Quantifying Changes in Economic and Social Justice: The U.S. 1960-2000

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Abstract

The notion of Equality of Opportunity (EO) has pervaded much of economic and social justice policy and research over the last half century. The sense that differences in agent outcomes that are the consequence of their individual choice and effort are acceptable, whereas variation in agent outcomes that are the consequence of circumstances beyond their control are not has underpinned much gender, race, education and family law and policy over that period, making it a many dimensioned issue. Here a new approach to evaluating levels of and changes in EO which readily accommodates these many dimensions is introduced and progress in the extent of equality of opportunity in the United States is studied over the period 1960-2000. The evidence is that gains were made in all categories throughout the period, more so for boys than girls (though girls were better off in an EO sense to start with), more so for children in single parent circumstances, and more so for the poorly endowed.

1 Introduction

In recent years there has been considerable interest amongst philosophers and economists in quantifying various aspects of Economic and Social Justice in its many dimensions (Arrow, Bowles and Durlauf (2000), Brighouse and Robeyns (2010), Dworkin (2011), Rawls (2001), and Sen (2009)). The various notions of justice are essentially statements about the desired joint density function of a collection of outcome and circumstance variables, and a measure of degree to which justice exists, would be the proximity of the existing joint density to the desired joint density relevant to a particular notion.

An aspect of social and economic justice that has perhaps resonated most with law and policy makers alike in recent years is the notion of Equality of Opportunity (EO), the sense that inequalities that are the result of differences in individual choice and effort are acceptable whereas inequalities that derive from differences in individual circumstances are not[1]. It has underpinned much gender, race, and education law and policy in the past 50 years, all of which can be interpreted as attempts to release one generation from the constraints of circumstances inherited from their forefathers[2]. Since so much of an individual's circumstance can be associated with their parents, much "Equal Opportunity" research and policy, under the banner of Generational Mobility, has focused on the degree to which an individual's outcome can be considered as, or made independent of, the corresponding parental outcome. However the "level playing field" motif suggests that, given similar effort and choices, all should have the same chance of success (or failure) regardless of color, gender and socio-economic background, namely a multitude of circumstances that are not purely parental. Thus if progress in EO is to be evaluated a technique is required which will relate an outcome measure (or a collection of outcome measures) to a variety of circumstance measures simultaneously so that the distance of the existing joint density from that of independence can be evaluated.

A policy maker following a pure equal opportunity mandate (making outcomes independent of circumstances whatever those circumstances may be) would value releasing the well endowed child from its circumstances just as much as releasing the poorly endowed child from its circumstances. However the pursuit of a pure equal opportunity goal has not been unequivocal; Cavanagh (2002) expresses some philosophical reservations, Jencks and Tach

[1]See Arneson (1989), Cohen (1989), Dworkin (1981a), Dworkin (1981b), Dworkin (2000), Roemer (1998) and Roemer (2006) for the philosophical foundations.

[2]As such it can also be construed as part of an agenda associated with advocates of a functionings and capabilities approach to societal wellbeing and Human Development (Sen (2009); Nussbaum (2011)).

(2006) have questioned whether an equal opportunity imperative should require the elimination of all sources of economic resemblance between parents and children[3] and in a similar vein Dardanoni, Fields, Roemer and Puerta (2006) question how demanding the pursuit of equal opportunity should be in terms of the feasibility of such a pursuit. Furthermore, most observed law and policy practice has been more qualified in its approach to equal opportunity, appearing much more asymmetric in its intent, relieving poorly endowed children of dependence upon their circumstance, whilst leaving the dependence of richly endowed children upon their circumstance more or less intact. Thus the policy objective appears to be one of progress toward, rather than attainment of, the ultimate goal of equality of opportunity with an emphasis on facilitating the upward mobility of the poorly endowed, and methods for evaluating the degree of progress should be able to reflect this asymmetric, conditional and progressive nature of the policy objective.

Hitherto most techniques for assessing mobility have been of the generational regression variety or of the generational transition (Markov chain) matrix variety, each of which in its own way maps parental outcomes into child outcomes and seeks to evaluate the degree of dependence/independence in the mapping. Each technique has its problems for this purpose especially when policy is pursued asymmetrically over a variety of child and parent outcomes. For example in the context of a generational regression ($y = a+bx+e$) framework an asymmetric policy seeks to "convexify" with respect to x the deterministic component of the relationship and engender greater negative (relative to x) heteroskedasticity in the random component e. In the context of Markov methods, transition matrices and the related summary statistics are very hard to formulate when y and x are each measured in many discrete and continuous dimensions and not in the same metric.

In the following, the progress toward equality of opportunity over the last four decades of the 20$^{\text{th}}$ century in the United States is examined in the context of changes in the relationship of the educational attainment of 18 year olds to the circumstances they faced in terms of their race, gender, family type and economic status over the period. The analysis employs a new measure of equality of opportunity which measures the proximity to independence between an agent's set of outcomes and its set of circumstances. Existing approaches to measuring equality of opportunity are discussed and the new measure is introduced in section 2. Section 3 outlines some of the pro-equal opportunity policies that were introduced over the period of 1960-2000 in the U.S. in the context of civil rights, gender discrimination and family law

[3]Indeed in terms of the nature versus nurture debate, it is doubtful that resemblances due to nature can be totally eliminated or compensated for.

policy, and section 4 reports the empirical results of the examination of these policies in the U.S. over the same period. Some conclusions are drawn in section 5.

2 Measuring Equality of Opportunity

Generally Equality of Opportunity has been studied and evaluated in the context of an agent's outcomes being measurably independent of its circumstances (usually measured as the agent's corresponding parental outcomes, which has led to a generational mobility interpretation). Mostly there have been two approaches, Generational Regressions and Mobility matrices. Generational Regressions, where child outcomes are regressed on indicators of their circumstances (generally parental characteristics), evaluate EO by the proximity of the circumstance coefficients to zero (note this approach weights equally trends away from dependence of the richly and poorly endowed upon their circumstances). Transition Matrices between "parent outcomes" and corresponding "child when adult" outcomes, evaluate EO by the proximity of the matrix structure to that which would be engendered by independence between outcomes and circumstances (again this approach weights equally trends away from dependence of the richly and poorly endowed upon their circumstances). Here it is contended that both approaches present problems for evaluating the progress of equal opportunity beyond not reflecting the asymmetric nature of policy imperatives and an alternative technique is proposed which does not suffer these deficiencies.

The main difficulty with Generational Regressions hinges on the notion that zero covariance, the basis for inferences about mobility in regressions, does not imply independence (an interpretational difficulty that is compounded when outcomes and circumstances are represented by a collection of variables). This renders changes in β in the equation $y = x\beta + e$ (where y is the child outcome and x the parental quality and e represents all other influences) a poor foundation for thinking about changes in generational disadvantage or equal opportunity[4]. Viewed as a technological relationship it is a strange equation, the incremental change in the child outcome per incremental change in parental quality is the same regardless of the level of parental quality. Furthermore the variability of all other influences (than parental)

[4]Much time is spent in introductory statistics courses stressing that, while independence implies zero covariance, zero covariance (the basis of inference on β) does not imply independence! Think about an exact non-independent relationship $y = 0.5 + 2(x - x^2)$ for $0 < x < 1$, (a fairly plausible technology), with parent quality uniformly distributed in $[0, 1]$, a random sample of agents from this would yield zero covariance between y and x, and hence a zero estimate of β implying independence for what is a completely dependent relationship.

is the same at all levels of parental ability, in other words the pure randomness of child outcomes is unaffected by parental abilities or effort. So we have a constant returns technology with parental indifference to (or inability to influence) other influences at all levels of the ability spectrum (Do we really believe these things?).

The implications of intergenerational mobility for the transition matrix have been examined in van de Gaer, Schokkaert and Martinez (2001). They axiomatically developed measures which could distinguish between a) mobility as agents move within a society, b) calibrated equal opportunity and c) indicated life chances, all three of which they showed to be incompatible concepts. Aside from these conceptual difficulties a practical difficulty with the transition matrix approach is that it relies on partitioning the outcome space and circumstance space into common segments in order to define the transition matrix. One minor problem is that proximity to independence in this context is difficult to evaluate, usually some function of the matrix components (frequently in the form of the trace or the determinant of the transition matrix) is considered. Another minor problem is the potential test inconsistency issue which arises when the difference between two continuous distributions is compared at discrete points of support (which is effectively what is done in the transition matrix approach). Test inconsistency is about the chance of correctly rejecting the null hypothesis not going to 1 as the sample size grows without bound (see Cox and Hinkley (1979)). In the present context the independence of x and y (defined by their joint density $f(x,y) = f(x)g(y)$, the respective marginal densities, for all possible values of x and y) is evaluated by considering the closeness to zero of objects of the form:

$$\int_a^b \int_c^d \left(\frac{f(x,y)}{g(y)} - f(x) \right) dydx \tag{1}$$

where (a,b) and (c,d) are chosen partition points. Clearly the possibility exists for this object to be equal to 0 while $f(x,y) \neq f(x)g(y)$ for some values of $x \in (a,b)$ and $y \in (c,d)$ (hence the test inconsistency issue). Practically the implication here is that an injudicious choice of partition structure could result in inferring a magnitude of independence which in truth was not there by rendering the test inconsistent or at least substantially weakening its power.

More serious is the difficulty of forming the transition matrix when child outcomes and circumstances are each defined on quite different sets of variables and when many variables (i.e. more than one) are involved in describing either (or both) child outcomes or circumstances. A more comprehensive way of evaluating the extent and type of dependency between two quite distinct collections of variables is required.

The statistics literature abounds with types of dependence. Lehmann (1966) outlines three types of dependence, all of which deal with monotone relations between X and Y (see also Bartolucci, Forcina and Dardanoni (2001)). Here a more omnibus notion of dependence is required since relationships between parent and child characteristics need not be monotone, so a more general concept of "distance from independence" is employed which admits such non-monotone as well as monotone relationships(which would for example admit the dependency relationship discussed in footnote 4).

Letting x be an n-dimensional vector and $f_a(x)$ and $f_b(x)$ be two continuous multivariate distributions. The extent to which $f_a(x)$ and $f_b(x)$ overlap can be measured as:

$$OV = \int_{-\infty}^{\infty} \dots \int_{-\infty}^{\infty} \min\{f_a(x), f_b(x)\} \tag{2}$$

If $f_a(x)$ is the unrestricted joint p.d.f. of x and $f_b(x)$ is the joint distribution when the x's are independent, then $0 \leq OV \leq 1$ is an index of independence and $1 - OV$ is a general index of dependence, be it monotone or not. In recent work, Anderson, Linton and Whang (2009) show that the kernel estimator of $\theta = \int \min\{f_a(x), f_b(x)\}dx$ is distributed as follows:

$$\sqrt{n}(\widehat{\theta} - \theta) - \alpha_n \longrightarrow N(0, v) \tag{3}$$

where

$$\begin{aligned}
v &= p_0\sigma_0^2 + p_a(1-p_a) + p_b(1-p_b) \\
p_0 &= \Pr(X \in C_{f_a,f_b}); \qquad C_{f_a,f_b} = \{x \in \mathbb{R}^n : f_a(x) = f_b(x) > 0\} \\
p_a &= \Pr(X \in C_{f_a}); \qquad C_{f_a} = \{x \in \mathbb{R}^n : f_a(x) < f_b(x)\} \\
p_b &= \Pr(X \in C_{f_b}); \qquad C_{f_b} = \{x \in \mathbb{R}^n : f_a(x) > f_b(x)\}
\end{aligned}$$

and where α_n and σ_0^2 are bias correction factors. The slight wrinkle for the application here however, is that x is a mixture of discrete and continuous variables. Denoting them by x_d and x_c respectively so that $x \in (x_d, x_c)$, the appropriate overlap measure is:

$$OV_{mix} = \int_{-\infty}^{\infty} \sum_{x \in x_d} \min\{f_a(x), f_b(x)\}dx_c \tag{4}$$

Here summation is over the discrete components and integration is over the continuous components. The discrete version of OV has been developed in Anderson, Ge and Leo

(2010b) so the properties of OV_{mix} can be derived as a mixture of the two cases. Moreover, OV_{mix} lends itself quite naturally to a measure of dependence. The Overlap Measure proposed in this paper can be adapted to the three conceptions of intergenerational mobility suggested by van de Gaer et al. (2001), since each transition matrix has an implied structure on the joint density matrix, which the empirical joint density can be measured against. Further, the third mobility measure for Markov chains proposed by van de Gaer et al. (2001) is related to the Overlap measure in the sense that it measures the complement to the overlapping region of the conditional probabilities. Moreover the overlap measure lends itself to the measurement of other notions of social justice by letting $f_a(x)$ be the empirical distribution and $f_b(x)$ the desired distribution under the particular definition of social justice. To see how, let y be a vector of agent outcomes with joint distribution $f(y)$ and x be a vector of child circumstances with joint density $h(x)$. The joint distribution of outcomes and circumstances is denoted by $g(y, x)$. Under independence, $g(y, x) = f(y)h(x)$ and the following measure of their independence can be constructed:

$$OV = \int \sum \min\{g(y,x), (f(y)h(x))\} dz \in (0,1) \tag{5}$$

or alternatively in its conditional form,

$$OV = \int \sum \min \left\{ \frac{g(y,x)}{h(x)}, f(y) \right\} dz \in (0,1) \tag{6}$$

where integration is over z, the continuous components of y and x and summation is over the discrete components of y and x. A greater degree of dependence between y and x implies less overlap between $g(y, x)$ and $f(y)h(x)$, leading to lower values of OV. Furthermore the statistic can be calculated conditionally on income or educational status of the parents for example to check whether equality of opportunity improvements are symmetric with respect to poorly or richly endowed children or on the marital status of the parents for example to check whether equality of opportunity policies have affected those groups differentially.

3 Equal Opportunity Policies in the U.S. Between 1960-2000

It is possible to break down legislation which promotes equality of opportunity into two broad groups, policies which promote outcomes of the poorly endowed and more general anti-discrimination policies. The former group is comprised of family law policies (usually a state level issue) which promote the outcomes of children in disadvantaged home circumstances and schooling policies, which have largely been a federal matter in the style of "No Child Left Behind" policies. The latter group have largely appeared under a civil rights banner.

Divorce law changes, associated with facilitating Unilateral Divorce (either party in the marriage having the ability to leave the marriage without consent from the other party), and No-Fault Divorce (the party leaving not needing to prove he/she is leaving because the other party has transgressed during the marriage) occurred first in California in 1969, and by 1980s, almost all states had it[5]. They can be thought to have reduced the incidence of children living in the context of a dysfunctional family. Likewise child custody law changes can be said to have begun in California in 1980, (but at least 3 states had acknowledge the possibility of joint custody in the 1970s). By 2000, only 7 states had not implemented this law, namely Nebraska, New York, North Dakota, Rhode Island, Vermont,West Virginia, and Wyoming. The impact of the law's adoption is exemplified in California, where joint custody decisions rose from 2.2% of all final decrees in 1979, to 13% in 1981 (Maccoby and Mnookin 1994). Further, its breadth of influence was evident among states which permitted divorced parents to reevaluate custodial arrangements made prior to the regime shift, obtaining fresh judgments based on current application of the new law (Mason 1999). Basically, the change in statute allows for both parents to share in the custody whereas prior, the law acknowledged maternal preference in their rulings[6]. These changes increased the resources available to child development especially at the lower end of the endowment scale.

With respect to schooling policies Title 1 was the centerpiece of the Elementary and Secondary Education Act signed into Law by Lyndon Johnson in 1965 to provide financial assistance to local education agencies in districts with high incidences of poverty. Its implementation and impact have been critically discussed in Kosters and Mast (2003), Cohen and Moffitt (2009). Over one billion dollars were assigned over and above the regular school budget (i.e. this was not a re-allocation of the school budget) in the first year. In the ensuing 35 years almost $200 billion was allocated. The asymmetric nature of these family and

[5]Studies into the effect of divorce law changes include the following, (a.) Divorce rates (Peters (1986); Allen (1992); Peters (1992); Friedberg (1998); Wolfers (2006)), (b.) Marriage rates (Rasul 2006), (c.) Child outcomes (Gruber (2004) and Johnson and Mazingo (2000)), (d.) Marriage specific investments (Stevenson 2007), and (e.) Domestic violence rates Stevenson and Wolfers (2006).

[6]Studies of the effect of custodial law changes include, (a.) Implications for a non-custodial parent's willingness to make child custody payment; (Weiss and Willis (1985)) Del Boca and Ribero (1998), (b.) Implications for divorce and marriage rates, and consequent impact on child investments (Rasul (2006), (Brinig and Buckley (1998), Halla (2008), Halla and Holzl (2007)),(Leo (2008) and Nunley and Seals (2009)).

schooling laws may well reflect the presence of a second policy imperative which modifies or qualifies a pure equal opportunity policy so that poorly endowed children are relieved of connection to their circumstances while the connection between richly endowed children and their circumstance is maintained. Another way of interpreting the second imperative is that it is a Paretian objective wherein no child should be made worse of by an equal opportunity policy[7]. If so techniques for evaluating such policy outcomes should be able to reflect the asymmetric nature of their intent.

Title IV of the Civil Rights Act of 1964 desegregated public education in the US, it was largely as a response to the Supreme Courts ruling on Brown versus the Board of Education of Topeka 1954 (Brown). Brown was the best known of a sequence of cases initiated by the National Association for the Advancement of Colored People (NAACP) Legal Defense and Educational Fund to break down racial segregation in the field of education and beyond. In the ruling Justice Warren declared that "in the field of public education, the doctrine of 'separate but equal' has no place. Separate educational facilities are inherently unequal." Previously Court decisions held that educational segregation was acceptable as long as conditions and curriculum in the separate schools were equal[8]. The 1964 Act enforced the assignment of students to schools without regard to their race, colour, religion or national origin and was explicit in averring that desegregation did not mean assigning students to schools to overcome racial imbalance. It offered technical assistance, training assistance and grants to school boards to facilitate desegregation.

Title IX of the Education Amendment Act of 1972 addressed discrimination with respect to gender in education. Modeled on Title IV of the 1964 act, the preamble to Title IX declared that: "No person in the United States shall, on the basis of sex, be excluded from participation in, be denied the benefits of, or be subject to discrimination under any educational programs or activity receiving federal financial assistance. With respect to employment opportunities Section 703 (a) of Title VII of the 1964 Civil Rights act made it unlawful for an employer to "fail or refuse to hire or to discharge any individual, or otherwise to discriminate against any individual with respect to his compensation, terms, conditions or privileges or

[7] Anderson, Leo and Muelhaupt (2010a) show that in a constrained world with no growth in average child outcomes movement toward an equal opportunity outcome for one group of children must make another group of children worse off.

[8] Interestingly some school boards met the equality mandate by penalizing white schools, King George County, Virginia, for example, chose to equalize its curriculum by dropping several advanced courses from its white high school rather than add them at the black school, an example of a symmetric equal opportunity policy which we argue is not generally observed in the 1960 - 2000 period.

employment, because of such individual's race, color, religion, sex, or national origin." The final bill also allowed sex to be a consideration when sex is a bona fide occupational qualification for the job. Title VII of the act also created the Equal Employment Opportunity Commission (EEOC) to implement the law.

Generally all of these legislative changes took place in the early part of our data period, in the 1960's and 1970's. However the policies often took some time to implement. Hutchinson (2011) notes that "... it was only in the 1980's that ... school district were obligated by federal courts to implement mandatory busing plans ... that high schools long formally desegregated still had different bells for black and white students ... separate basket ball teams ... at Mississippi's Charleston High School ... only in 2009 ... the first integrated prom dance occurred.". To accommodate the gradual nature of policy adoption, measures of EO for 1960 (before the policies had effect) and 2000 (after the policies were adopted) will be compared.

4 Results

Census data from 1960-2000 drawn from the Integrated Public Use Microdata Series (IPUMS) was employed, utilizing the marital status, educational attainment and income variables. Using the parental marital status[9] and parental location variables, the observations were separated into three family structures; intact, divorced and separated, and widowed parent families. The grade attainment indicator is: 1 if preschool or had no education, 2 if grade 1 to 4, 3 if grade 5 to 8, 4 if grade 9, 5 if grade 10, 6 if grade 11, 7 if grade 12, 8 if 1 to 3 years of college and 9 if more than 4 years of college. For intact families the maximum of the parental educational attainments was employed, while family income is in constant dollars and is family size deflated according to the square root rule (Brady and Barber 1948). The analysis below focuses on children of age 18 because for most states, compulsory education ceases to be binding then[10].

As background consider the summary statistics of the data for the years 1960 and 2000 for 18 year old children by gender presented in table 1, panels A to C, while table 2 presents

[9]The respective coded parental marital status responses are as follows: Married, spouse present is 1; Married, spouse absent is 2; Separated is 3; Divorced is 4; Widowed is 5; Never married/single is 6. This paper does not examine children born outside of wedlock, nor marriages where one parent is "missing"(responses 2 and 6).

[10]Nonetheless, the results for children of age 16 and 17 are similar, and are available from the authors upon request.

Table 1: Summary Statistics by Gender & Family Structure

Year		Boys			Girls		
		Panel A					
		Intact Parents			Intact Parents		
		Child's Education	Parent's Education	Parent's Income	Child's Education	Parent's Education	Parent's Income
1960	Mean	5.7447	5.5721	12.7190	6.1364	5.6210	13.0830
	s.d.	(1.3724)	(2.0841)	(9.3442)	(1.1734)	(2.0530)	(9.4965)
	N	5819	5819	5819	4766	4766	4766
2000	Mean	6.3644	8.0600	27.7640	6.4862	8.0280	27.4920
	s.d.	(0.9263)	(0.9496)	(20.6680)	(0.9784)	(1.0249)	(20.6220)
	N	7312	7312	7312	6052	6052	6052
		Panel B					
		Divorced & Separated Parent			Divorced & Separated Parent		
		Child's Education	Parent's Education	Parent's Income	Child's Education	Parent's Education	Parent's Income
1960	Mean	5.3201	4.7385	5.8884	5.7585	4.9488	6.6655
	s.d.	(1.5333)	(1.9607)	(5.9571)	(1.3100)	(2.0348)	(5.2244)
	N	334	334	334	261	261	261
2000	Mean	6.3029	7.5558	14.4500	6.4158	7.5350	14.1170
	s.d.	(1.0232)	(1.2095)	(14.0700)	(0.9888)	(1.2053)	(13.9870)
	N	1780	1780	1780	1448	1448	1448
		Panel C					
		Widowed Parent			Widowed Parent		
		Child's Education	Parent's Education	Parent's Income	Child's Education	Parent's Education	Parent's Income
1960	Mean	5.2145	4.3028	5.7357	5.9312	4.7319	6.0581
	s.d.	(1.5934)	(2.1370)	(6.8933)	(1.3892)	(2.1304)	(6.1696)
	N	423	423	423	375	375	375
2000	Mean	6.2419	7.4312	12.7840	6.4548	7.2876	12.5830
	s.d.	(1.1013)	(1.5429)	(12.6070)	(1.1309)	(1.4812)	(9.9644)
	N	266	266	266	197	197	197

Note: The means and standard deviations are all weighted statistics.

Table 2: Summary Statistics by Race & Family Structure

Year		White Child			Black Child		
		Panel A					
		Intact Parents			Intact Parents		
		Child's Education	Parent's Education	Parent's Income	Child's Education	Parent's Education	Parent's Income
1960	Mean	5.9830	5.7061	13.4960	5.1926	4.2787	5.6810
	s.d.	(1.2617)	(2.0436)	(9.4663)	(1.5207)	(1.9232)	(4.5663)
	N	9755	9755	9755	830	830	830
2000	Mean	6.4163	8.0745	28.3200	6.4535	7.7203	20.0030
	s.d.	(0.9472)	(0.9770)	(20.8910)	(1.0054)	(1.0089)	(15.7750)
	N	12402	12402	12402	962	962	962
		Panel B					
		Single Parent			Single Parent		
		Child's Education	Parent's Education	Parent's Income	Child's Education	Parent's Education	Parent's Income
1960	Mean	5.7082	4.9042	6.8455	4.9432	3.7566	3.2660
	s.d.	(1.4271)	(2.0941)	(6.6097)	(1.6121)	(1.7998)	(3.1938)
	N	1077	1077	1077	316	316	316
2000	Mean	6.3514	7.5968	15.5590	6.3494	7.2934	9.4821
	s.d.	(0.9979)	(1.2246)	(14.6400)	(1.1021)	(1.3110)	(8.9945)
	N	2895	2895	2895	796	796	796

Note: Single parent families include divorced & separated, and widowed parent families. The means and standard deviations are all weighted statistics.

similar information by race. For intact families the boy−girl differences in 1960 were significant with girls significantly outperforming boys (a "t" statistic of -15.8201 $\Pr(T < t) = 0$) the gap was still significant in 2000 (t = -6.4057 $\Pr(T < t) = 0$) however it had been substantially reduced (the "t" for the difference-in-difference is -8.6458, $\Pr(T < t) = 0$). None of the boy−girl parental differences are particularly significant as is to be expected.

Qualitatively the results for children of divorced and separated, and widowed parents were the same as those for children of intact families with girls significantly out-performing boys in both 1960 and 2000 though the gap had substantially narrowed over the period (indeed for boys and girls of widowed parents, there was no significant difference in 2000). Again generally there are no substantive differences in the parental characteristics of parents of boys and girls. The increase in (a multiple of over 5) the numbers of children in divorced or separated households between 1960 and 2000 is noteworthy (possibly a result of the increased ease with which divorce was obtained over the period). Similarly the numbers of children in widowed parental circumstances almost halved over the period, undoubtedly the result of improved health circumstances of parents over the 40 year period.

On the other hand from table 2, for both intact and single parent family structures, white children's dominance in educational attainment has dwindled and is no longer statistically significant by 2000. This is despite significant parental educational attainment and income outcome differences, providing some initial evidence of the fruitfulness of the educational and civil rights policies over the five decades that transpired.

As for differences between family types, table 3 indicates that children from intact families clearly do better than children from single parent families, whether the head of household is divorced/separated or bereaved, and this is the case for both genders in 1960. However, this gap has narrowed by 2000, and is particularly so amongst children of bereaved families. Using these children of widowed parents as a comparison group, it is clear that the education outcomes of children of divorced/separated parents has improved by 2000 with no significant differences between them.

Table 3: Difference in Means Tests. (Standard Normal Tests & Lower Tail Probabilities)

	Boys	Girls	Boys	Girls	Boys	Girls
	Intact − Divorced	Intact − Divorced	Intact − Widowed	Intact − Widowed	Widowed − Divorced	Widowed − Divorced
1960	4.9482	4.5606	6.6639	2.7847	-0.9246	1.5954
	1.0000	1.0000	1.0000	0.9973	0.1776	0.9447
2000	2.0231	2.1653	1.5475	0.3490	-0.7350	0.4174
	0.9785	0.9848	0.9391	0.6364	0.2312	0.6618
Diff−Diff	3.9886	3.4546	3.6325	1.4944	-0.3159	0.9349
	1.0000	0.9997	0.9999	0.9325	0.3760	0.8251

Note: Divorced refers to both Divorced & Separated Parent

With regard to equality of opportunity, mobility across the spectrum of family incomes is first assessed by considering mobility by income quartile over all family types, results of which are reported in table 4. From panel A, all comparisons recorded statistically significant increases in mobility with the exception of boys in the highest income quartile and girls in the lowest income quartile. Panel B in turn reveals that the biggest gains (with the exception of girls in the lowest quartile) came from the lower quartiles reflecting the asymmetric nature of the policies in elevating the outcomes of the poor without denuding the outcomes of the wealthy[11]. Certainly not the hallmark of a "pure" (symmetric) equal opportunity policy. The exception is girls from the poorest group (first income quartile) who seem to be stuck in a mobility trap (notably daughters of widowed parents) though it should be noted that in the 1960 data set, they were already somewhat better off than boys in a mobility sense. However, this is the only income group within which girls failed to maintain their advantage over the period relative to boys. From panel C, with the exception of the highest income quartile in 1960 and the lowest income quartile in 2000, girls exhibited greater mobility than boys, but only the second and third quartile of the 1960 comparisons, and the first quartile 2000 comparisons were significant (The last being in favour of boys.).

Table 5 examines the differences in mobility gains across the quartiles with respect to the first income quartile. All quartile comparisons recorded larger mobility indicators for higher quartiles for both genders in both years, with all but the boys' first versus second in both years, being significant. This clearly reflects a persistent lack of mobility in the lower income groups.

Table 6 reports the mobility test by parental income quartiles for each race. Notice from panel A and B that mobility of whites at all income quartiles has improved significantly over the period, whereas mobility of the bottom income quartile blacks deteriorated (albeit from a relatively high level of mobility), while all other income quartile mobility measures improved. On the other hand in 1960, panel C shows that low income blacks had significantly higher mobility than the corresponding white quartile, whereas in the other income quartiles whites were more mobile than blacks. However, by 2000 all significant black−white mobility differences by income quartile had been eliminated.

It is worth reiterating that based on the usual story, mobility is low among low income quartiles (the dynastic poverty notion of Kanbur and Stiglitz (1986)), but high in high income quartiles, and this is the case for whites in both 1960 and 2000. Blacks present a different story in table 7, where in 1960 the poor were more mobile than the rich (and significantly so), but by 2000 all income quartile differences in the mobility of blacks had been eliminated.

Moving to the issue of mobility by family structure, a first consideration is whether or not different familial household structures have different transition structures. By considering the

[11] This finding corroborates with the findings in Canada (Anderson et al. 2010a)

overlap of the joint densities of intact and single parent families, the possibility of common transit structures can be examined. Similarly the overlap structures of widowed versus divorced/separated parent can be examined in the same manner. An overlap of one implies a common transit structure, and a value of less than one implies different transit structures. As table 8 indicates, the hypothesis of common transit structures can be rejected in every case.

With the difference in parent−child transition across family structures established, table 9 reports the degree of overlap between the empirical density against the hypothetical density generated by independence between parent−child outcomes. A value of one implies that parental outcomes has no effect on their children implying mobility, while deviation from that signals otherwise. The measure reported here is for parental educational attainment and income being transmitted to their child's educational outcome. In other words, the density estimated is a mixture of both continuous and discrete variables. Appendix A.1 provides a brief description of how the measure is estimated. The measure can be applied to other transmission hypotheses. It is clear from table 9 that neither boys or girls in any family structure exhibit mobility, however with the exception of girls from divorced/separated families, there is significant evidence of increased mobility between 1960 and 2000.

Examining within family structure changes in mobility, table 10 panel A reports the within year difference between boys and girls, while panel B examines the cross year changes for each gender, derived from the indices of table 9. With regard to the gender comparisons of panel A, in 1960's girls were significantly more mobile than boys in all family structures. However, by 2000 this pattern is no longer true with the exception of children from widowed parent families. In fact, for children in divorced/separated parent families, boys are significantly more mobile. The implied changes within each gender across the four decades are reflected in panel B where although all children experienced an increase in mobility, the improvements are larger for boys than they are for girls.

Panel C of table 10 extends the examination to cross family structure comparisons by gender and year. With the exception of the widowed versus intact comparisons for boys and divorced/separated versus widowed comparison for girls in 1960, children of single parent families exhibited significantly greater mobility than their intact counterparts. This pattern remains true for both boys and girls in 2000, with girls from widowed families being significantly more mobile compared to their counterparts from divorced/separated parent families. Using the children from widowed parent families as the "control" group, since they represent the possibilities that the policies not based on familial structure could have achieved.

This results thus suggests that the brunt of the legislative changes in familial law was borne primarily by girls since the pattern of children of widowed parent families being more mobile than their intact counterparts was not repeated for girls from divorced/separated parent families. On the other hand, the pattern for boys are consistent for both single parent family situations.

To establish whether there is indeed a connection between parent−child transition and the family structure the child is born into, as well as their gender, we treat family structure and gender as variables in the transmission function, the results of which are reported in table 11. Panel A examines whether the transition is dependent on family structure, revealing the growing dependence on family structure over the past four decades, while panel B highlights the growing similarity between children of either gender over the same periods, though gender remains a significant determinant of the parent−child transition function. Finally, treating the two additional variables consequently as integral to the production of a child's educational attainment, panel C reexamines the independence of child outcome hypothesis and concurs with the results of table 9 and 10, that although there is still significant dependence, overall the trend is towards mobility.

Table 4: Gender Mobility Indices by Parental Income Quartile Across All Family Structures

	Panel A: Gender Mobility Index			
	Boys		Girls	
Quartile	1960	2000	1960	2000
1st	0.8824	0.9343	0.9021	0.9044
S.E.	(0.0100)	(0.0065)	(0.0105)	(0.0068)
N	1714	2439	1298	2050
2nd	0.8962	0.9512	0.9232	0.9593
S.E.	(0.0077)	(0.0075)	(0.0089)	(0.0084)
N	1668	2473	1308	2012
3rd	0.9283	0.9623	0.9545	0.9829
S.E.	(0.0074)	(0.0088)	(0.0085)	(0.0095)
N	1586	2267	1409	1891
4th	0.9499	0.9701	0.9355	0.9738
S.E.	(0.0077)	(0.0101)	(0.0086)	(0.0111)
N	1608	2179	1387	1744

	Panel B: Differences Across Years by Income Quartile & Gender	
	Boys (1960−2000) "t" [$\Pr(T < t)$]	Girls (1960−2000) "t" [$\Pr(T < t)$]
1st	-4.3515	-0.1839
	[0.0000]	[0.4271]
2nd	-5.1168	-2.9498
	[0.0000]	[0.0016]
3rd	-2.9571	-2.2279
	[0.0016]	[0.0129]
4th	-1.5905	-2.7276
	[0.0559]	[0.0032]

	Panel C: Differences Across Gender by Income Quartile & Year	
	1960 (Boys−Girls) "t" [$\Pr(T < t)$]	2000 (Boys−Girls) "t" [$\Pr(T < t)$]
1st	-1.3586	3.1785
	[0.0871]	[0.9993]
2nd	-2.2942	-0.7193
	[0.0109]	[0.2360]
3rd	-2.3248	-1.5908
	[0.0100]	[0.0558]
4th	1.2475	-0.2465
	[0.8939]	[0.4026]

Table 5: Quartile Differences Between 1st versus 2nd, 3rd & 4th by Gender

	1st−2nd Quartile "t" [$\Pr(T < t)$]	1st−3rd Quartile "t" [$\Pr(T < t)$]	1st−4th Quartile "t" [$\Pr(T < t)$]
1960 Boys	-1.0934	-3.6896	-5.3482
	[0.1371]	[0.0001]	[0.0000]
1960 Girls	-1.7028	-2.5593	-2.9806
	[0.0443]	[0.0052]	[0.0014]
2000 Boys	-1.5329	-3.8788	-2.4609
	[0.0626]	[0.0001]	[0.0069]
2000 Girls	-5.0799	-6.7192	-5.3314
	[0.0000]	[0.0000]	[0.0000]

Table 6: Race Mobility Indices by Parental Income Quartile Across All Family Structures

	Panel A: Race Mobility Index			
	Whites		Blacks	
Quartile	1960	2000	1960	2000
1st	0.8758	0.9218	0.9532	0.9258
S.E.	(0.0079)	(0.0053)	(0.0165)	(0.0104)
N	2240	3580	772	909
2nd	0.9078	0.9510	0.9024	0.9572
S.E.	(0.0060)	(0.0058)	(0.0211)	(0.0186)
N	2722	4077	254	408
3rd	0.9439	0.9735	0.8736	0.9596
S.E.	(0.0057)	(0.0067)	(0.0306)	(0.0246)
N	2908	3890	87	268
4th	0.9434	0.9740	0.7227	0.9550
S.E.	(0.0057)	(0.0077)	(0.0472)	(0.0331)
N	2962	3750	33	173
	Panel B: Differences Across Years by Income Quartile & Race			
	Whites (1960–2000)		Blacks (1960–2000)	
	"t" [$\Pr(T < t)$]		"t" [$\Pr(T < t)$]	
1st	-4.8409		1.4039	
	[0.0000]		[0.9198]	
2nd	-5.1666		-1.9495	
	[0.0000]		[0.0256]	
3rd	-3.3440		-2.1883	
	[0.0004]		[0.0143]	
4th	-3.2059		-4.0313	
	[0.0007]		[0.0000]	
	Panel C: Differences Across Race by Income Quartile & Year			
	1960 (Whites–Blacks)		2000 (Whites–Blacks)	
	"t" [$\Pr(T < t)$]		"t" [$\Pr(T < t)$]	
	-4.2384		-0.3427	
	[0.0000]		[0.3659]	
	0.2428		-0.3180	
	[0.5959]		[0.3752]	
	2.2576		0.5423	
	[0.9880]		[0.7062]	
	4.6441		0.5601	
	[1.0000]		[0.7123]	

Table 7: Quartile Differences Between 1st versus 2nd, 3rd & 4th by Race

	1st − 2nd Quartile	1st − 3rd Quartile	1st − 4th Quartile
	"t" [$\Pr(T < t)$]	"t" [$\Pr(T < t)$]	"t" [$\Pr(T < t)$]
1960 Whites	-3.2305	-7.0058	-6.9370
	[0.0006]	[0.0000]	[0.0000]
1960 Blacks	1.8965	2.2877	4.6128
	[0.9711]	[0.9889]	[1.0000]
2000 Whites	-3.6895	-6.0132	-5.5954
	[0.0001]	[0.0000]	[0.0000]
2000 Blacks	-1.4745	-1.2638	-0.8408
	[0.0702]	[0.1031]	[0.2002]

Table 8: Common Transition Structures. (Overlap measure & (Standard Error))

Year	Single vs. Intact Family	Divorced & Separated vs. Widowed Family
1960	0.7946	0.9031
	(0.0044)	(0.0026)
2000	0.7414	0.9277
	(0.0019)	(0.0071)

Table 9: Equal Opportunity Measures By Family Type.

	Intact		Divorced & Separated		Widowed	
	Boys	Girls	Boys	Girls	Boys	Girls
1960 Index	0.8804	0.9187	0.9073	0.9468	0.8824	0.9519
s.e.	(0.0010)	(0.0011)	(0.0043)	(0.0049)	(0.0038)	(0.0041)
N	5819	4766	334	261	423	375
2000 Index	0.9415	0.9415	0.9658	0.9514	0.9671	0.9825
s.e.	(0.0009)	(0.0010)	(0.0018)	(0.0021)	(0.0048)	(0.0054)
N	7312	6052	1780	1448	266	197

Note: The overlap index reported are bias corrected. See the appendix for a brief discussion. Standard errors (s.e.) are in parenthesis.

Table 10: Differences by Family Type

	Panel A: Boys − Girls Difference by Family Type		
	Intact Families	Divorced & Separated	Widowed
1960	-25.0098	-6.0984	-12.5170
	[0.0000]	[0.0000]	[0.0000]
2000	0.0360	5.2217	-2.1200
	[0.5144]	[1.0000]	[0.0170]
	Panel B: 1960 − 2000 Difference by Family type		
	Intact Families	Divorced & Separated	Widowed
Boys	-44.0474	-12.5194	-13.8955
	[0.0000]	[0.0000]	[0.0000]
Girls	-14.8513	-0.8610	-4.4975
	[0.0000]	[0.1946]	[0.0000]
	Panel C: Differences in Family Type		
	Divorced − Widowed	Divorced − Intact	Widowed − Intact
Boys 1960	4.3477	6.1069	0.5127
	[1.0000]	[1.0000]	[0.6959]
Boys 2000	-0.2563	11.7361	0.2563
	[0.3989]	[1.0000]	[0.6011]
Girls 1960	-0.8065	5.6406	7.8976
	[0.2100]	[1.0000]	[1.0000]
Girls 2000	-5.3409	4.3063	7.3966
	[0.0000]	[1.0000]	[1.0000]

Table 11: Test of Independence

	1960	2000	t test
	Panel A: Independence of Family Structure		
Overlap	0.9746	0.9321	-45.1922
s.e.	(0.0007)	(0.0006)	(0.0009)
N	11978	17055	[0.0000]
	Panel B: Independence of Gender		
Overlap	0.9510	0.9847	35.7661
s.e.	(0.0007)	(0.0006)	(0.0009)
N	11978	17055	[0.0000]
	Panel C: Composite Independence		
Overlap	0.8840	0.9334	52.5833
s.e.	(0.0007)	(0.0006)	(0.0009)
N	11978	17055	[0.0000]

Table 12: Stochastic Dominance Test by Family Type & Race

	1960		2000	
	Panel A: Stochastic Dominance Test by Gender			
Family Structure\Hypothesis	Boys $\succ^i$ Girls	Girls $\succ^i$ Boys	Boys $\succ^i$ Girls	Girls $\succ^i$ Boys
Intact	6.3076	-0.0676	3.3651	0.0896
	[1.0000]	[0.0000]	[1.0000]	[0.0159]
Result	Girls $\succ^1$ Boys		Girls $\succ^1$ Boys	
Single	3.4246	-0.0106	1.7016	0.0318
Parent	[1.0000]	[0.0000]	[0.9969]	[0.0020]
Result	Girls $\succ^1$ Boys		Girls $\succ^1$ Boys	
	Panel B: Stochastic Dominance Test by Race			
Family Structure\Hypothesis	White $\succ^i$ Black	Black $\succ^i$ White	White $\succ^i$ Black	Black $\succ^i$ White
Intact	0.0000	21.8600	5.8470	1.6321
	0.0000	1.0000		
Result	White $\succ^1$ Black		No Dominance	
Single	0.0000	11.9580	0.4736	3.0115
Parent	0.0000	1.0000		
Result	White $\succ^1$ Black		No Dominance	

Note: $\succ^i$ denotes ith order stochastic dominance. The tests performed tests up to third order dominance, and if no dominance relationship is revealed, it is concluded that there is “No Dominance”. The upper tail probabilities of the test statistic are in brackets

The growing similarity in mobility says nothing nonetheless about the probability of performing better in educational attainment by one gender or race over the other. Table 12 performs the stochastic dominance test, utilizing the similar ideas in the mixture method of the density comparisons above, estimating the continuous variable using kernel density estimation methods. Notice that despite the improvements among boys in terms of mobility, the educational outcomes of 18 year old girls continue to first order stochastically dominate boys regardless of their familial background. In other words, all things equal girls have a higher probability of performing better in school relative to boys. The comparisons pertaining to race on the other hand affirms the improvements that the civil rights policies have afforded African Americans, since whereas in 1960, whites first order stochastically dominated blacks, there is no longer any dominance relationship in 2000 for all family structures.

5 Conclusions

A general, readily applicable method for quantifying the progress of social justice has been presented and applied to the Equality of Opportunity sense of Social Justice. The method relies upon measuring a sense of the distance of the joint probability distribution of agent characteristics from that which would be desired under a particular notion of Social Justice. The method does not run into the problems that bedevil regression and transition matrix techniques which are commonly employed, and it is sufficiently flexible to admit a variety of agent characteristics that may be either discretely or continuously measured. The technique has been used to measure the progress of Equality of Opportunity in the United States over the last 4 decades of the last century.

The last four decades of the last half century saw considerable efforts through various family, education and civil rights law and policy to equalize opportunity in the U.S., especially with regard to elevating outcomes of those who were disadvantaged in their circumstance whether it be gender, race or family background based. While these efforts have been much lauded, their success has been contested by some. Here a new measure that provides a metric for the level of equality of opportunity has been provided which has a well defined asymptotic distribution and which can handle collections of circumstance and outcome variables that are both discrete and continuous. Using the measure to relate 18 year old school attainments to their circumstances in the form of their gender, race, family background (in tact, or divorced/separated, or widowed parents) and the educational status and income of the family, it is possible to conclude that the efforts have met with some qualified success. With the exception of one group, daughters in the lowest parental income quartile (especially those daughters of a widowed parent), all groups in all family types and of both genders have experienced improvements in mobility over the period though some have advanced more than others though it should be said that the genders started from different positions with girls generally more mobile than boys in the 1960's era.

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A Appendix

A.1 Estimation of Mixed Overlap Measure

In the instance such as the current where one of the variables considered in the transmission is continuous, the measure proposed by Anderson et al. (2010b) is subject to biases. However Anderson et al. (2009) proposed a similar measure using Kernel estimation techniques. This means we can mix the two techniques with not implications on the bias and asymptotic results. Let $x \in X$ be the grade variable for the children, and $y \in Y$ variable be the continuous income variable. For the income→grade comparison, the overlap measure is,

$$\mathbf{OV} = \sum_{x \in X} \left\{ \int_{y \in Y} \min\{f(x,y), g(x,y)\} dy \right\} \tag{A-1}$$

Notice that to estimate this mixed overlap index, all that is needed is to sum over the estimated uni-dimensional density at each discrete attainment outcome. Keeping in mind that $g(.)$ may refer to either the hypothesized density in question or the density of another population under comparison. We will describe the comparison of two mixed distributions here which was used to generate tables 1 and 2. The application to the examination of mobility or immobility hypothesis can be easily adjusted from the procedure given below.

1. First calculate the overlap index,

   $$\widehat{\mathbf{OV}} = \sum_{j=1}^{J} \int_{y \in Y} \min\{f_n(x_j, y), g_n(x_j, y)\} dy \tag{A-2}$$

   where j indexes the J unique discrete realization. The estimators for the densities are,

   $$f_n(x_j, y) = \frac{1}{nb^d} \sum_{i=1}^{n} K\left(\frac{y - Y_i^f}{b}\right) \tag{A-3}$$

   $$g_n(x_j, y) = \frac{1}{nb^d} \sum_{i=1}^{n} K\left(\frac{y - Y_i^g}{b}\right) \tag{A-4}$$

   and d denotes the number of dimensions ($d = 1$ one in the current case) in the observed variables $\{Y_i^f\}_{i=1}^n$ and $\{Y_i^g\}_{i=1}^n$. The kernel function used is the Epanechnikov kernel ($K(u) = 6\left(\frac{1}{4} - u^2\right) \mathbf{1}[|u| \leq 0.5]$) as suggested in Anderson et al. (2009), and the bandwidth used in estimating the overlap index is the Silverman's rule of thumb ($b_s = 1.84sn^{-1/5}$, where s is the sample standard deviation).

2. However, the above measure is biased which needs to be adjusted. To do so, we have to first find the estimated contact set and its complements,

$$\widehat{C}_{f,g} = \{x \in \mathbb{R}^d : |f_n(x) - g_n(x)| \leq c_n, f_n(x) > 0, g_n(x) > 0\} \tag{A-5}$$
$$\widehat{C}_{f} = \{x \in \mathbb{R}^d : f_n(x) - g_n(x) < -c_n, f_n(x) > 0, g_n(x) > 0\} \tag{A-6}$$
$$\widehat{C}_{g} = \{x \in \mathbb{R}^d : f_n(x) - g_n(x) > c_n, f_n(x) > 0, g_n(x) > 0\} \tag{A-7}$$

where equation (A-5) describes the contact set, while the others are its complement, and c_n is the tuning parameter which was set to $b_s^{3/2}$ if $b_s < 1$, and $b_s^{2/3}$ otherwise.

3. The bias corrected overlap measure and its variance are as follows,

$$\widehat{\mathbf{OV}}^{bc} = \widehat{\mathbf{OV}} - \widehat{a}_n n^{-0.5} \tag{A-8}$$
$$\widehat{v} = \widehat{p}_0 \sigma_0^2 + \widehat{\sigma}_1^2 \tag{A-9}$$

where the calculations required to obtain these values, in sequence, are

(a) $||K||_2^2$ and $||K||_2$ are

$$||K||_2^2 = \int_{\mathbb{R}^d} K^2(u)du \tag{A-10}$$
$$\Rightarrow ||K||_2 = \sqrt{\int_{\mathbb{R}^d} K^2(u)du} \tag{A-11}$$

Note that for the univariate uniform kernel function,

$$\begin{aligned} ||K||_2^2 &= \int_{-\infty}^{\infty} \mathbf{1}(|u| \leq 0.5)du \\ &= \int_{-0.5}^{0.5} du = 1 \\ \Rightarrow ||K||_2 &= 1 \end{aligned}$$

(b) $\widehat{a}_n$ is the bias correction factor,

$$\widehat{a}_n = \mathbf{E}\min\{Z_1, Z_2\} \frac{||K||_2}{2b^{\frac{d}{2}}} \left(\int_{C_{f,g}} f_n^{\frac{1}{2}}(x)dx + \int_{C_{f,g}} g_n^{\frac{1}{2}}(x)dx \right) \tag{A-12}$$

where $\mathbf{E}\min\{Z_1, Z_2\} = -0.56$, and Z_1 and Z_2 are independent standard normal random variables if the sample sizes are the same for both densities under consideration. But when they are different, letting the sample for $f_n(.)$ be n and that for $g_n(.)$ be m, such that the ratio of the sample sizes are $m/n \to \tau \in (0, \infty)$, $\mathbf{E}\min\{Z_1, Z_2\} = -\frac{1}{\sqrt{\pi}} = -0.5642$ needs to be augmented with $\mathbf{E}\min\{Z_1, Z_2/\tau\} = -\frac{\sqrt{1+1/\tau}}{2}\sqrt{\frac{2}{\pi}}$.

(c) The kernel constant, σ_0^2, is defined as follows,

$$\sigma_0^2 = ||K||_2^2 \int_{T_0} \operatorname{cov}\left(\min\{Z_1, Z_2\}, \min \left\{ \begin{array}{l} \rho(t)Z_1 + \sqrt{1-\rho(t)^2}Z_3 \quad , \\ \rho(t)Z_2 + \sqrt{1-\rho(t)^2}Z_4 \end{array} \right\} \right) dt = 0.6135 \tag{A-13}$$

where $T_0 = \{t \in \mathbb{R}^d : ||t|| \leq 1\}$ and

$$\rho(t) \quad = \quad \frac{\int_{\mathbb{R}^d} K(u)K(u+t)du}{||K||_2^2} \tag{A-14}$$

Note that the value for the kernel constant above is for case when the sample sizes considered are the same. When this is not the case, the kernel constant for that case can be calculated as,

$$\sigma_0^2(\tau) = \frac{1+\tau^{-1}}{2}\sigma_0^2 \tag{A-15}$$

(d) $\widehat{p}_0$ in the calculation of the variance can is estimated by

$$\widehat{p}_0 = \frac{1}{2}\left(\int_{\widehat{C}_{f,g}} f_n(x)dx + \int_{\widehat{C}_{f,g}} g_n(x)dx \right) \tag{A-16}$$

(e) Finally, $\widehat{\sigma}_1^2$ is estimated by

$$\widehat{\sigma}_1^2 \quad = \quad \widehat{p}_f(1-\widehat{p}_f) + \widehat{p}_g(1-\widehat{p}_g) \tag{A-17}$$

where

$$\widehat{p}_f \quad = \quad \int_{\widehat{C}_f} f_n(x)dx \tag{A-18}$$

$$\widehat{p}_g \quad = \quad \int_{\widehat{C}_g} g_n(x)dx \tag{A-19}$$

And if the samples are not equal,

$$\widehat{\sigma}_1^2(\tau) \quad = \quad \widehat{p}_f(1-\widehat{p}_f) + [\widehat{p}_g(1-\widehat{p}_g)/\tau] \tag{A-20}$$

For a complete discussion of the asymptotic results, and intuition regarding the measure and the proofs, see Anderson et al. (2009).

When testing for mobility, the overlap index generated by this mixture of discrete and continuous variables is,

$$\widehat{\mathbf{OV}} \quad = \quad \sum_{j=1}^{J} \int_{y \in Y} \min\{f_n(x_j, y), g_n^1(x_j)g_n^2(y)\}dy \tag{A-21}$$

where j indexes the J unique discrete realization as before.