observing the following three educational groups, individuals who never completed high school, individuals who graduated high school, and those who attended but did not complete college education, African Americans "were less likely to be waitlisted/transplanted in" all three educational groups. It is important to note, however, that there was no statistically significant difference in access to kidney transplantation for African Americans who completed college when compared to white individuals. The findings suggest that racial disparities among individuals "might be alleviated in highly educated individuals."[4]

Similar to Gill (2013), the authors did not take into account the quality of the transplants being underwent. Thus, it is unclear as to whether or not receiving a transplant truly improved the outcomes of the patients. Although this analysis is unable to be performed in this paper due to the lack of included variables, the conceptual understanding of race and education by Goldfarb-Rumyantzev (2010) can be carefully applied to make inferences regarding the implication race could play.

4. Smoking

Individual's health also plays a role in transplant consideration and outcomes. Various studies, including Underwood et. al. (2014), Nourbala (2011), Kasiske (2000), Woo et. al. (2002), Agarwal (2011), Hurst et. al. (2011), show the negative relationship between smoking and kidney recipient survival rates. All authors, but Khalil (2017) in particular, demonstrated that this relationship stemmed from the correlation between smoking and "perioperative complications, wound infections, and mortality in transplant recipients." Similar studies (Khalil (2017), Kasiske (2000), Agarwal (2011), Hurst et. al. (2011)) have asserted that smoking has a similarly negative impact on graft survival rates. When observing 1-, 5-, and 10-year post-transplant graft survival rates, Khalil (2017) reports that individuals who smoke have survival rates of 84%, 65%, and 48%, while those who do not smoke are associated with rates of 88%, 78%, and 62% respectively. Non-smokers had higher survival rates across all time periods compared to smokers, and the magnitude difference between smokers and non-smoker survival

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[4] It is important to note the intersectionality between education and race. However, race has been omitted from the dataset examined here, for the protection of patient identity. Subsequently, the following estimates are pooled by race and we are thus unable to offer separate estimates for white and black individuals to make predictions about how race may impact one's access to kidney transplants.

rates increased in conjunction with time. Subsequently, these findings suggest that smoking for longer periods of time worsened relative survival rate percentages for all individuals.

Moreover, smoking impacts both graft and recipient survival. Using data from USRDS, Kent et. Al. (2012) observed the trends of smoking and access to kidney transplants from 1995 and 2006 across all dialysis patients. The use of Cox Regression showed that mortality rates were higher for individuals who smoked, and the likelihood of kidney transplantation were significantly lower for individuals who smoked than for individuals who did not regardless of age. These studies, however, solely considered whether or not an individual smoked and the duration of them doing so. They did not take into account additional health related variables, such as BMI. These variables may be comorbid with smoking and are therefore likely to impact and or be reflected in patient health.

5. BMI

Poor health can be expected to adversely impact one's access to a kidney transplant. However, due to limited data this question remains unresolved. One way we may approach exploring this relationship, however, is through an individual's body mass index, or BMI. Marks (2004) study undermined previously conceived notions regarding BMI and transplant outcomes. The authors studied 247 individuals from a random selection of kidney transplant candidates from 1999 to 2000. This analysis showed that patients who suffered from obesity, or a BMI that exceeds 34, did not experience different waiting lists and transplant outcomes than individuals whose BMI was below 34. Thus, the authors concluded that obese patients' survival rates were akin to those patients who did not suffer from obesity. Nevertheless, Marks (2004) did conclude that obese patients were found to experience higher readmission rates, "greater complications and a greater number of days in the hospital." The findings of this study, however, are certainly questionable due to the small sample size. While the entire dataset was comprised of 247 individuals, the findings pertaining to obese patients were based solely on 23 individuals. The small sample size affects the reliability of the authors' findings and warrants additional study.

Utilizing a larger sample size, Segev (2008) further sought to understand the relationship between patient BMI and the ability to access the transplant list. Studying a random cohort of 132,353 individuals, from 1995 to 2006, the authors stratified the data in terms of individuals' BMI and probability of transplant. They found that an "increasing degree of obesity", meaning a high BMI, was correlated with a decreased "likelihood of receiving a transplant" among all individuals. The authors expanded on this finding by showing that the likelihood of being passed over as a recipient increased with each increasing "category of obesity" or BMI.

Grosso (2012) expanded these findings by exhibiting that such trends were present in transplant success rates. In undergoing a survival analysis, Grosso (2012) showed that compared to nonobese recipients, "graft loss was significantly higher among obese". Furthermore, the one-year and three-year post-transplant survival rates were found to be "significantly lower" for obese patients.

While results presented by Segev (2008) and Grosso (2012) do not suffer from a limited sample size, the authors fail to take into account the holistic impact that BMI can have on one's access to a kidney transplant. While a high BMI is not beneficial to one's health, a low BMI does not necessitate a healthy individual. Viewing BMI in this manner limits its applications. In order to have a more holistic understanding of the impact of BMI on kidney transplantation, studies should take into consideration both ends of the spectrum: individuals with both an extremely below and above average BMI. In its current form of literature, the question of weight is unresolved. However, we intend to address this issue by accounting for both ends of the weight distribution in comparison to the middle

The outcomes of these previously conducted studies reveal that the following variables of interest, Age, Education, Smoking, and BMI, influence an individual's likelihood of receiving a transplant. Despite these findings justifying further examination of these variables, these literary works have limitations. Most notably, these works fail to establish a connection to the current transplant system. Thus, while certain factors may leave a given individual at an advantage within the market, the mechanisms through which these factors persist are unclear. Subsequently, it is ambiguous as to whether this favoritism is the result of shortcomings within the transplant system or external factors.

To address this shortcoming in the following analysis, individuals within the dataset will be assigned an EPTS score in accordance with the EPTS formula provided by the Organ Procurement and Transplant Network. Utilizing this metric, we will seek to understand whether the EPTS score is truly indicative of an individual’s likelihood of receiving a transplant and thus the fairness of such a system. The additional variables, such as Education, Smoking, BMI, and follow-up characteristics will then be utilized to understand if discrepancies exist, in which magnitudes and variables.

V. Data Description

A. Data Overview

The data that will be utilized in the following analysis is sourced from the Registry of Organ Donation and Transplantation, RODT. The total number of observations, which encapsulates the total number of patients within the dataset, is 1,692. These individuals are followed from time zero, at which time they begin receiving dialysis, until 9,955 days after their first dialysis treatment. This corresponds to roughly 27.3 years of observation. During this observation period, various metrics such as an individual’s duration of time on dialysis, whether the individual was placed on the transplant list, their duration of time on the transplant list, whether they received a transplant, what type of transplant, and whether or not death occurred are captured and recorded.

The dataset provides extensive information regarding an individual’s current health status. While not only including typical health metrics such as BMI and smoking history, but the data also includes current medical diagnoses such as the type of kidney disease an individual is suffering from and whether or not they have experienced any additional organ failure. Moreover, the dataset affords specific metrics with regards to an individual’s kidney function, such as the type of dialysis they are receiving and the duration of time for which they have been receiving this type of dialysis treatment.

Furthermore, the data encapsulates a holistic understanding of patients’ statuses within the transplant allocation system. For instance, the data set contains information on: whether an individual is currently waitlisted on the transplant list, how long they have been waitlisted, whether they have received a transplant, and, if so, the type of transplant they received, and whether an individual died awaiting a transplant or after receiving a transplant during the observation period. These metrics will be utilized in the following analysis to further understand which variables, if any, increase the probability of being admitted to the waitlist and/or receiving a transplant.

The data, however, does present several shortcomings. To protect patient identity, the dataset has omitted information on patients' race and gender. Subsequently, the following estimates are pooled by both race and gender. Therefore, the analysis is unable to evaluate if the impact of any given variable on receiving a transplant or length of time waiting for a transplant differs, *ceteris paribus*, between men and women and between black and white individuals. Furthermore, the data does not directly contain information regarding the patient's socioeconomic status. However, education can be used as a proxy for socioeconomic status. Individuals who are of a higher educational attainment status tend to be of a higher socioeconomic status. Thus, while the education effect may be overstated because it captures some of these effects, it can be used to propose a hypothesis for further testing regarding patients' socioeconomic status and their access to kidney transplants. Since we are unable to directly control for these characteristics, the estimates presented may suffer from omitted variable bias.

B. Summary Statistics: Survival Analysis Until Admittance to the Waitlist and Survival Analysis Until Kidney Transplant Once on the Waitlist

The incidence rate depicted below provides insight as to the frequency of the occurrence of each variable in the dataset as it reflects the number of occurrences of the specified variable over the total number of observations. An individual is considered to be "at risk" when they have yet to experience the event of interest, such as admittance to the transplant waitlist or the reception of a kidney transplant. Therefore, time at risk corresponds to the duration of time an individual is considered to be "at risk" in reference to the specified event.

The median survival time, depicted below, corresponds to the average duration of time an individual will spend at risk before incurring the event of interest. As we recall, the first event of interest is admittance to the waitlist while the second event is the offering of a kidney transplant. When undergoing survival analysis, with regards to the time until waitlisting, the time variable is the number of months while the event variable is assignment to the transplant list. Thus, a shorter survival time is indicative of an earlier admittance to the waitlist. Likewise, when undergoing survival analysis with regards to the time until a kidney transplant, once on the waitlist, the time variable is the number of months while the event variable is the reception of a kidney transplant. Thus, a shorter survival time is indicative of an earlier kidney transplant. Therefore, lower median survival times are associated with a higher likelihood of being admitted to the waitlist and receiving a kidney.

Table 1: Descriptive Statistics of Key Variables

		Access to the Transplant Waitlist		Access to Kidney Transplant	
Variable	Number of Observations	Incidence Rate	Median Survival Time	Incidence Rate	Median Survival Time
Weight					
Underweight	58	0.012	57	0.014	78
Normal	763	0.014	56	0.014	53
Overweight	334	0.016	56	0.013	53
Obese	537	0.014	58	0.011	63
Smoking					
Yes	756	0.015	54	0.013	61
No	936	0.014	58	0.014	53
Age					
Young	399	0.015	53	0.017	43
Middle-Age	922	0.014	58	0.012	60
Old	371	0.015	54	0.012	63
Education					
< High School	64	0.015	56	0.012	84
= High School	928	0.014	58	0.013	58
> High School	700	0.015	54	0.015	50
Type of Dialysis					
Hemodialysis	1,556	0.014	56	0.13	58
Peritoneal Dialysis	136	0.019	48	0.014	40
Raw EPTS					
High Quality	1,355	0.015	55	0.014	53
Low Quality	337	0.014	60	0.011	73

Data Source: *Registry of Organ Donation and Transplantation, RODT*

VI. Empirical Approach

A. Survival Analysis

The following analysis examines the impact the variables of interest have on an individual's ability to be placed on the kidney waitlist and to subsequently receive a transplant. The primary reason for examining such variables is to test hypotheses or the relative importance of these various factors. Since the duration of time is a key point of observation in this study, survival analysis is warranted as it is utilized to observe "data in which time until the event is of interest" (*Lecture 15 Introduction to Survival Analysis*).

When analyzing survival data, both survival probability and hazard probability play a role. One's survival probability is the likelihood that an individual will survive from the initial time, t_0, or time of origin, past a specified future time t. Given by the survivor function $S(t)$, an individual's survival probability can be modeled as $S(t) = Pr(T > t) = 1 - F(t)$ for a given response variable T and time t. The hazard probability, on the other hand, observes the probability that an individual will experience an event in the span of time t_0 to t. The hazard function, given by $h(t)$, calculates the "instantaneous rate at which events occur", on the basis that no prior events have occurred:

$$h(t) = \lim_{\Delta t \to 0} \frac{Pr(t < T \leq t + \Delta t | T > t)}{\Delta t} = \frac{f(t)}{S(t)}.$$

The point of departure between these two functions is that the survival probability observes only time whereas the hazard probability observes the occurrence of an event.

B. Kaplan-Meier Graphs

While observing both the survival probability and the hazard probability is key to understanding survival analysis, some techniques such as the Kaplan Meier Survival Model study only the survivor function. For a given time interval, the Kaplan Meier Survival Model uses a non-parametric method to plot the estimated probability of survival for each individual. The probability of survival can be calculated as $S(t_i) = S(t_{i-1})(1 - \frac{d_i}{n_i})$ (Goel, Manish Kumar, et al.). The probability of survival for a given individual, $S(t_i)$ is dependent on the probability of surviving to time t_{i-1}, as represented by $S(t_{i-1})$ and n_i the number of patients who survived to t_i and $d_i$the number of events, such as acceptance to the waitlist or offered a transplant, at time t_i . Kaplan-Meier Survival Estimates can then be plotted against time to produce a Kaplan-Meier Survival Curve. This plotting provides a visual representation of the overall survival trends between patients in the population and time.

It is important to note, however, that Kaplan Meier Survival Models are produced by undergoing univariate analysis. Thus, Kaplan Meier Survival Models present the effect of a single variable as they are unable to incorporate multiple predictors. This restricted view ignores the possible impact of additional variables and thus suffers from omitted variable bias. Moreover, such models are solely applicable to categorical variables. While some of the aforementioned variables of interest are categorical variables, such as gender and race, others are quantitative variables and are thus unable to be observed in these ways.

C. Cox Proportional Hazards Model

The Cox Proportional Hazards Model is used for multivariate analysis. Therefore, the model takes numerous variables into account when observing survival, providing a more holistic view. Further, this model is applicable to both categorical and predictor variables, enabling additional analysis to be carried out. The larger scope and application of the Cox Model can be used to address the shortcomings of the Kaplan-Meier Models and further the analysis.

One potential weakness of the Cox Proportional Hazards Model is it assumes the hazard functions are proportional; that is, the relative hazard is constant across time and different levels of the explanatory variables. This assumption is a testable hypothesis, however, and we will verify that this assumption seems to be satisfied with regard to the following analysis. The proportional hazards test employs a null hypothesis that the hazard functions are proportional. The results of the testing are displayed below, in Table 2.

Table 2: Proportional Hazards Testing

Cox Proportional Hazards Model	Chi-Squared	P-Value
Analysis One		
Access to the Transplant Waitlist	8.76	0.555
Analysis Two		
Access to Kidney Transplant	4.76	0.9068

Data Source: *Registry of Organ Donation and Transplantation, RODT*

The proportional hazards testing did not produce results that are statistically significant. Consequently, the null hypothesis, that the hazard rates are proportional, for the specified models, is unable to be rejected. The proportional assumption of the Cox Proportional Hazards Model is therefore met, and the model can subsequently be employed in the following analysis.

By estimating hazard rates, this model allows for the understanding of "how specified [variables] influence the rate of a particular event happening at a particular point in time" (*STHDA)*. A specific variable's influence on an event is called the variable's hazard rate. For the given variables or covariates $x_1, x_2, \ldots, x_n$, the Cox Model works to estimate a hazard function, $h(t) = h_0(t) * exp(b_1x_1 + b_2x_2 + \ldots + b_nx_n)$ for a survival time t (*STHDA)*. Similar to a regular regression model, the covariate coefficients, $b_1, b_2, \ldots, b_n$ are the measured impacts that the covariates have on the hazard function. The term, h_0, can be interpreted as the baseline hazard as it impacts the hazard function when $x_i = 0$ for all i.

Individual covariates' hazard ratios are given by the quantity $exp(b_i)$. A given variable's hazard ratio should be analyzed in reference to one. A hazard rate equal to one indicates that the variable has no effect on the patient's probability. A hazard rate of less than one indicates that there is a reduction in the possibility of the given event occurring. Thus, as the given covariate increases, the hazard rate decreases, and the estimated length of survival increases.

D. Analysis Specifications

As aforementioned, survival analysis observes the time spanned before an event occurs. To holistically understand the kidney transplant allocation system, two survival analyses will be conducted (first admittance to the waitlist and then transplantation). The first survival analysis will observe the time until an individual receives a spot on the transplant waitlist. This span of time will be observed in terms of number of months and the event of interest will be admittance to the transplant waitlist. The second analysis, however, will observe the time to an individual receiving a transplant once on the waitlist. Thus, the duration of time is the number of months, and the event of interest is the receipt of a kidney transplant. Overall, this specific survival analysis will observe time, in the number of months, to an event, where the first event is admittance to the waitlist and the second event is a kidney transplant occurring.

The key variables of interest in this analysis are the factors identified earlier in the conceptual Marginal Cost-Marginal Benefit analysis. These factors are expected to influence the time until an individual is placed on the waitlist and the time until an individual receives a kidney transplant. The MC-MB conceptual framework can aid in forming hypothesis regarding the key variables of interest. Factors that are anticipated to increase marginal cost and or decrease marginal benefit, *ceteris paribus*, can be seen as harmful to an individual's access to the transplant system. On the other hand, factors that decrease marginal cost and or increase marginal benefit, *ceteris paribus*, are viewed as beneficial to an individual's ability to access the waitlist and a transplant. Employing this conceptual understanding, the following hypothesis were constructed to be further tested in the following analysis:

a) The increased marginal cost associated with individuals who are of a high and low BMI status results in these individuals being less likely to be admitted to the waitlist and/or recipients of a kidney transplant.

b) The increased marginal cost associated with individuals who smoke results in these individuals being less likely to be admitted to the waitlist and/or recipients of a kidney transplant.

c) The increased marginal cost associated with individuals who are of an advanced age results in these individuals being less likely to be admitted to the waitlist and/or recipients of a kidney transplant.

d) The decreased marginal cost and increased marginal benefit associated with individuals who are of a younger age result in these individuals being more likely to be admitted to the waitlist and/or recipients of a kidney transplant.

e) The increased marginal benefit associated with individuals who are of a high educational attainment result in these individuals being more likely to be admitted to the waitlist and/or recipients of a kidney transplant.

When undergoing the following analysis, these variables will be grouped into three categories, Lifestyle Choices (i.e. smoking and body mass index), Utilization (i.e. age and education), and Kidney Status (i.e. type of dialysis and proxy EPTS score) in an attempt to further understand the mechanisms through which they impact the likelihood of receiving a transplant.

1. Lifestyle Choices

The first category to consider is lifestyle choices. This category incorporates the variables of BMI and smoking. The aforementioned conceptual MC-MB framework allows us to form hypotheses regarding how each variable is expected to impact the two events of interest: acceptance to the waitlist and a kidney transplant. This hypothesis is based on how the factors of BMI and smoking shift the MC and MB curves.

Intermediaries want to ensure successful transplants and thus use an individual's health to determine whether a body is capable of accepting and maintaining an organ donation. Body Mass Index, or BMI, is used to understand a body's fat level. High-fat levels place additional stress on the body and organ function, resulting in declining overall health. This risk increases MC. Thus, individuals with an above average or high BMI are not likely to be favored for waitlist admittance and a kidney donation as intermediaries would fear the stress-- and thus increased likelihood of failure--the organ would face.

A low BMI, however, does not necessitate a healthy individual. An extremely below-average BMI often suggests an underweight individual. Thus, individuals who possess a BMI can also be viewed as having a positive effect on the MC curve. Such an individual may be deemed too risky for a transplant. To account for these influences, BMI has been stratified into four categories, underweight, normal weight, overweight, and obese. A BMI under 18.5 is considered underweight, between 18.5 and 25 is average, over 25 is overweight, and over 30 is obese. The analysis will then seek to understand whether individuals of these differing BMI categories experience bias in the transplant process. We expect underweight individuals and obese individuals to fare poorly with regards to waitlist acceptance and transplant offerings.

An extreme BMI profile, meaning a relatively low or relatively high BMI, is expected to shift the MC curve to the left or upward. Consequently, we can expect the associated quantity of individuals with such BMI profiles to be of a lower magnitude than the quantity of individuals with a normal BMI at equilibrium. Thus, we expect extreme BMI measures to decrease one's likelihood of being admitted to the waitlist and increase the magnitude of time one must wait, once on the list, before receiving a transplant.

Observing lifestyle choice such as BMI and smoking sheds light on whether or not an individual prioritizes their health and wellbeing or if they undergo actions that leave them susceptible to other illnesses. Increasing one's predisposition to such factors may have an adverse effect on an individual's ability to access a transplant as they face a greater risk of failure for transplant success and survival. Smoking increases an individual's risk of complications and failure during transplant. In turn, smoking increases the MC faced by the intermediaries within the market and thus shifts the MC curve to the left or upward. Thus, through similar mechanisms as addressed above, we can expect the quantity of smokers at equilibrium to be lower than that of non-smokers. In addition, we can expect the duration of time such individuals spend on the waitlist to be greater than those who do not smoke.

2. Utilization

Intermediaries will not only examine whether a transplant is feasible but also take into consideration the possible benefits of such a transplant. Thus, the second category to consider is utilization. This category will account for the benefits associated with an individual's age and education. Intermediaries seek to allocate the best functioning kidneys to the individuals who can use the transplants for the longest period of time. On average, younger individuals have a larger duration of time remaining in their lifetime. Thus, if given a transplant, they are able to provide a larger positive externality to society through their use of the transplant. Therefore, younger individuals are seen as having a positive effect on the MB curve. Moreover, such individuals are less receptive to medical complications and are thus associated with less risk than older patients, imposing a negative effect on the MC curve. Thus, following the allocation ideology, one would expect younger candidates to be favored in the waitlist and allocation process as their age would allow them to use the kidney for a longer period.

Age is not the only factor that constitutes an individual's productive capacity. The societal contributions an individual may make, if given a transplant, may also be taken into consideration. Such actions include social participation, civic duties, and contributions to the economy. These contributions can be thought of as providing a positive externality to the community in which the transplant is undergone. Akin to the discussion above, these contributions have a positive effect on the MB curve.

Although it is difficult to quantify such benefits, an individual's level of education can provide insight as to the human capital individuals may possess and thus their ability to participate within society. Education has been stratified into three categories, within the data, to observe this relation, those whose educational attainment is less than high school, those that completed high school, and then those who participated in higher education. Education's positive impact on MB suggests that educated individuals would be favored in the waitlisting and kidney allocation process.

3. Kidney Status

The status and estimated future of an individual's kidney function will also be taken into consideration using the Type of Dialysis variable and a proxy EPTS variable. Although not included in the dataset, the EPTS variable was created using the following formula:

$$\begin{aligned}\text{Raw EPTS } &= 0.047 * max(\text{Age} - 25, 0) - 0.015 * \text{Diabetes} * max(\text{Age} - 25, 0)\\ &+ 0.398 * \text{Prior Solid Organ Transplant} - 0.237 * \text{Diabetes} * \text{Prior Organ Transplant}\\ &+ 0.315 * log(\text{Years on Dialysis} + 1) - 0.099 * \text{Diabetes} * log(\text{Years on Dialysis} + 1)\\ &+ 0.130 * (\text{Years on Dialysis} = 0) - 0.348 * \text{Diabetes} * (\text{Years on Dialysis} = 0) + 1.262 * \text{Diabetes}\end{aligned}$$

It is important to note, however, that the dataset does not include information regarding whether an individual has received a previous transplant. Thus, the effect of this transplant is not able to be represented in the EPTS formula, which therefore suffers from some amount of measurement error, by default. Nevertheless, the EPTS variable provides a direct link to UNOS, the institutionalized matching system, and still appears to be a reasonable proxy for the true Raw EPTS variable. The strong ties that this proxy measure has to UNOS suggests that individuals who are perceived as quality recipients, and thus possess a low EPTS score, are favored within the transplant processes. Therefore, we would expect that individuals with a low EPTS score are likely to be prioritized with regards to waitlist admittance and transplant receival.

As aforementioned, intermediaries seek to allocate high-quality transplants to individuals who will utilize them for the longest period of time. An individual's EPTS score provides an estimate regarding the magnitude of this duration of time. Those with a low EPTS score are considered quality recipients as they are expected to utilize a donation longer than the majority of competing recipients. This low score would prioritize the patients in the transplant process, according to UNOS. Observing whether there is a correlation between one's score and their ability to access a transplant will demonstrate whether the transplant allocation system functions in the manner in which UNOS declares.

To begin, each section of the hazard study will be viewed independently. First, the hazard model will be observed solely considering the health of the individual, then their utilization, and finally the individuals' kidney status. Then, these factors will be taken into account altogether in the final hazard function. This function is of the form

$$h(t) = h_0(t) * \exp\,(b_1x_1 + b_2x_2 + \ldots . + b_nx_n)$$

The first analysis undergone will observe the hazard over time, $h(t)$, in number of months, of being admitted to the transplant list. The key covariates within the study, or independent variables, are age, education, BMI, smoking, type of dialysis, and proxy Raw EPTS score.

$$\begin{gathered} Hazard\ of\ Kidney\ Transplant(t) = \\ h_0(t) * \exp\,(b_1Age + b_2Education + b_3BMI + b_4Smoking + b_5TypeOfDialysis + \\ + b_6Proxy\ RawEPTS) + \varepsilon \end{gathered}$$

The second analysis observes the hazard over time, in number of months, of receiving a transplant once on the waitlist. The key covariates within the study, or independent variables, are age, education, BMI, smoking, type of dialysis and proxy Raw EPTS.

$$\begin{gathered} Hazard\ of\ Kidney\ Transplant(t) = \\ h_0(t) * \exp\,(b_1Age + b_2Education + b_3BMI + b_4Smoking + b_5TypeOfDialysis + \\ b_6Proxy\ RawEPTS) + \varepsilon \end{gathered}$$

V. Results

A. Kaplan-Meier Graphs

Survival analysis will be observed in terms of number of the number of months until admittance to the waitlist for a kidney transplant and then in terms of number of months until being offered a kidney transplant. Kaplan-Meier Graphs will first be observed to understand the overall survival trends regarding the variables of interest. When observing Kaplan-Meier graphs, it is important to note that the y-axis represents survival probability while the x-axis represents time in number of months. The individual Kaplan-Meier graphs can be viewed in Section B and C of Appendix. However, the median findings of the Kaplan-Meier graphs can be viewed below, in Table 3. Log-Rank tests are then employed to test the null hypothesis that there is no difference in the survival functions for the specified variables at any given time. The results of such tests are presented below, in Table 4.

Table 3: Kaplan-Meier Results – for the Mean Person

	Access to the Transplant Waitlist		Access to Kidney Transplant	
Variable	Time Until Placed on the Waitlist (Months)	Expected Effect	Time Until Transplant Once on Waitlist (Months)	Expected Effect
	Panel A: Lifestyle Effects			
Weight				
Underweight	64	-	47	+
Normal	61	Reference	49	Reference
Overweight	63	-	52	-
Obese	62	-	65	-
Smoking				
Yes	58	-	62	-
No	63	Reference	55	Reference
	Panel B: Utilization Effects			
Age				
Young	64	+	45	+
Middle-Age	68	Reference	63	Reference
Old	65	+	76	-
Education				
< High School	61	-	61	-
= High School	60	Reference	60	Reference
> High School	58	+	51	+
	Panel C: Kidney Status			
Type of Dialysis				
Hemodialysis	54	Reference	59	Reference
Peritoneal Dialysis	60	+	51	+
Proxy Raw EPTS				
High Quality	56	Reference	53	Reference
Low Quality	59	-	72	-

Data Source: *Registry of Organ Donation and Transplantation, RODT*

Table 4: Log Rank Test for Equality of Survival Functions

	Access to the Transplant Waitlist		Access to Kidney Transplant	
Variable	Chi-Squared	P-Value	Chi-Squared	P-Value
	Panel A: Lifestyle Effects			
Weight	6.86	0.077*	11.70	0.009***
Smoking	4.52	0.034**	1.20	0.272
	Panel B: Utilization Effects			
Age	1.89	0.3894	17.27	0.000***
Education	1.93	0.3815	4.78	0.0918*
	Panel C: Kidney Status			
Type of Dialysis	15.46	0.000***	8.54	0.014**
Proxy Raw EPTS	2.84	0.092*	6.98	0.008***

Notes: *** $p<0.01$, **$p<0.05$, *$p<0.1$

Data Source: *Registry of Organ Donation and Transplantation, RODT*

1. BMI

The body mass indices of the individuals within the data are split into four categories: underweight, normal weight, overweight, and obese. When undergoing the following analysis, individuals who are identified as being a normal weight will be the reference group. Recall that extreme body mass, or weight, increases the MC of a transplant. Similarly, a very low body mass can impose additional stress on the body and increase the MC of a transplant. Thus, we expect individuals who fall within an extreme body mass category, such as underweight or overweight, to experience longer times till waitlisting and transplant offering.

When undergoing the first analysis, the Kaplan-Meier graph for Body Mass Index – presented in Appendix Section B – indicates that, at the median survival probability, underweight individuals have the longest survival time while individuals who have a normal BMI range have the shortest survival time. Similarly, obese and overweight individuals are associated with a longer survival time than individuals who are identified as falling within the normal weight range. Failure, within this context, is defined as admittance to the waitlist. Thus, individuals who fall within a normal BMI range are likely to experience failure and thus be admitted to the transplant list prior to individuals who are underweight, overweight, and obese. This result corresponds directly with the expected hypothesis from the theoretical MC-MB model.

When undergoing the second analysis, however, the Kaplan-Meier graph – presented in Appendix Section C – indicates that, at the median survival probability, underweight individuals have the shortest survival time while obese individuals have the longest survival time. Since, within this context, failure is defined as the reception of a kidney transplant, these results appear to suggest that underweight individuals are likely to receive a kidney transplant prior to individuals of a normal weight while obese individuals are expected to incur a longer wait time. This finding does not directly coincide with the proposed hypothesis as it suggests that underweight individuals are prioritized over normal weight individuals within the transplant process. Nevertheless, the finding does support the hypothesis that obese individuals are not favored.

The Log-Rank test for weight, both in analysis one and analysis two, produced statistically significant results, at the ten and one percentile level, supporting our hypothesis that individuals of various weight categories experience different survival functions.

2. Smoking

Individuals are also categorized in terms of their smoking behavior: individuals who currently smoke, or who have a history of smoking, and individuals who have never smoked. As addressed in the conceptual framework, smoking is viewed as having a positive effect on MC as it increases the risk of complications and graft failure associated with undergoing a transplant. Thus, we expect those who smoke to be less likely to receive a spot on the transplant list and a kidney transplant.

At the median percentile for survival times in analysis one, individuals who have a history of smoking are associated with a shorter wait time than individuals who do not have a history of smoking. Since failure is defined as admittance to the waitlist, it follows that those individuals who smoke are more likely to be admitted to the transplant list prior to those who do not smoke. This finding does not align with our hypothesis as it depicts smoking as a factor that increases the likelihood of being admitted to the waitlist.

When observing the median percentile for survival times for analysis two, individuals who have a history of smoking or who currently smoke are associated with a longer analysis time than individuals who do not possess a history of smoking. This result suggests that individuals who have never smoked are likely to receive a transplant prior to individuals with a smoking history and thus concurs with our hypothesis.

When undergoing Log-Rank tests with regards to smoking, the results of analysis one, access to the transplant waitlist, are statistically significant at the fifth percentile. The results for the second analysis, access to the transplant list, however, are not significant. These outcomes suggest that smoking plays a larger role in an individual's access to the waitlist than their access to a kidney transplant.

3. Age

Within the dataset, age has been stratified into three categories: young (between the ages of 18 and 39), middle-aged (between the ages of 40 and 59), and old (60 years or older). Young individuals will be the reference group in the following analysis. As touched upon in the conceptual framework, younger individuals allow for a longer period of utilization if given a kidney transplant. Thus, they are associated with having a positive effect on MB. Moreover, younger individuals impose less testing costs and risk for the intermediaries and are therefore associated with a lower MC. Subsequently, we expect younger individuals to be favored for a spot on the transplant list and for a kidney transplant.

The Kaplan-Meier results for analysis one depicts young individuals as having the shortest analysis and middle-aged individuals having the longest analysis time. Since failure event within this context is defined as admittance to the waitlist, it follows that middle-aged individual are, on average, less likely to be admitted to the waitlist than young and old individuals. While the results did show that younger individuals are favored overall, older individuals are favored with regards to waitlist admittance compared to middle-aged individuals. Thus, these finding aligned with our proposed hypothesis as it supported the notion that younger patients are prioritized in waitlisting; however, it does present some evidence that the benefit of young age reaches a threshold after which its impact is null.

In the second analysis, at the median percentile, young individuals have the lowest analysis time while old individuals are depicted as having the longest analysis time. These results suggest that younger individuals are more likely to receive a transplant before older individuals and that middle-aged individuals are expected to receive a transplant before older individuals. Thus, these findings directly support our proposed hypothesis.

When undergoing Log-Rank tests, age is not found to be statistically significant when undergoing analysis one. When undergoing analysis two, however, age was statistically significant at the one percentile level. Thus, while there appears to be no difference in the survival functions with regards to waitlisting, differences in the survival function with regards to kidney transplantation persist.

4. Education

Individual's educational attainment has been classified into three categories: less than high school, high school, and educational attainment exceeding high school. When undergoing the following analyses, individuals with an educational attainment exceeding high school are employed as the reference group. The conceptual framework, outlined above, presents the ideology that individuals with a higher educational attainment are seen as producing a larger positive externality to society. Subsequently, they are associated with a larger MB than individuals of other educational statuses. Thus, we should expect that individuals of a higher educational attainment are likely to be favored for a spot on the transplant list and for a kidney transplant.

At the median percentile for survival analysis one, individuals who participated in higher education are associated with a lower survival time than the additional groups. Since failure is defined as admittance to the transplant list, this indicates that individuals who are of a higher educational attainment level tend to be admitted to the transplant list sooner than those of a lower educational attainment. Thus, this finding supports our proposed hypothesis.

When undergoing the second analysis, individuals who have participated in higher education are again observed as having a lower survival time than the remaining groups at the median percentile. This finding suggests that individuals with higher educational attainment receive access to a kidney transplant more promptly than those with less education. This positive relationship between educational attainment and access to a transplant supports our hypothesis.

Similar to the Log-Rank results observed for the age variable, education is not statistically significant when undergoing analysis one. When undergoing analysis two, however, education is significant at the tenth percentile level. Therefore, while the survival functions of kidney transplant recipients do not seem to vary by waitlisting, they differ by transplantation.

5. Type of Dialysis

The two major types of dialysis within the dataset are Hemodialysis and Peritoneal Dialysis. While Hemodialysis is typically administered to patients with ESRD, Peritoneal Dialysis is a more aggressive dialysis treatment and is thus correlated with individuals whose health is rapidly declining. Individuals who receive Peritoneal Dialysis are seen as having shorter survival times and thus time until waitlisting when compared to individuals who received Hemodialysis in analysis one. A similar result is produced by analysis two, as individuals who receive Peritoneal Dialysis have shorter survival times until transplantation. This suggests that individuals who receive Peritoneal Dialysis are more likely to be waitlisted and receive a transplant prior to those who undergo Hemodialysis treatment.

Type of Dialysis is shown to be statistically significant, at the first and fifth percentile level, when undergoing analysis one and two. These findings support the understanding that individuals who undergo differing types of dialysis treatments prior to waitlisting and or transplantation experience different survival functions.

6. Proxy Raw EPTS

Proxy Raw EPTS score have been stratified into two categories: high quality recipients and low-quality recipients. High quality recipients have an estimated EPTS score below 45 while low-quality recipient's scores exceed 45. It is important to recall that an individual's EPTS scores is given in terms of their ability to be outperformed by others with regards to transplant use. Thus, lower a EPTS score indicates a higher quality recipient. When undergoing analysis one, individuals with a high-quality proxy EPTS score are associated with a lower survival time compared to those with a low-quality proxy EPTS score. For analysis two, individuals with a high-quality proxy EPTS score are depicted as having a shorter analysis time than individuals with a low-quality proxy EPTS score. Thus, high-quality recipients, with a low proxy EPTS score, appear to experience failure and thus receive admittance to the waitlist and a kidney transplant prior to those with a high, meaning low quality, proxy EPTS score.

The Proxy EPTS variable is statistically significant at the tenth percentile mark in analysis one and at the one percentile when undergoing analysis two. Thus, the survival functions for individuals with a low and high equality proxy EPTS score differ in both analyses.

B. Cox Proportional Hazards Model

Similar to Kaplan-Meier graphs, the variables of interest when undergoing the Cox Proportional Hazards Model are age, education, BMI, smoking, type of dialysis, and proxy EPTS. This analysis, however, was undergone utilizing specific reference groups for each variable. The results are presented below in Table 5.

Table 5: Cox Proportional Hazard Results

Variable	Time Until Placed on the Waitlist Hazard Rate	Expected Effect	Time Until Transplant Once on Waitlist Hazard Rate	Expected Effect
Panel A: Lifestyle Effects				
Weight				
Underweight	0.704**	-	0.886	-
Overweight	1.182**	+	1.027	+
Obese	1.054*	+	0.787***	-
Log Rank Comparison				
Obese & Underweight	5.68*		6.66**	
Smoking				
Yes	0.905*	-	1.043	+
Panel B: Utilization Effects				
Age				
Middle Age	0.826***	-	1.338***	+
Old	4.955***	+	1.677**	+
Log Rank Comparison				
Middle Age & Old	78.45***		15.81***	
Education				
< High School	1.111	+	0.846	-
= High School	0.922	-	0.861*	-
Log Rank Comparison				
<HS & = HS	3.03		3.98	
Panel C: Kidney Status				
Type of Dialysis				
Peritoneal Dialysis	1.593***	+	0.725*	-
Proxy Raw EPTS				
Low Quality	0.165***	-	0.537**	-

Notes: *** *p<0.01, **p<0.05, *p<0.1*

Data Source: *Registry of Organ Donation and Transplantation, RODT*

1. BMI

The reference group for BMI is individuals who fall within a normal BMI range. In comparison to the reference group, when undergoing analysis one, underweight individuals have an associated hazard rate of 0.704. This hazard rate is less than one and so the likelihood of an underweight individual experiencing failure is lower than that of the reference group. Failure, however, is identified as admittance to the waitlist and so these results suggest that individuals with an extremely low BMI are less likely to be admitted to the waitlist than individuals who are of normal weight. The finding is statistically significant at the fifth percentile level.

The opposite relationship, however, persists for overweight and obese individuals. Compared to the reference group, overweight individuals had a hazard rate of 1.182 whereas obese individuals have a hazard rate of 1.054. Thus, these findings suggest that individuals who are overweight and obese are more likely to be admitted to the transplant waiting list prior to individuals who are in a normal BMI range. Subsequently, these findings do not function in support of our hypothesis. Such findings are statistically significant at the fifth and tenth percentile.

Continuing to use the normal BMI range as the reference group while undergoing analysis two, individuals who are underweight have a hazard rate of 0.886. Thus, their low BMI appears to negatively impact their likelihood of receiving a kidney transplant. This conclusion works in support of our hypothesis regarding underweight individuals. Individuals who are overweight, however, have a hazard rate of 1.027 while those who are obese have a hazard rate of 0.787. Thus, while obese individuals have a lower likelihood of receiving a transplant when compared to the reference group, overweight individuals appear to be prioritized within the allocation process as their hazard rate exceeds one. This prioritization does not attend to our hypothesis as it suggests that weight has a positive impact on one's access to a kidney transplant. The hazard rate for obese individuals, however, was the only statistically significant finding with regards to weight. It is statistically significant at the first percentile mark.

Log-Rank tests were then employed to further understand the impact extreme weight categories, underweight and overweight, have on an individual's ability to access the waitlist and a kidney transplant. The Log-Rank analysis tests whether the survival functions, of underweight and obese individuals, are equivalent. The tests produced a chi-squared value of 5.68, significant at the tenth percentile, with regards to analysis one, and a chi-squared value of 6.66 for analysis two, which is statistically significant at the fifth percentile. The statistically significant results for analyses one and two allow us to reject the null, supporting the notion that individuals of various weights experience different survival functions.

2. Smoking

When observing the impact of smoking, non-smokers are used as the reference category. With regards to analysis one, smokers have a hazard rate of 0.905. The magnitude of this result is less than one and therefore indicates that individuals who smoke or who have smoked have a lower likelihood of experiencing failure and thus being admitted to the waitlist than non-smokers. The finding is statistically significant at the tenth percentile level. The negative impact that smoking imposes on one's ability to access the waitlist, as shown by this result, supports our hypothesis.

When undergoing analysis two, smokers surprisingly have a hazard rate of 1.043. This hazard rate exceeds one and thus indicates that individuals who smoke have a higher probability of receiving a transplant than individuals who do not smoke. This conclusion was not congruent with our hypothesis as it indicates that smoking increases the probability of receiving a transplant. This finding, however, was not statistically significant.

3. Age

When observing age, young individuals, or individuals who are 18 to 39 years old, are used as the reference group. When undergoing analysis one, individuals who are middle age, 40 to 59 years of age, are associated with a hazard ratio of 0.826. Since the magnitude of this ratio does not exceed nor equal one, the finding suggests that individuals who are middle age are less likely to experience failure, and thus be admitted to the transplant list, than individuals who are young, 18 to 39 years old. This finding is statistically significant at the first percentile. This outcome thus suggests that older individuals have a lower likelihood of experiencing failure and thus being omitted to the waitlist than the younger age group. This finding works in support our hypothesis as it shows that younger individuals are favored in the waitlisting processes.

When observing individuals who are 60 years of age or older, the associated hazard rate is 4.995 in comparison to the reference group. The magnitude of this hazard rate suggests that elderly individuals, 60 years old or older, are far more likely to be admitted to the waitlist than younger individuals. This result is statistically significant at the first percentile and thus appears to highlight that elderly individuals are favored over younger individuals for a spot on the transplant list. Subsequently, this finding does not support our proposed hypothesis.

Analysis two produces similar results. Individuals who are middle aged, 40 to 59 years old, have a hazard rate of 1.338 while individuals who were of an advanced age, over 60, have a hazard rate of 1.677. Both associated hazard rates exceed one and thus signal that increasing age aids one's likelihood of receiving a transplant. Thus, this finding does not support our hypothesis that younger individuals are favored in the transplant process. The result for middle-age and old individuals are significant at the first and fifth percentiles.

Log-Rank tests were then employed to understand if any differences in waitlisting and transplant reception are relevant between middle age and old individuals. A chi-squared value of 78.45 was produced for analysis one, while a chi-squared value of 15.81 was produced for analysis two, both findings are significant at the first percentile. Thus, middle age and old individuals experience different survival functions with regards to waitlisting and transplantation.

4. Education

When observing educational attainment, individuals whose educational attainment exceeds high school is used as the reference group. Throughout analysis one, individuals who have not completed high school were found to have a hazard rate of 1.111 while individuals who have completed high school have a hazard rate of 0.922. The magnitude of these results suggest that while individuals who have not completed high school are more likely to receive a spot on the waitlist compared to individuals whose educational attainment exceeds high school, individuals who have completed high school are not. Thus, while the result associated with individuals who had completed high school is congruent with our hypothesis, showing increased educational attainment is beneficial in the waitlist process, the result for individuals who had not completed high school works against our hypothesis. Neither metric, however, is statistically significant. Consequently, it is inconclusive whether the findings support our proposed hypothesis regarding education.

The results produced by analysis two, however, are more conclusive. In comparison to the reference group, individuals who have not completed high school possess a hazard rate of 0.846 while individuals who have completed high school are associated with a hazard rate of 0.861. These findings suggest that educational attainment aids one's ability to access a kidney transplant, for individuals had not completed high school and who had, in comparison to those participating in high education, were shown to have a lower likelihood of receiving a transplant.

Although, these findings appear to affirm our hypothesis, the only finding of statical significance is for individuals who have completed high school.

Log-Rank tests were then utilized to compare the survival functions of individuals who have not completed high school and who have completed high school. Neither result, for analysis one nor analysis two, were statistically significant. These findings suggest there exists no significant difference between the survival functions of individuals who have and who have not completed high school.

5. Type of Dialysis

The type of dialysis regimen an individual receives as part of their treatment is also taken into consideration when undergoing analyses one and two. Hemodialysis is the most common form of dialysis and was thus utilized as the reference group. Under analysis one, Peritoneal Dialysis was found to have a hazard rate of 1.593 in comparison to patients who undergo Hemodialysis. The magnitude of this rate suggests that individuals who receive Peritoneal Dialysis are more like to experience the hazard than those who receive Hemodialysis. Thus, Peritoneal Dialysis is associated with a shorter wait-time until waitlisting than Hemodialysis. This metric is statistically significant at the first percentile.

When undergoing analysis two, Peritoneal Dialysis has a hazard rate of 0.725 compared to patients who undergo Hemodialysis. This finding suggests that individuals who undergo Peritoneal Dialysis are less likely to receive a transplant than those who receive Hemodialysis. It is statistically significant at the tenth percentile level. Although Peritoneal Dialysis appears to aid one's ability to be admitted to the transplant list, it is not conducive to a higher likelihood of acquiring a transplant.

6. Proxy Raw EPTS Score

Individuals whose proxy EPTS falls below 45, indicating they are high-quality recipients, are employed as the reference group throughout analyses one and two. In comparison, low-quality recipients have a hazard rate of 0.165 and 0.537 in analyses one and two. These low magnitude hazard rates suggest that lower-quality recipients, and thus higher proxy EPTS scores, are not conducive to earlier waitlisting nor access to a transplant. Thus, such findings do suggest that there is validity in UNOS' allocation system as the proxy EPTS results do correspond to the outcomes they asset. Both findings are statistically significant, at the one and five-percent levels.

VII. Conclusion

The kidney allocation process, as outlined by the Organ Procurement and Transplant Network, unites kidney donors and recipients through the utilization of donors' KPID and recipients' EPTS scores. Acting as intermediaries, OPTN and UNOS strive to create matches that maximize the benefits produced by these matches and reaped by society. These benefits are said to increase in magnitude as the longevity and quality of the matches increase. The aforementioned theoretical framework allows for the prediction of characteristics assumed to maximize an individual's longevity and quality. These characteristics were identified as being healthy, young, of a high educational attainment, and a low EPTS score.

The Cox Proportional Hazards Model produced unexpected waitlisting results with regards to the impact of an individual's weight category and age. Individuals who are of a higher weight category (overweight and obese) and elderly are shown to be highly favored within the waitlisting process. These findings appear to contradict the proposed hypothesis and medical understanding that increased weight and age advance the risk of complications during the transplant process and would thus deter the waitlisting of such individuals.

When observing the occurrence of a kidney transplant, the Cox Model results concerning an individual's smoking habits and age negated the hypothesized outcomes. Individuals who smoked are more likely to receive a transplant, but not at a statistically significant level. Similarly, elderly individuals, both in the middle-age and old category are more likely to receive a transplant than younger individuals. We expected the intermediaries to perceive such characteristics as increasing the hazard of transplant failure and death, leading to the disregard of such individuals as transplant candidates.

While the waitlisting and transplant findings regarding the proxy EPTS variable did align with the allocation system, it appears as though individuals with better physical health were not favored, contradicting the ideology that healthy individuals are ideal candidates. When undergoing survival analysis, it is difficult to quantify whether these individuals were truly prioritized or if worsened health from their high BMI status, smoking, or age elevated their immediate need for transplant. The inclusion of metrics regarding the severity of patients' transplant status in data collection methods would shed light on the true reason for the waitlisting and transplantation of such patients.

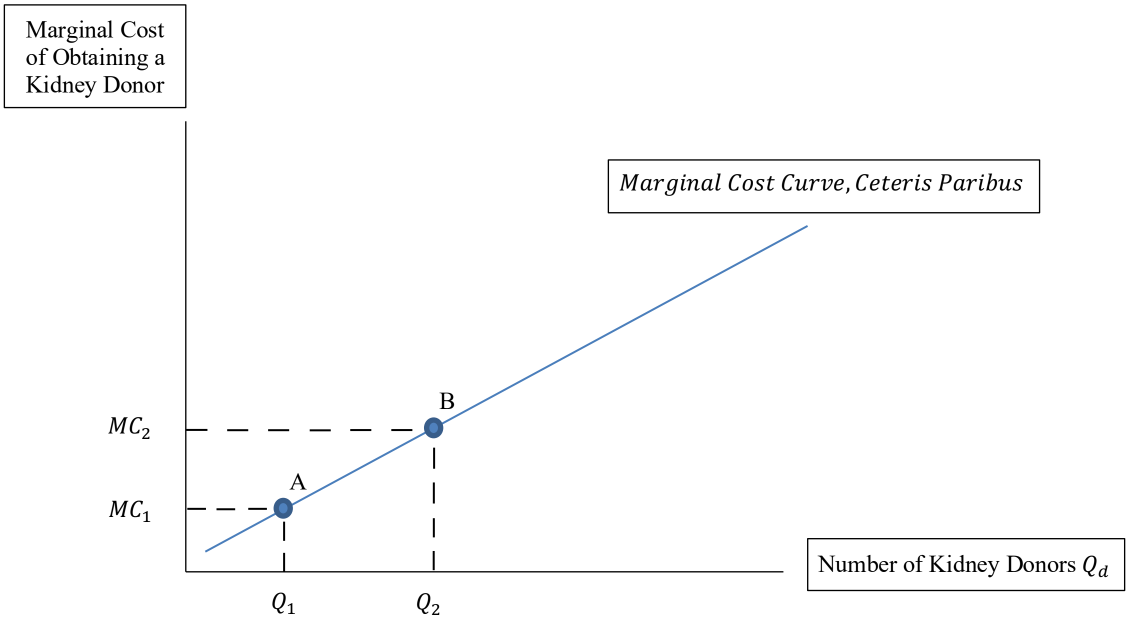
Similarly, individuals' race and gender should also be accounted for. To protect patients' identity, gender and race are omitted from the dataset. While patient protection should continue to be prioritized, omitting alternative identifying features, such as patients' previous medical history, as a substitute for gender and race, would be beneficial. The presence of gender and race-based discrimination is rampant throughout our world, and most likely in the donation allocation system. Future policy recommendations should be focused on mandating the inclusion of gender and race within the allocation data. The exclusion of such variable is not protecting patient identity, but rather dissuading individuals from understating the extent of racism that is prevalent within the healthcare system.

Overall, the allocation system would benefit from increased transparency, particularly on behalf of the donation allocation criteria. At this time, the factors that influence a donor's KPIDs score are unclear. Obtaining these inputs would allow for a more holistic and comprehensive understanding of this system that have the potential to illuminate where discrepancies lie.

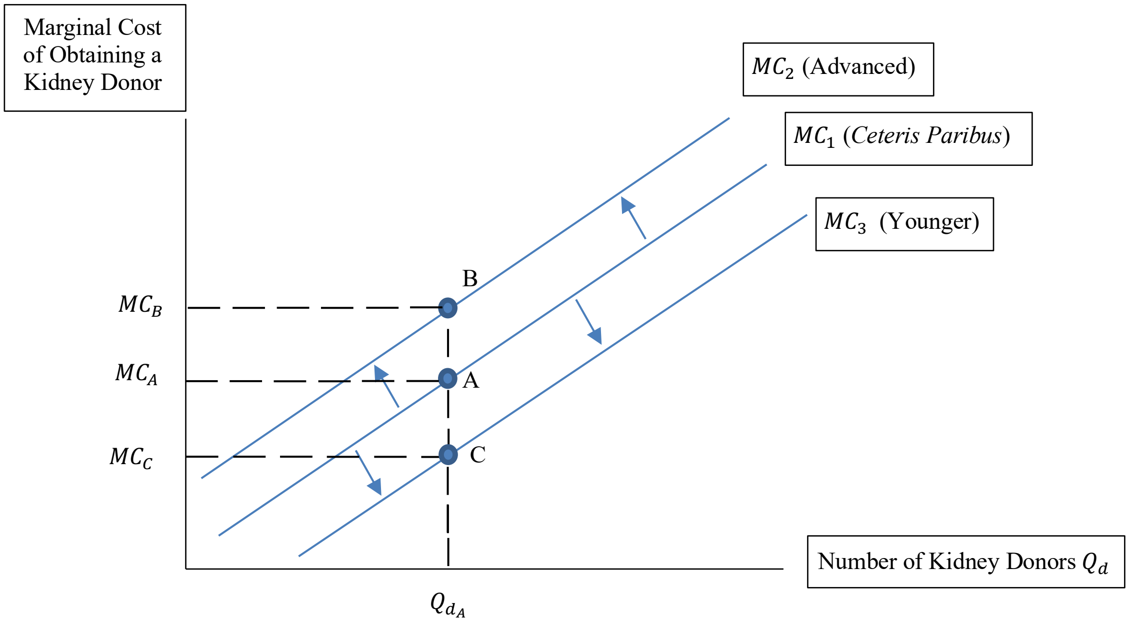
VIII. Appendix

A. MC-MB Framework

Figure 1: The Slope of the Marginal Cost Curve



Scenario 1: *Ceteris Paribus*, Age



Scenario 1 Summary: *Ceteris Paribus* Violations, MC Curve

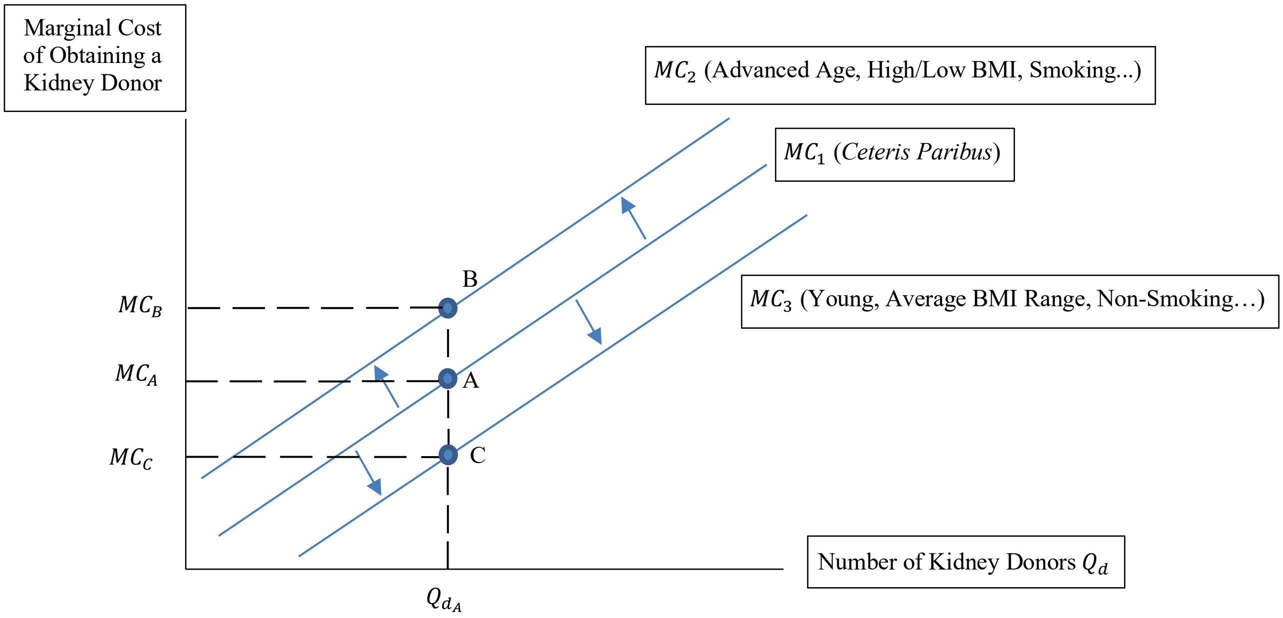
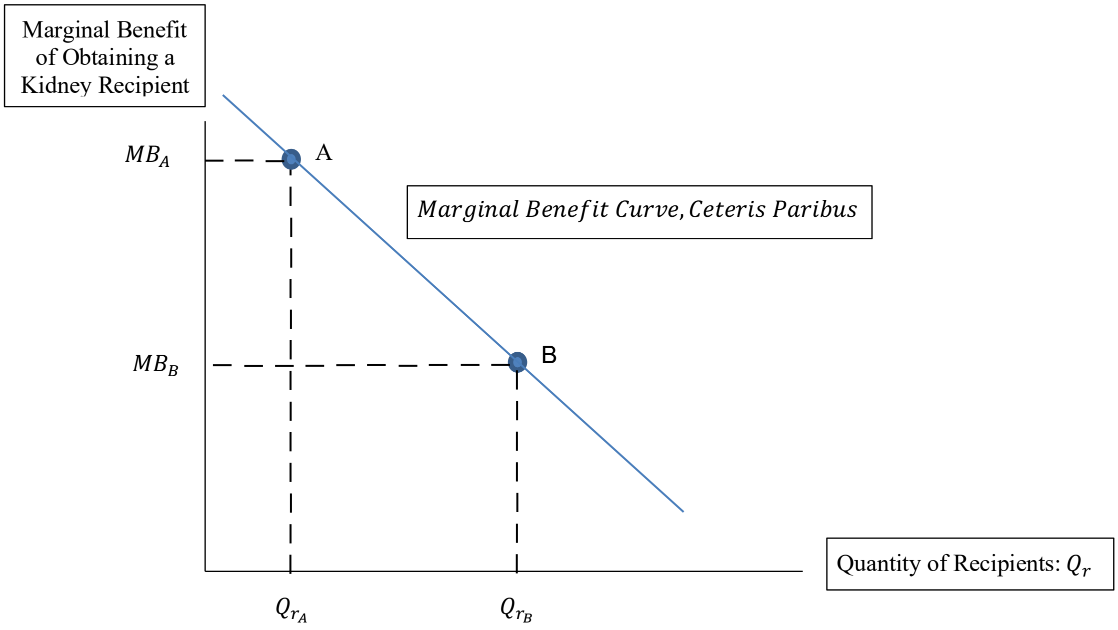
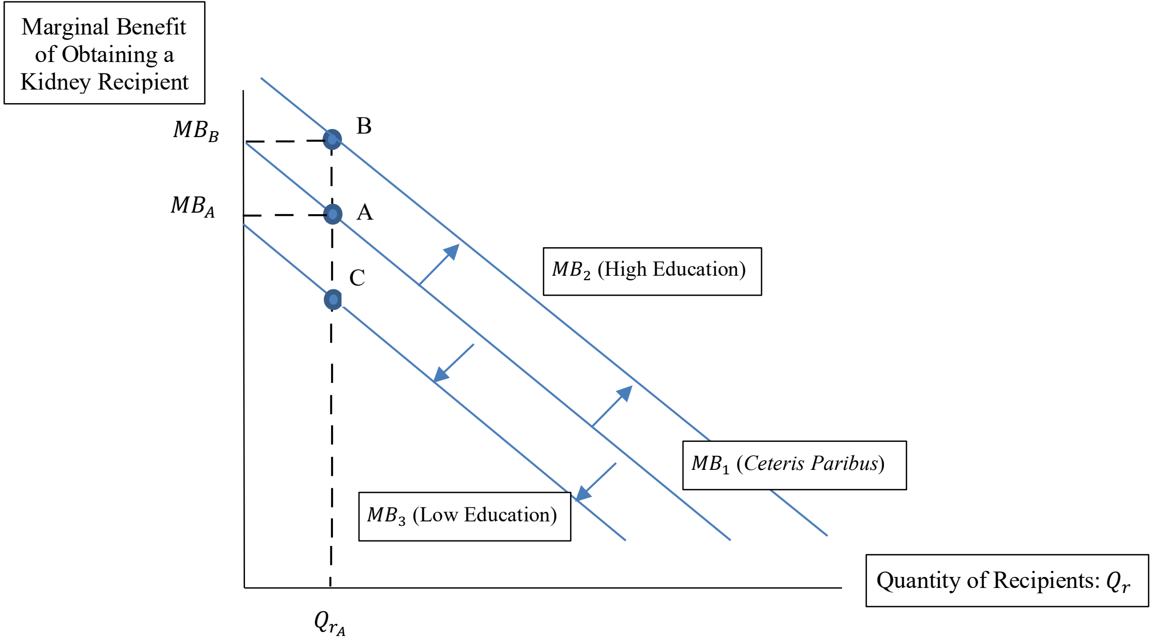


Figure 2: The Slope of the Marginal Benefit Curve



Scenario 2: *Ceteris Paribus* Violation, Education



Scenario 2 Summary: *Ceteris Paribus* Violations, MB Curve

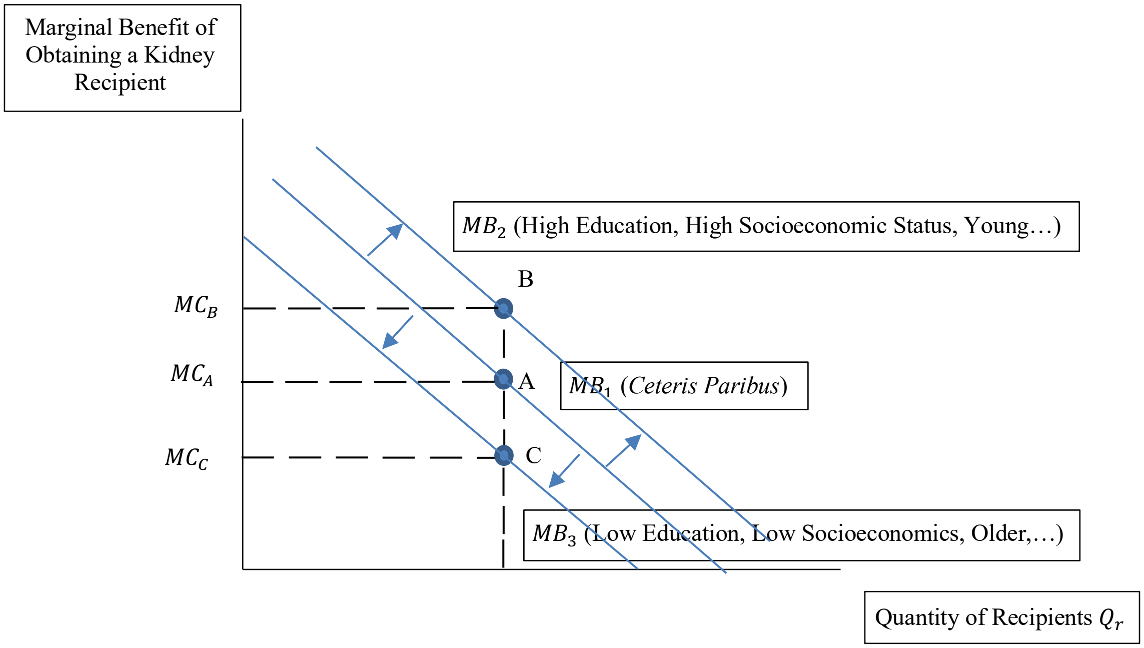
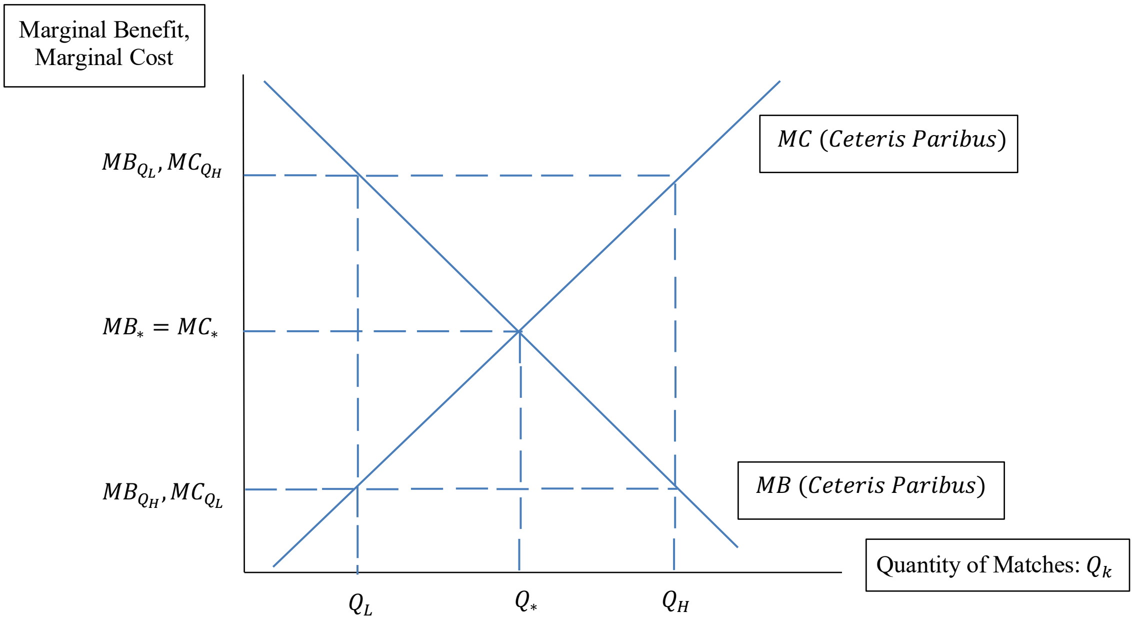
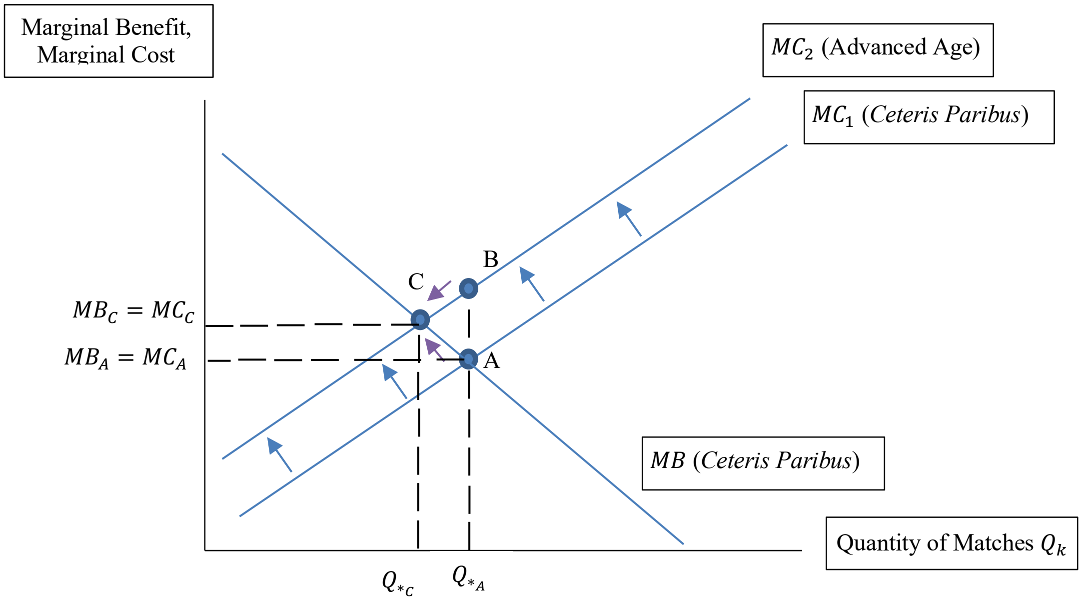


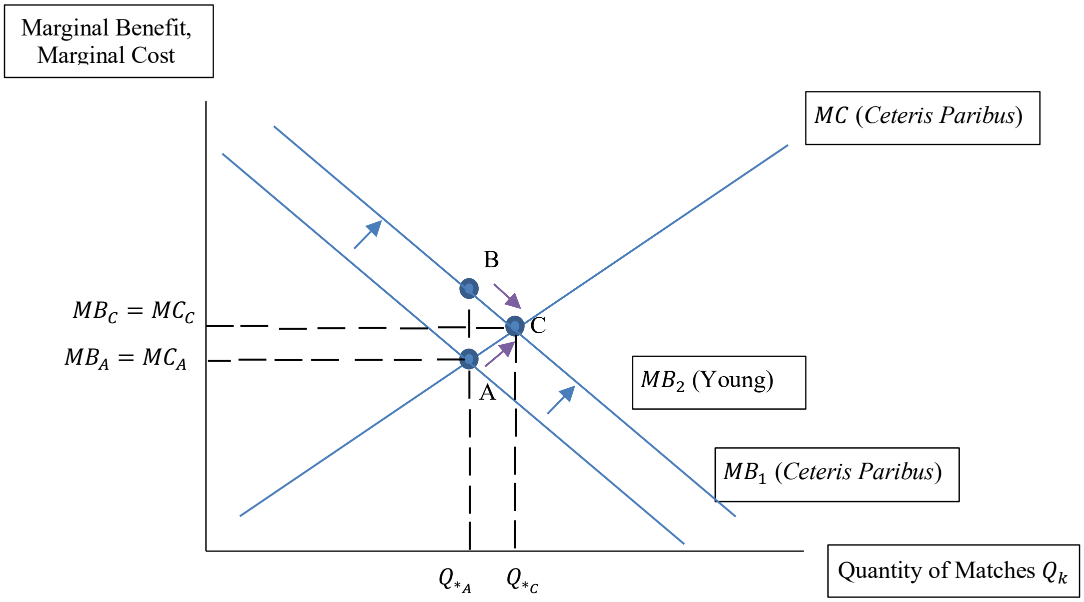
Figure 3: MC-MB, Finding Equilibrium



Scenario 3 A: Equilibrium and MC Ceteris Paribus, Age

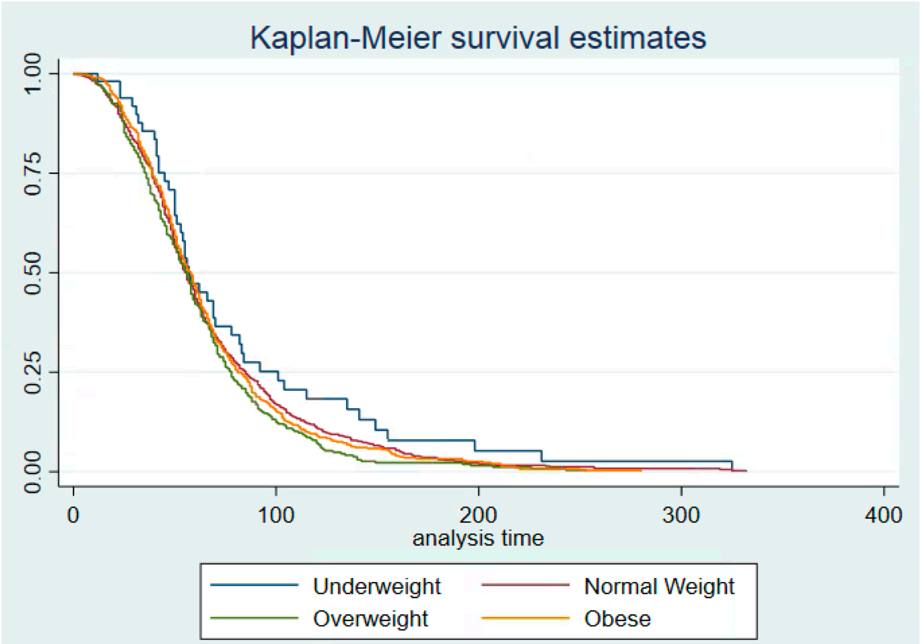


Scenario 3 B: Equilibrium and MB *Ceteris Paribus*, Age



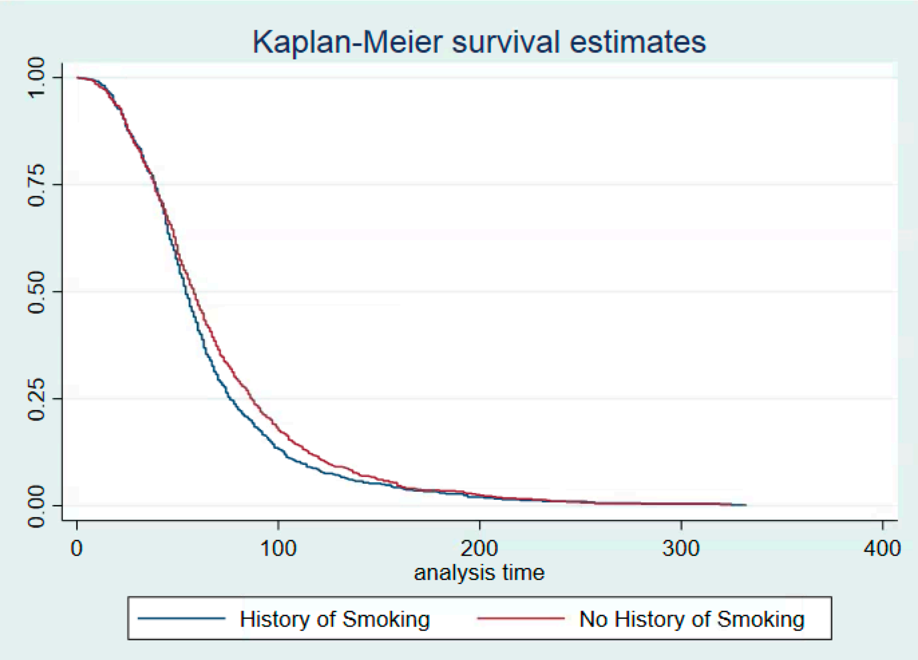
B. Kaplan-Meier Graphs: Admittance to the Waitlist

Graph 1, Kaplan-Meier Survival Function: BMI



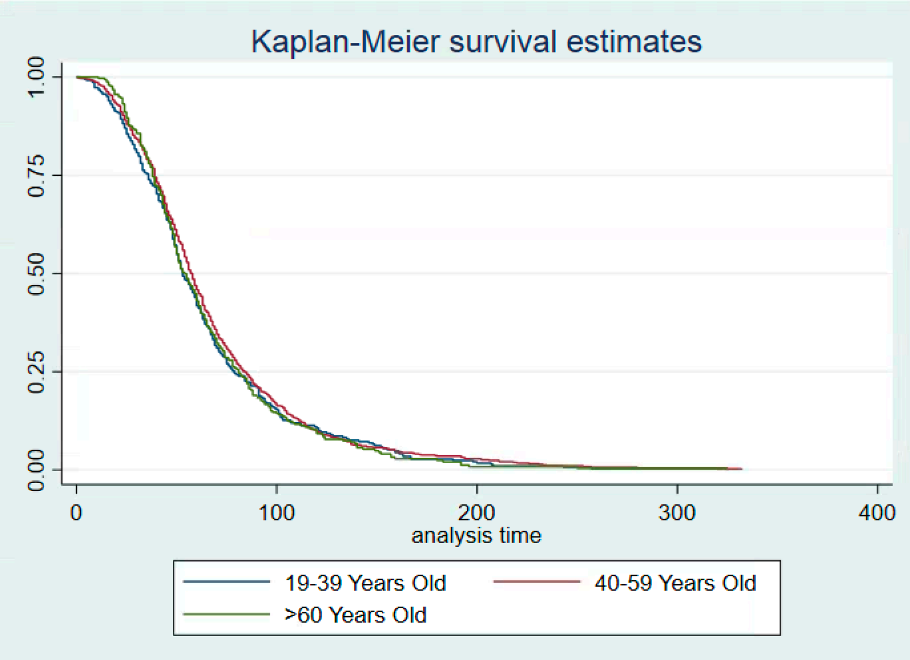
Data Source: *Registry of Organ Donation and Transplantation, RODT*

Graph 2, Kaplan-Meier Survival Function: Smoking



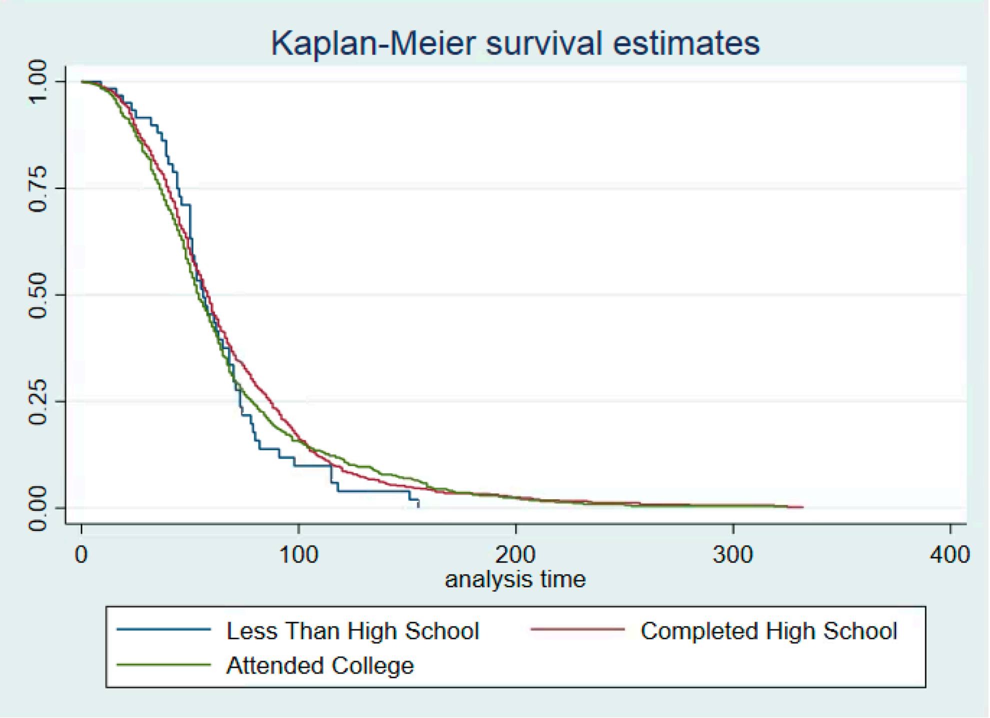
Data Source: *Registry of Organ Donation and Transplantation, RODT*

Graph 3, Kaplan-Meier Survival Function: Age



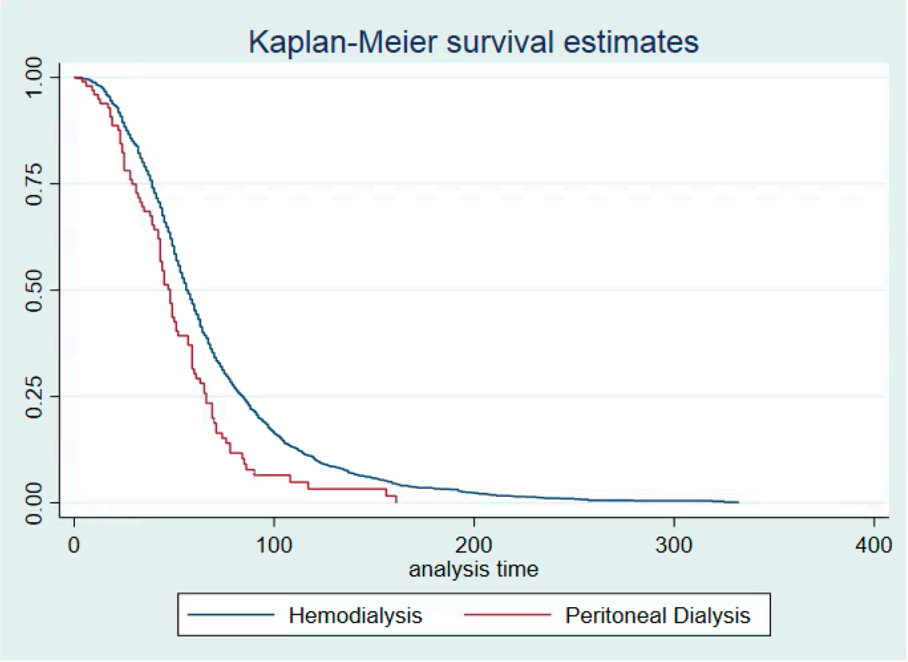
Data Source: *Registry of Organ Donation and Transplantation, RODT*

Graph 4, Kaplan-Meier Survival Function: Education



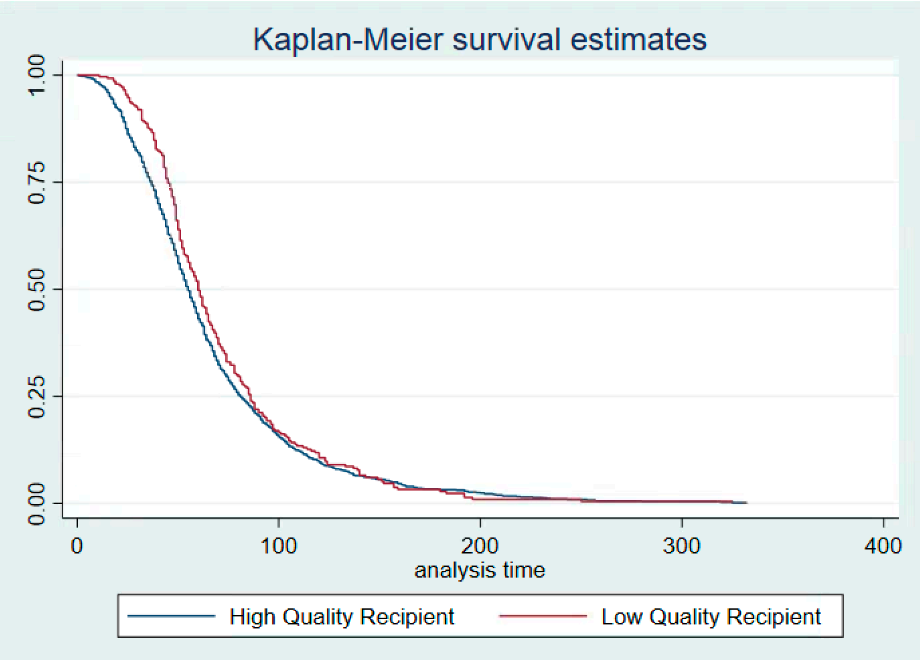
Data Source: *Registry of Organ Donation and Transplantation, RODT*

Graph 5, Kaplan-Meier Survival Function: Type of Dialysis



Data Source: *Registry of Organ Donation and Transplantation, RODT*

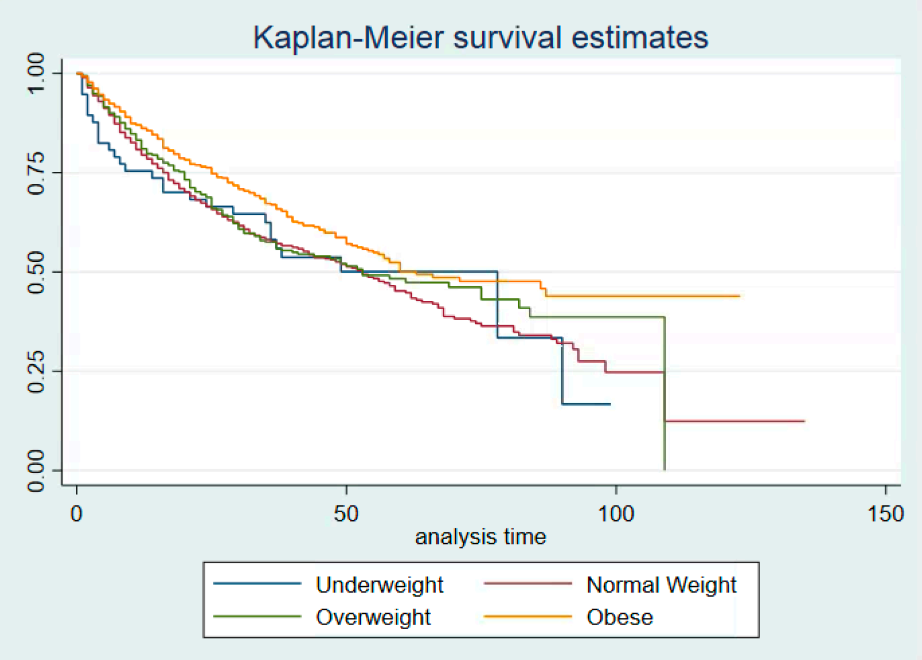
Graph 6, Kaplan-Meier Survival Function: Poxy Raw EPTS Score



Data Source: *Registry of Organ Donation and Transplantation, RODT*

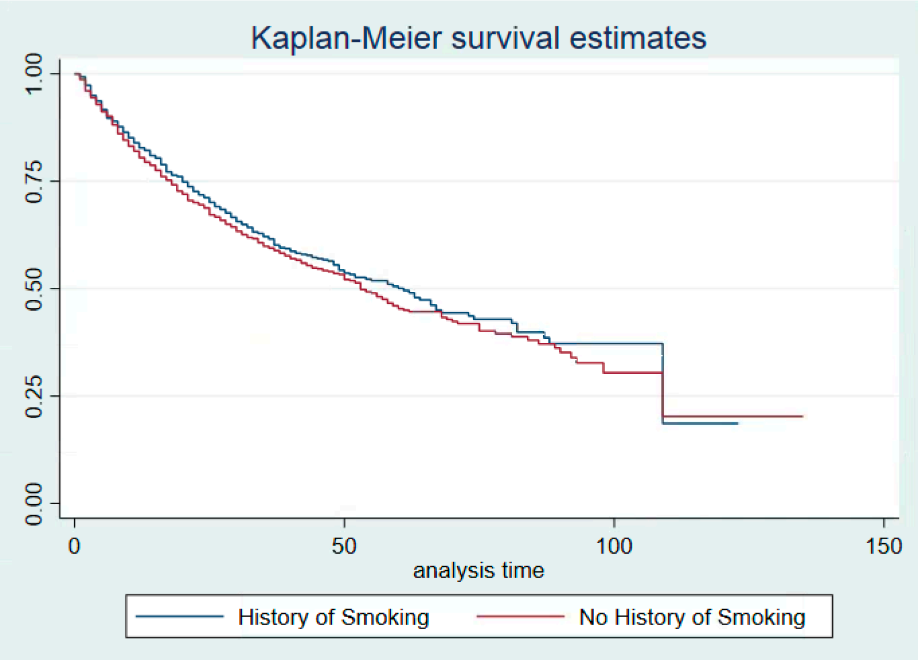
C. Kaplan-Meier Graphs: Kidney Transplant

Graph 7, Kaplan-Meier Survival Function: BMI



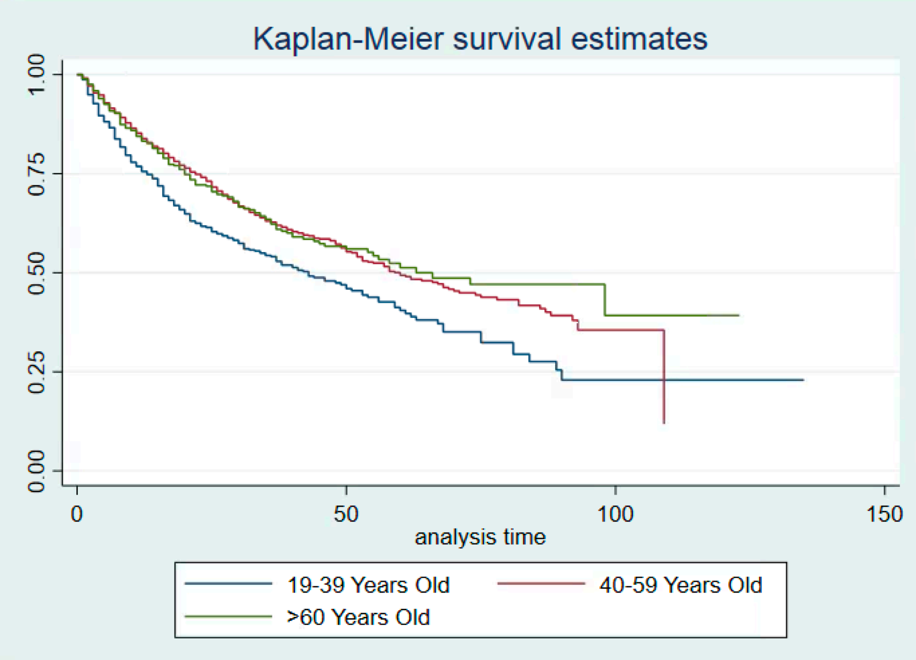
Data Source: *Registry of Organ Donation and Transplantation, RODT*

Graph 8, Kaplan-Meier Survival Function: Smoking



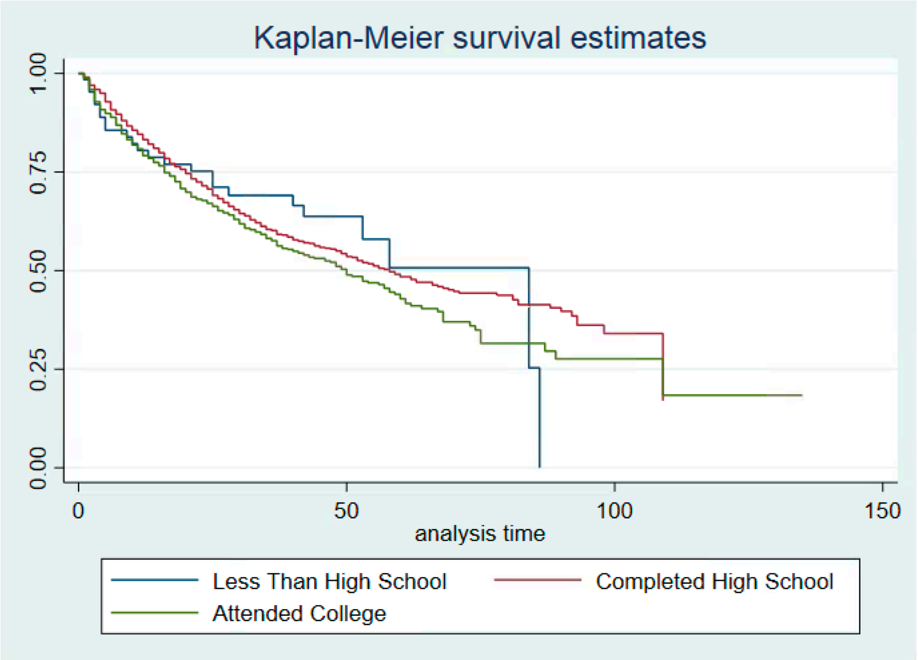
Data Source: *Registry of Organ Donation and Transplantation, RODT*

Graph 9, Kaplan-Meier Survival Function: Age



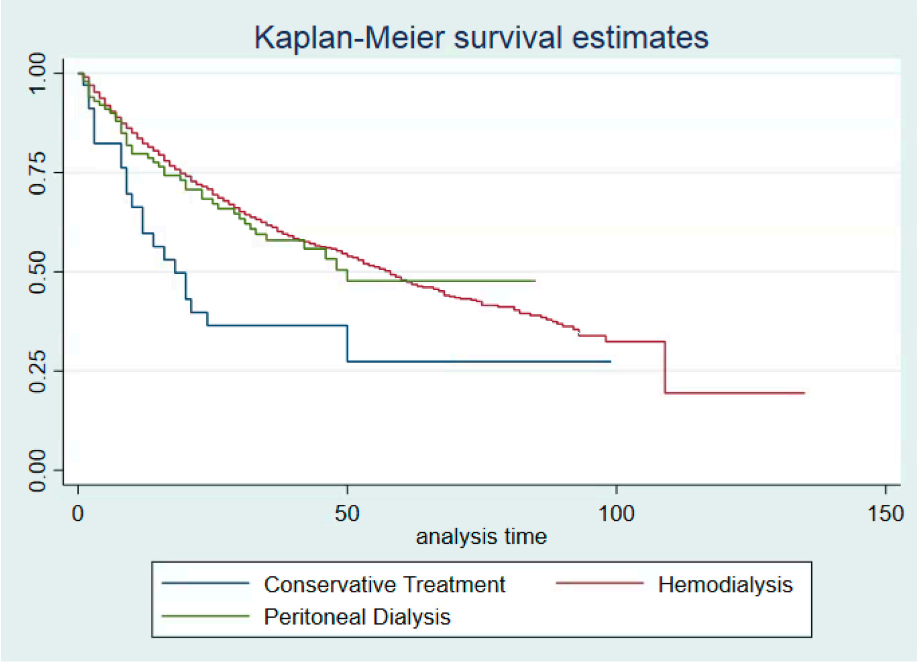
Data Source: *Registry of Organ Donation and Transplantation, RODT*

Graph 10, Kaplan-Meier Survival Function: Education



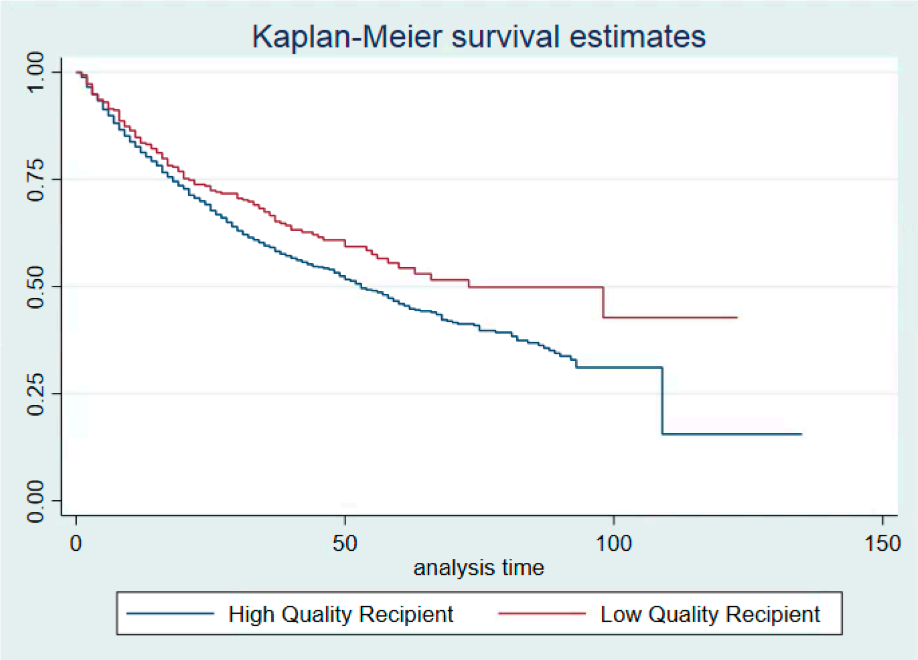
Data Source: *Registry of Organ Donation and Transplantation, RODT*

Graph 11, Kaplan-Meier Survival Function: Type of Dialysis



Data Source: *Registry of Organ Donation and Transplantation, RODT*

Graph 12, Kaplan-Meier Survival Function: Proxy Raw EPTS Score



Data Source: *Registry of Organ Donation and Transplantation, RODT*

IX. References

Andreoni, Kenneth A., et al. "Age-Related Kidney Transplant Outcomes." *JAMA Internal Medicine*, vol. 173, no. 16, 2013, p. 1524., https://doi.org/10.1001/jamainternmed.2013.8495.

B. Kasiske et. al. "Explained and unexplained ischemic heart disease risk after renal transplantation," *Journal of the American Society of Nephrology*, vol. 11, no. 9, pp. 1735–1743, 2000

Cecka, J. Michael, et al. "UNOS Scientific Renal Transplant Registry." *Clinical Transplantation*, vol. 53, no. 1, 1992, pp. 59–63., https://doi.org/10.1097/00007890-199201000-00011.

"Cox Proportional-Hazards Model." *STHDA*, http://www.sthda.com/english/wiki/cox-proportional-hazards-model.

Fabrizii, V., et. al. "Patient and Graft Survival in Older Kidney Transplant Recipients: Does Age Matter?" *Journal of the American Society of Nephrology*, vol. 15, no. 4, 2004, pp. 1052–1060., https://doi.org/10.1097/01.asn.0000120370.35927.40.

Gill, Jagbir, et al. "The Effect of Race and Income on Living Kidney Donation in the United States." *American Society of Nephrology*, American Society of Nephrology, 1 Nov. 2013, https://jasn.asnjournals.org/content/24/11/1872.short.

Goel et al. “Understanding Survival Analysis: Kaplan-Meier Estimate.” *International Journal of Ayurveda Research*, Medknow Publications & Media Pvt Ltd, Oct. 2010, https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3059453/.

Goldfarb-Rumyantzev et al. “Effect of Education on Racial Disparities in Access to Kidney Transplantation.” *The Journal of Clinical and Translational Research* , John Wiley & Sons A/S, 27 Dec. 2010, https://onlinelibrary.wiley.com/doi/10.1111/j.1399-0012.2010.01390.x.

Goldfarb-Rumyantzev, et al. “Role of Socioeconomic Status in Kidney Transplant Outcome.” *Clinical Journal of the American Society of Nephrology*, vol. 1, no. 2, 2006, pp. 313–322., https://doi.org/10.2215/cjn.00630805.

Grosso, G, et al. “The Role of Obesity in Kidney Transplantation Outcome.” *Science Direct* , Elsevier , 11 Sept. 2011, https://www.sciencedirect.com/science/article/pii/S0041134512005866.

Humpries, Harry, et. al. “Framing the Gift of Life: An Empirical Examination of Altruism, Social Distance and Material Incentives in Non-Directed Kidney Donor Motivation.” *Kidney.org*, https://www.kidney.org/sites/default/files/v31_a3.pdf.

Johansen, Kirsten L., et al. “Association of Race and Insurance Type with Delayed Assessment for Kidney Transplantation among Patients Initiating Dialysis in the United States.” *Clinical Journal of the American Society of Nephrology*, vol. 7, no. 9, 2012, pp. 1490–1497., https://doi.org/10.2215/cjn.13151211.

Joshi, Shivam, et al. “Disparities among Blacks, Hispanics, and Whites in Time from Starting Dialysis to Kidney Transplant Waitlisting.” *Transplantation Journal*, vol. 95, no. 2, 2013, pp. 309–318., https://doi.org/10.1097/tp.0b013e31827191d4.

Kasiske, Bertram L., et al. “Preemptive Kidney Transplantation: The Advantage and the Advantaged.” *American Society of Nephrology*, American Society of Nephrology, 1 May 2002, https://jasn.asnjournals.org/content/13/5/1358.short.

Kasiske, et al. “Race and Socioeconomic Factors Influencing Early Placement on the Kidney Transplant Waiting List.” *Journal of the American Society of Nephrology*, vol. 9, no. 11, 1998, pp. 2142–2147., https://doi.org/10.1681/asn.v9112142.

Lecture 15 Introduction to Survival Analysis... - Columbia University. http://www.stat.columbia.edu/~madigan/W2025/notes/survival.pdf.

Lv, Ji-Cheng, and Lu-Xia Zhang. “Prevalence and Disease Burden of Chronic Kidney Disease.” *Advances in Experimental Medicine and Biology*, 2019, pp. 3–15., doi:10.1007/978-981-13-8871-2_1.

Maenosono, Ryoichi, and Stefan G. Tullius. “Saving Lives by Saving Kidneys for Transplant.” *JAMA Internal Medicine*, vol. 179, no. 10, 2019, p. 1374., doi:10.1001/jamainternmed.2019.2609.

M. H. Nourbala, E. Nemati, Z. Rostami, and B. Einollahi, “Impact of cigarette smoking on kidney transplant recipients a systematic review,” *Iranian Journal of Kidney Diseases*, vol. 5, no. 3, pp. 141–148, 2011.

Marks, William H, et al. “Morbid Obesity Is Not a Contraindication to Kidney Transplantation.” *The American Journal of Surgery*, Elsevier, 6 May 2004, https://www.sciencedirect.com/science/article/pii/S0002961004000728?casa_token=WXcxHoFYbcsAAAAA%3AKckiQUDF0iLXvW71mlcojeAvjiowWBAx3aNWgWor-rEhgYezYZu7Xvh6WORWdMXqMwLjHLUkBA.

McAdams-DeMarco, Mara A., et al. “Trends in Kidney Transplant Outcomes in Older Adults.” *Journal of the American Geriatrics Society*, vol. 62, no. 12, 2014, pp. 2235–2242., https://doi.org/10.1111/jgs.13130.

Moers, Cyril, et al. “The Influence of Deceased Donor Age and Old-for-Old Allocation on Kidney Transplant Outcome.” *Transplantation*, vol. 88, no. 4, 2009, pp. 542–552., https://doi.org/10.1097/tp.0b013e3181b0fa8b.

Oniscu, G. C., et al. “How Great Is the Survival Advantage of Transplantation over Dialysis in Elderly Patients?” *Nephrology Dialysis Transplantation*, vol. 19, no. 4, 2004, pp. 945–951., https://doi.org/10.1093/ndt/gfh022.

OPTN/SRTR 2017 Annual Data Report: Kidney. https://srtr.transplant.hrsa.gov/annual_reports/2017/Kidney.aspx.
Organ Donation and Transplantation.” *Cleveland Clinic*, my.clevelandclinic.org/health/articles/11750-organ-donation-and-transplantation.

“Organ Donation and Transplantation Statistics.” *National Kidney Foundation*, 11 Jan. 2016, https://www.kidney.org/news/newsroom/factsheets/Organ-Donation-and-Transplantation-Stats.

Øien, Cecilia M., et al. “Gender Imbalance among Donors in Living Kidney Transplantation: The Norwegian Experience.” *OUP Academic*, Oxford University Press, 8 Feb. 2005, https://academic.oup.com/ndt/article/20/4/783/1834487.

“Organ Procurement and Transplantation Network.” *OPTN*, https://optn.transplant.hrsa.gov/data/view-data-reports/.

“Questions and Answers for Transplant Candidates about Kidney Allocation.” *United Network for Organ Sharing*, UNOS, 2021, https://unos.org/wp-content/uploads/Brochure-103-Kidney-allocation.pdf.

P. Agarwal et al. “Smoking is a risk factor for graft failure and mortality after renal transplantation,” *American Journal of Nephrology*, vol. 34, no. 1, pp. 26–31, 2011.

P. Hurst, et al., “Effect of smoking on kidney transplant outcomes: analysis of the United States renal data system,” *Transplantation*, vol. 92, no. 10, pp. 1101–1107, 2011.

P. W. Underwood, K. H. Sheetz, D. C. Cron, M. N. Terjimanian, M. J. Englesbe, and S. A. Waits, "Cigarette smoking in living kidney donors: donor and recipient outcomes," *Clinical Transplantation*, vol. 28, no. 4, pp. 419–422, 2014.

Rao, Panduranga S., et al. "Renal Transplantation in Elderly Patients Older than 70 Years of Age: Results from the Scientific Registry of Transplant Recipients." *Transplantation*, vol. 83, no. 8, 2007, pp. 1069–1074., https://doi.org/10.1097/01.tp.0000259621.56861.31.

Reeves-Daniel, Amber Michelle, et al. "Ethnicity, Medical Insurance, and Living Kidney Donation." *Clinical Transplantation*, vol. 27, no. 4, 2013, https://doi.org/10.1111/ctr.12168.

Rodger, R Stuart C. "Approach to the Management of End-Stage Renal Disease." *RCP Journals*, Royal College of Physicians, 1 Oct. 2012, https://www.rcpjournals.org/content/clinmedicine/12/5/472.

Schaeffner, Elke S., et al. "Educational Level as a Determinant of Access to and Outcomes after Kidney Transplantation in the United States." *American Journal of Kidney Diseases*, vol. 51, no. 5, 2008, pp. 811–818., https://doi.org/10.1053/j.ajkd.2008.01.019.

Segev, Dorry L, et al. "Obesity Impacts Access to Kidney Transplantation." *Journal of the American Society of Nephrology : JASN*, American Society of Nephrology, Feb. 2008, https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2396750/.

Shen, Jenny I., et al. "Association of Citizenship Status with Kidney Transplantation in Medicaid Patients." *American Journal of Kidney Diseases*, vol. 71, no. 2, 2018, pp. 182–190., https://doi.org/10.1053/j.ajkd.2017.08.014.

Schold, Jesse D., et al. "Deceased Donor Kidney and Liver Transplantation to Nonresident Aliens in the United States." *Transplantation*, vol. 84, no. 12, 2007, pp. 1548–1556., https://doi.org/10.1097/01.tp.0000296289.69158.a7.

"Survival Analysis." *Wikipedia*, Wikimedia Foundation, 31 Dec. 2021, https://en.wikipedia.org/wiki/Survival_analysis.

The Kidney Transplant Waitlist – What You Need to Know." *National Kidney Foundation*, 8 Sep. 2021, https://www.kidney.org/atoz/content/transplant-waitlist.

Tonelli, Marcello, and Miguel Riella. "Chronic Kidney Disease and the Aging Population." 2014. *Brazilian Journal of Nephrology*, Sociedade Brasileira De Nefrologia, https://www.scielo.br/j/jbn/a/Yh9RsTbnS3qcKTT5HJ7hLRF/?lang=en.

"Types of Transplants." *American Kidney Fund (AKF): Fighting on All Fronts*, American Kidney Fund, Inc., https://www.kidneyfund.org/kidney-disease/kidney-failure/treatment-of-kidney-failure/kidney-transplant/types-of-transplants/#deceased-donor-transplant.

"U.S. Renal Data System 2019 Annual Data Report: Epidemiology of Kidney Disease in the United States." *U.S. Renal Data System 2019 Annual Data Report: Epidemiology of Kidney Disease in the United States | Michigan Medicine*, 5 Nov. 2019, https://www.uofmhealth.org/news/archive/201911/us-renal-data-system-2019-annual-data-report-epidemiology.

Veroux, M., et al. "Age Is an Important Predictor of Kidney Transplantation Outcome." *Nephrology Dialysis Transplantation*, vol. 27, no. 4, 2011, pp. 1663–1671., https://doi.org/10.1093/ndt/gfr524.

Wesselman, Hannah, et al. "Social Determinants of Health and Race Disparities in Kidney Transplant." *Clinical Journal of the American Society of Nephrology*, vol. 16, no. 2, 2021, pp. 262–274., https://doi.org/10.2215/cjn.04860420.

What Is UNOS?: About United Network for Organ Sharing." *UNOS*, 20 Oct. 2021, unos.org/about/.

Y. Woo et al. "The influence of pre-operative electrocardiographic abnormalities and cardiovascular risk factors on patient and graft survival following renal transplantation," *Journal of Nephrology*, vol. 15, pp. 380–386, 2002